Dissolved oxygen and primary productivity in a small agricultural stream in Iowa

by

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ABSTRACT

Hourly values of dissolved oxygen and temperature were measured in Big Creek, Boone County, Iowa during the summer of 1982. Estimates of gross primary productivity and community respiration were calculated with the diurnal oxygen curve method. In addition, primary productivity of suspended algae, and suspended and attached chlorophyll a were measured. Oxygen and temperature both showed distinct diurnal changes, increasing by day and decreasing by night. Average daily oxygen concentrations decreased until midsummer, then increased as fall approached. Supersaturation occurred on all but 14 of the 73 days observed. In midsummer, nighttime oxygen concentrations often fell below 5 mg/l. Average daily temperatures followed a pattern reciprocal to that of oxygen. Average primary productivity and respiration values were 10.0 g O_2/m^2/day and 18.2 g O_2/m^2/day respectively. These rates were high compared to values reported for other streams, however, they are similar to those found in Iowa lakes. Almost all production took place on the stream bed rather than the open water. Suspended algal chlorophyll a comprised only 1.4% of the total chlorophyll a collected.

INTRODUCTION

In the past, water quality studies involving Iowa streams have been limited to the larger, more polluted rivers, primarily for the enforcement of water quality standards. Small streams, however, have received little attention, even though they make up a large portion of the total length of streams within the state. These streams often provide not only a habitat for wildlife, but also an inexpensive source of water for livestock rearing and other agricultural activities, as well as areas suitable for park and recreational facilities in urban areas. Small streams also play an important role in controlling the water quality of the rivers, reservoirs, and lakes into which they flow.

Recently, students from the Department of Animal Ecology at Iowa State University have begun a series of investigations into the ecology of small, central Iowa streams. As part of that series, this study was instituted to measure daily changes in dissolved oxygen and temperature in a small stream in Boone County, Iowa, and to use these measurements to estimate the stream's gross primary productivity and community respiration.

Oxygen concentrations in streams are controlled by the metabolic activities of stream biota (Westlake, 1969; Hynes, 1972), the flux of oxygen by diffusion across the air-water interface, and by drainage accrual. Metabolic activities by stream organisms add, or remove, oxygen through photosynthesis or respiration respectively. Because the photosynthetic production of oxygen occurs only when light is available, diurnal changes in dissolved oxygen often result. Oxygen concentrations increase during daylight hours, and decrease at night (Odum, 1956; McDiffett et al., 1972; Kelly et al., 1974; McDonnell, 1982).

In small streams, which have a high surface area to volume ratio, diffusion will act to moderate any changes in dissolved oxygen. When oxygen concentrations depart from saturation, oxygen will diffuse into, or out of, the stream, tending to maintain a concentration near 100% saturation. Changes in dissolved oxygen due to metabolic activities of stream biota will only be observed when the rates of diffusion are exceeded by the rates of oxygen production by photosynthesis, or the rates of oxygen consumption by respiration.

Under some circumstances, changes in dissolved oxygen concentrations can also result from the introduction of oxygen rich, or oxygen poor, water by drainage accrual. In central Iowa, drainage accrual may occur as groundwater seepage, surface runoff, or input from agricultural drainage tiles. Because these waters usually have low dissolved oxygen concentrations, their introduction may simulate the oxygen consumptive effects of respiration, lowering the overall oxygen concentrations within the steam.

In streams where drainage accrual is negligible, and diffusion rates can be obtained, the direct relationship between changes in dissolved oxygen concentrations and the metabolic activity of the stream biota can be used to estimate primary productivity and respiration. The diurnal oxygen curve method, presented by Odum (1956), estimates gross primary productivity and community respiration using plots of oxygen changes (corrected for temperature and diffusion) against time. Because this method measures the metabolic rates of the entire stream community, it should provide more realistic estimates than those obtained using benthic chambers, which measure only benthic productivity. Where diffusion coefficients can be reliably estimated, the diurnal oxygen curve method can provide an accurate measure of gross primary productivity (Bott et al., 1978).

Little is known about the metabolic rates in agriculturally impacted streams, or the effects these rates have on oxygen concentrations. Past studies on small streams have been concerned primarily with woodland systems, which tend to be very heterotrophic (Vannote et al.,1980). The riparian vegetation surrounding these streams has a major impact on the metabolic rates within the streams, and the trophic structure of the system. Consisting mostly of trees and shrubs, the overstory reduces primary productivity by shading out light, and increases respiration by contributing large amounts of organic debris. The low rates of production, combined with high diffusion rates, can result in only small diurnal changes in dissolved oxygen during daylight hours.

In 1980, Vannote et al. introduced the river continuum concept, in which river systems are viewed as a continuum of geophysical and hydrological changes with an associated gradient of biotic communities in which structure and function changes. In the proposed concept, small headwater streams were generalized as being strongly influenced by riparian vegetation, which reduced primary production by shading, and provided large amounts of organic detritus. As a result, the stream's gross primary productivity to community respiration (P/R) ratio should have a value less than one. It was pointed out (Minshall, 1978), however, that this concept was modeled after natural, undisturbed stream ecosystems. Unnatural disturbances (or in the case of Iowa, lack of woody riparian vegetation) might alter the P/R ratio, shifting it to a higher, more autotrophic level in small streams.

While most small Iowa streams are unpolluted by municipal or industrial wastes, they are often in close proximity to agricultural activities. Nutrient inputs from feedlots and agricultural fields, and modification of riparian vegetation by grazing, farming, or stream channelization may have a significant impact on the metabolic activities of stream biota. Riparian vegetation along Iowa streams usually consists of grasses which cause little shading. High light intensities during daylight hours, combined with high nutrient levels would be expected to result in high rates of oxygen production, which would, in turn, create substantial changes in dissolved oxygen concentrations. Because the grasses along many Iowa streams provide only limited amounts of allochthonous organic material, the rates of respiration would be expected to be only moderately high.

In this study, I looked at a small Iowa stream, Big Creek. I expected it to have high rates of production, and moderately high rates of respiration, causing large diurnal changes in dissolved oxygen concentrations.

The objectives of this study were:

1. To determine the daily and seasonal fluctuations of dissolved oxygen and temperature in a small agricultural stream.
2. To determine the gross primary productivity and community respiration in a small agricultural stream.

3. To determine where the primary production occurs within a small agricultural stream, and the factors that control it.

METHODS

Site Location and Description

Big Creek is a first order stream located in Boone County, Iowa. The research site (SW 1/4, NE 1/4, NW 1/4, Sec. 12, T-83N, R-26W) (Latitude 42° 01' 05" N, Longitude 93° 51' 42" W) was located 6 km southeast of Boone and 6 km north of Luther. The stream's headwaters are near Highway 30, approximately 1.7 km north of the research site. Big Creek flows into Big Creek Lake 24 km downstream from the research site.

The stream is relatively small in size, 2 to 4 m wide and less than 1 m deep. Inflow from drainage tiles makes up a large portion of the flow, especially during periods of heavy precipitation. The plant community in Big Creek includes macrophytes, as well as benthic and epiphytic algae. Substrates vary considerably, from rocky to fine silt.

The land surrounding the site is used to graze cattle during the summer, however, they were never observed feeding in the stream itself. The cattle actually appeared to avoid the stream, crossing primarily at a point with inclined banks 60 m upstream from the study site.

Procedures

Measurement of dissolved oxygen and temperature began on June 2, 1982, and continued until October 21, 1982. A YSI Model 56 Dissolved Oxygen-Temperature Monitor was used for these measurements. Dissolved oxygen concentrations for meter calibration and suspended productivity assays were determined using an azide modification of the Winkler method (A.P.H.A., 1975).

On October 21, 1982, the strip chart was removed from the monitor. Dissolved oxygen (mg/l) and temperature (°C) values for each hour were entered into a computer file for analysis.

Gross primary productivity and community respiration for each day were estimated using diurnal changes in dissolved oxygen (Hall and Moll, 1975). Equations presented by Owens (1974) provided an estimation of the rate of diffusion across the air-water interface for streams with a rate of flow of 0.03-1.50 m/sec, and a mean depth of 0.12-3.35 m. Big Creek did meet these requirements throughout the study. Dividing the areal rate of diffusion by the mean depth of the stream, resulted in a volumetric rate of oxygen diffusion in g $O_2/m^3/hr$, which was then added to, or subtracted from, the hourly change in dissolved oxygen.

Rates of dissolved oxygen loss at sunset were usually not the lowest values found during the day. This suggests that the sunset hour does not represent a time when the effects of primary productivity are negligible. The effects of primary productivity are seen for 4 to 5 hours after sunset. To correct for this lag, the midnight value for change in dissolved oxygen was chosen to represent respiration. This procedure for the estimation of gross primary productivity and community respiration was adapted into a computer program which is presented in Appendix B.

To use the single station diurnal oxygen curve method, the drainage accrual entering Big Creek must be negligible. Drainage accrual can be considered any water entering the stream from outside the system, including surface runoff, groundwater seepage, and agricultural tile drainage. In Big Creek, however, this assumption may not have been correct. Inputs from groundwater and tile drainage may have had a significant impact on the changes in dissolved oxygen. This water often has dissolved oxygen concentrations well below saturation (Hynes, 1970). Upon entering the stream, the drainage accrual can lower the overall concentration of dissolved oxygen. The single station diurnal oxygen curve method interprets any negative change in oxygen, other than diffusion, as respiration. If drainage accrual is significant, respiration rates will be overestimated. The estimates of gross primary productivity, however, will remain unaffected by the accrual, since they are corrected for respiration effects. Because the effects of drainage accrual in Big Creek are similar to those of respiration, it may be best to think of the respiration estimates as "apparent rates of respiration". Actual rates of respiration would be lower than the apparent rates.

The stream's rate of flow and mean depth were estimated twice weekly from June to July, and once a week during September and October. Discharge was determined by measuring the stream channel dimensions, and the rate of stream flow. Rate of flow in each segment was determined by timing the travel of fluorescein dye over a known distance.

Suspended algal primary productivity was measured using the dissolved oxygen light-dark bottle technique described by Vollenweider (1969). Six bottles, three "light" and three "dark", were placed on the stream bottom in midstream (0.5-1.0 m deep) and incubated for 4 hours. Any sedimentation on the bottles was removed as it occurred, yet this proved to be no real problem. Upon removal from the stream, the samples were fixed, and the dissolved oxygen concentrations were determined as described for meter calibration.

Suspended algal chlorophyll a and phaeophyton were measured twice weekly until September, when measurments were taken once weekly. For chlorophyll a and phaeophyton determinations, known volumes of water were filtered through Whatman GF/C glass fiber filters and stored with desiccant in a freezer for a maximum of 3 months. The filters were pulverized using a tissue grinder, and pigments were extracted using 90% acetone. Concentrations of chlorophyll a and phaeophyton were determined according to Richards with Thompson (1952) and Yentsch and Menzel (1963), using the equations of Strickland and Parsons (1968).

An approximation of benthic chlorophyll a and phaeophyton biomass was made by allowing algae to colonize on 9x13 cm bricks located on the stream bottom. Ten bricks were placed two abreast along the center of the stream. Sampling two bricks every week allowed them five weeks to colonize. After the period of colonization, the bricks were gently rinsed with stream water. Attached algal material was then scraped off, first with a razor blade, and then with a brush. Scraped bricks were then returned to the stream bed to be colonized again. Water was added to the algal sample to a volume of 1 liter. This sample was then vigorously shaken, and analyzed in the same manner as the suspended algae.

At the same time water samples were collected for the suspended chlorophyll a determination, samples were collected to measure turbidity, specific conductance, and total phosphorus. Turbidity was measured using a Hach Model 2100 Turbidimeter. Specific conductance was measured using a Hach Model 2511 Conductivity Meter. The total phosphorus concentration was determined using the persulfate digestion and ascorbic acid determination (A.P.H.A., 1975). Samples were centrifuged after digestion to remove suspended particles.

Values for total daily light energy, as measured in Ames, Iowa, were obtained from the Agronomy Department at Iowa State University. These measurements are in Langleys/day. Daily rainfall estimates were obtained from the Des Moines Register.

RESULTS

Big Creek, unlike many streams in central Iowa, has a significant population of macrophytes. Percent coverage by macrophytes averaged 62% in an 80 m section of stream just upstream from the study site. In some areas, macrophytes covered 100% of the stream bottom. In the area where the cattle crossed the stream, there was only 5% coverage by macrophytes. Potomogeton sp. comprised 45% of the coverage, while the other 17% was primarily Polygonum sp. Data on macrophyte biomass and %-coverage information are located in Appendix G.

Some areas of the stream bottom were kept clean of vegetation by currents, however, most of the bottom surfaces which were not covered by macrophytes, was blanketed by a substantial standing crop of attached algae. The most dominant alga was Cladophora. The rest of the community was comprised mostly of diatoms and yellow-brown algae (Chrysophyta). See Appendix H for a complete listing of algal genera. The mean areal chlorophyll a content of the attached algae was 53.47±9.011 mg/m^2 (Table 1).

Very few suspended algae were found in the water column. The areal chlorophyll a content of this water was only 0.779±0.222 mg/m^2 (Table 1), which is only 1.4% of the total algae collected. Only five genera of algae were found in the suspended water samples. Five of these genera

TABLE 1. Summary of suspended and attached algal chlorophyll *a* and phaeophyton

	Mean±S.E.M.	Range
Chlorophyll *a*		
Suspended Algae		
mg/m^3	27.720±0.763	0.451-17.073
mg/m^2	0.779±0.222	0.094-5.424
Attached Algae		
mg/m^2	53.47±9.011	20.48-144.28
Phaeophyton		
Suspended Algae		
mg/m^3	1.459±0.285	0.109-6.745
mg/m^2	0.355±0.052	0.073-1.052
Attached Algae		
mg/m^2	1.90±0.362	0.71-5.87

were also found in the attached algae (See Appendix H). As indicated by Swanson (1973), it is likely that the suspended algae originate from the benthic community.

The relative contribution of any one type of plant towards the total community primary productivity in Big Creek cannot be determined from this study. The majority of the plant biomass is located on the stream bottom in the form of macrophytes and attached algae. Since the algal samples from bricks placed in the stream had 98.6% of the total algae collected, and the increased surface area provided by the macrophytes serve to increase the attached algal population even further, it would probably be safe to assume that the vast majority of the primary production in

Big Creek originates from the stream bottom. Plots of suspended chlorophyll a versus time and attached chlorophyll a versus time are given in Figure 1 and Figure 2 respectively. The suspended chlorophyll levels remained low and nearly constant throughout most of the summer. The two highest peaks, in June and July, correspond to days of high discharge, and may be the result of scouring of the benthic algae. The peaks in September and October, however, are associated with periods of very low discharge, and may be the result of algae senescing. Attached algal chlorophyll showed a much different trend. Biomass was high in midsummer but decreased in September and October. The decrease at the end of the summer is likely due to the senescing of the attached algae.

Dissolved Oxygen and Temperature

Significant diurnal variations were found for dissolved oxygen and temperature in Big Creek (Figure 3). Dissolved oxygen concentrations typically increased during the morning hours to an average high of 10.6 mg/l around 1600 hours, then gradually decreased to a low averaging 6.3 mg/l around 0400 hours (Table 2). The average dissolved oxygen concentration for the summer was 8.0±0.07 mg/l (±S.E.M.).

Temperatures followed a similar pattern with an average

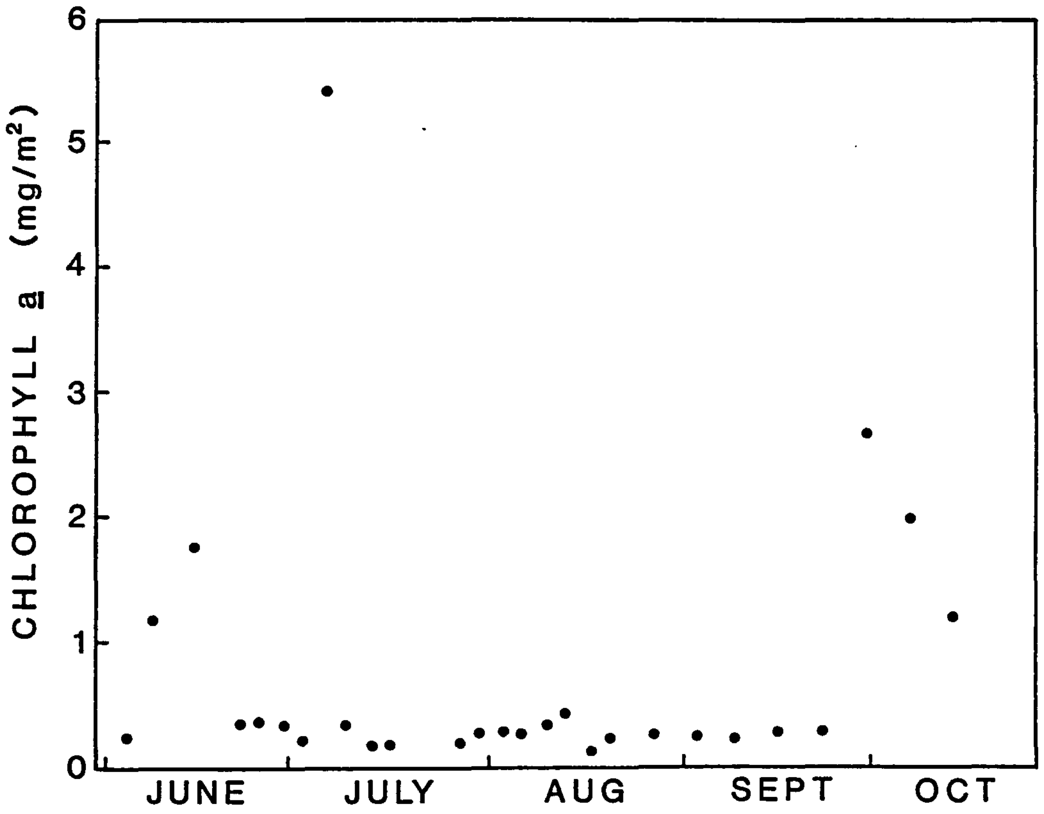

FIGURE 1. Suspended chlorophyll a concentration vs time

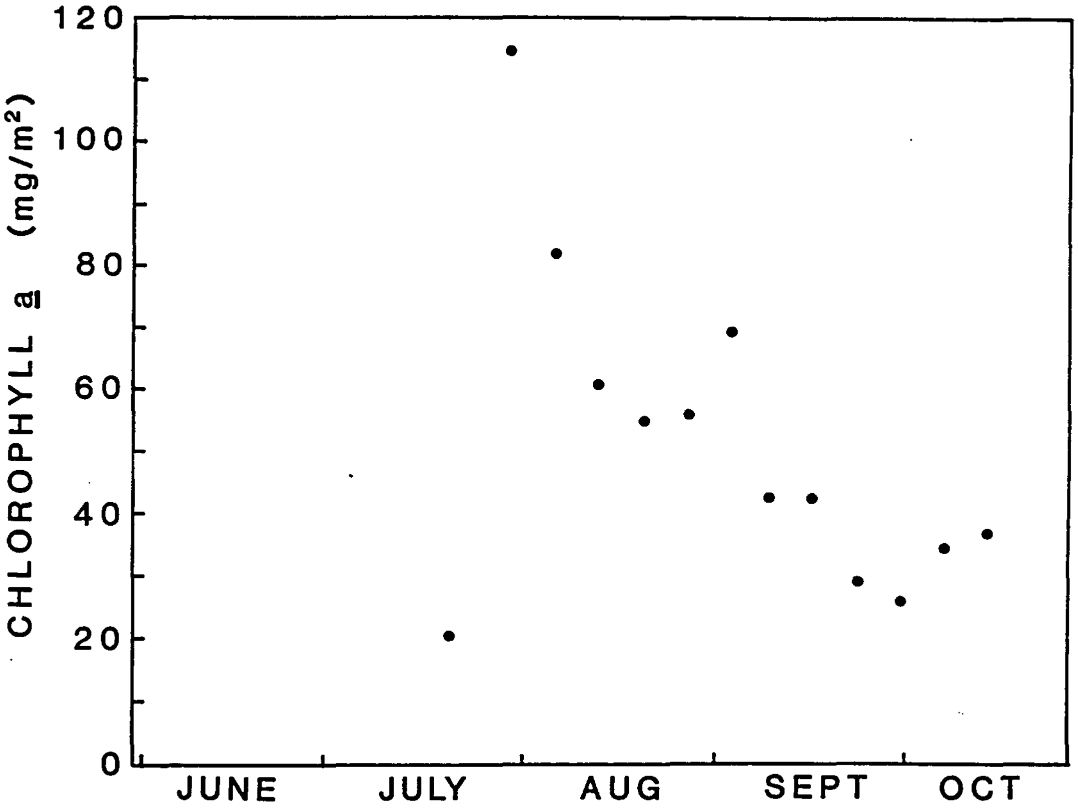

FIGURE 2. Attached chlorophyll a concentration vs time

high temperature of 18.3°C around 1700 hours, and an average low of 13.8°C around 0600 hours (Table 2). Big Creek had a mean summer temperature of 15.9 ± 0.08°C.

Percent saturation of oxygen in the stream also followed this diurnal cycle, with the average daily high and low being 121% saturation and 55% saturation respectively (Table 2). The average for the summer was 81 ± 0.7% saturation. On every day recorded, the oxygen concentration dipped well below saturation. Values of 40% to 60% of saturation were quite common at night. During daylight hours, the oxygen concentration rose to 120% to 140% of saturation on all but fourteen days. Average daily changes in dissolved oxygen concentration and temperature were 4.3 ± 0.22 mg/l and 4°C respectively. Daily changes up to 11.6 mg/l for dissolved oxygen and 9.0°C for temperature were observed, however, they were uncommon.

Both dissolved oxygen and temperature showed distinct seasonal patterns (Figures 4, 5, and 6). Dissolved oxygen values were fairly high in June, but decreased until the end of August (Figures 4 and 5). The lowest oxygen concentration, 2.3 mg/l (24% saturation), was observed on August 31. Oxygen concentrations increased in September, and continued to do so through October. On October 18, the highest dissolved oxygen concentration, 18.2 mg/l (177% saturation), was recorded.

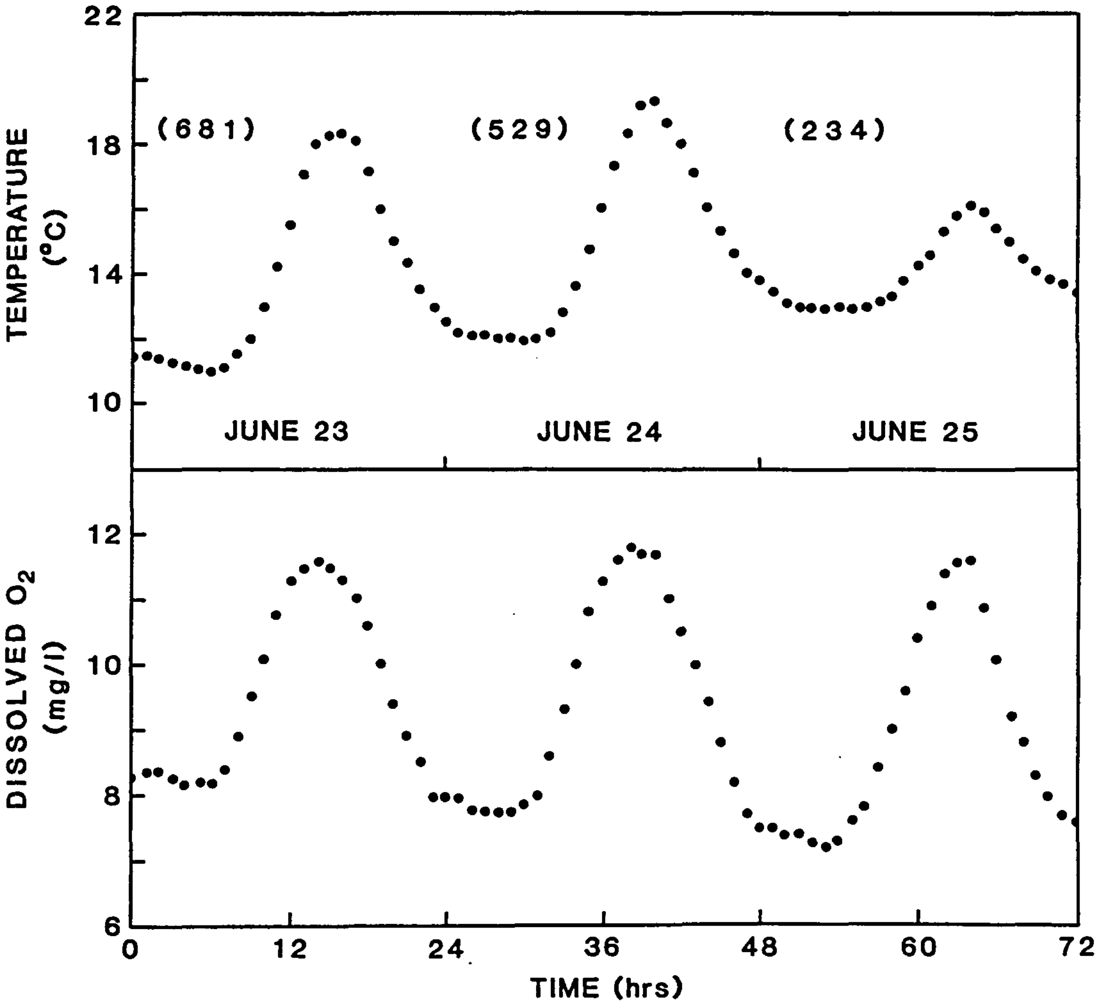

FIGURE 3. Temperature (°C) and dissolved oxygen concentration (mg/l) vs time from June 23-25, 1982. (Numbers in parentheses are solar ratiation in Langleys/day.)

TABLE 2. Summary of mean values for dissolved oxygen and temperature in Big Creek (Mean ± S.E.M.)

	Dissolved Oxygen			Temperature	
	mg/l	% Sat.	Hour	°C	Hour
Mean	8.0±0.07	80±0.7		15.9±0.08	
Range	2.3-18.2	24-177		5.4-24.4	
Mean Daily High	10.6±0.26	121±3.0	15:27	18.3±0.41	17:30
Mean Daily Low	6.3±0.17	55±1.6	3:48	13.8±0.37	6:00
Mean Daily Range	4.3±0.22	66±2.9		4.4±0.23	

Temperatures were relatively low in June, averaging about 14°C (Figure 6). In early August, however, the water temperatures increased to about 18°C. In late August, the daily temperatures began decreasing to a low in October of about 11°C. The last full day of the study, October 20, had a low temperature of 5.4°C, which was the lowest temperature observed during the study. The highest recorded temperature was 24.4°C, and was recorded on August 3.

Primary Productivity and Community Respiration

Using the diurnal dissolved oxygen curve method, estimates of gross primary productivity and community respiration were calculated. A summary of these values is presented in Table 3. The mean rate of productivity in Big Creek was 10.0±0.51 g O_2/m^2/day. The mean rate of

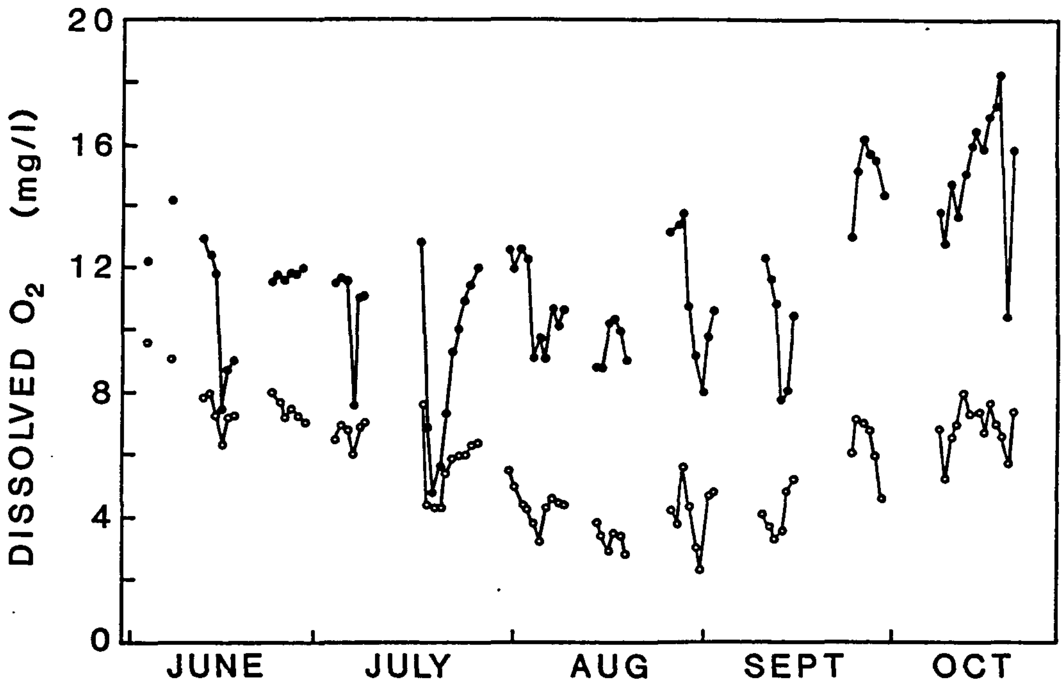

FIGURE 4. Daily high and low dissolved oxygen concentrations (mg/l) vs time. (Filled and open dots are high and low values respectively. Breaks indicate unrecorded days.)

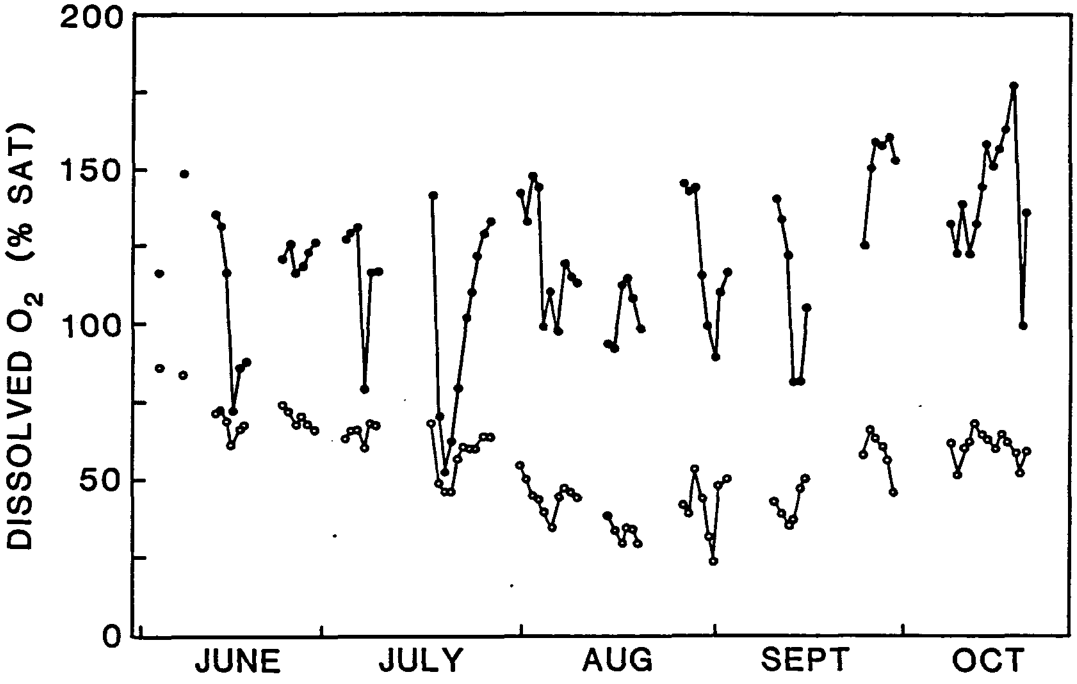

FIGURE 5. Daily high and low dissolved oxygen (% saturation) vs time. (Filled and open dots are high and low values respectively. Breaks indicate unrecorded days.)

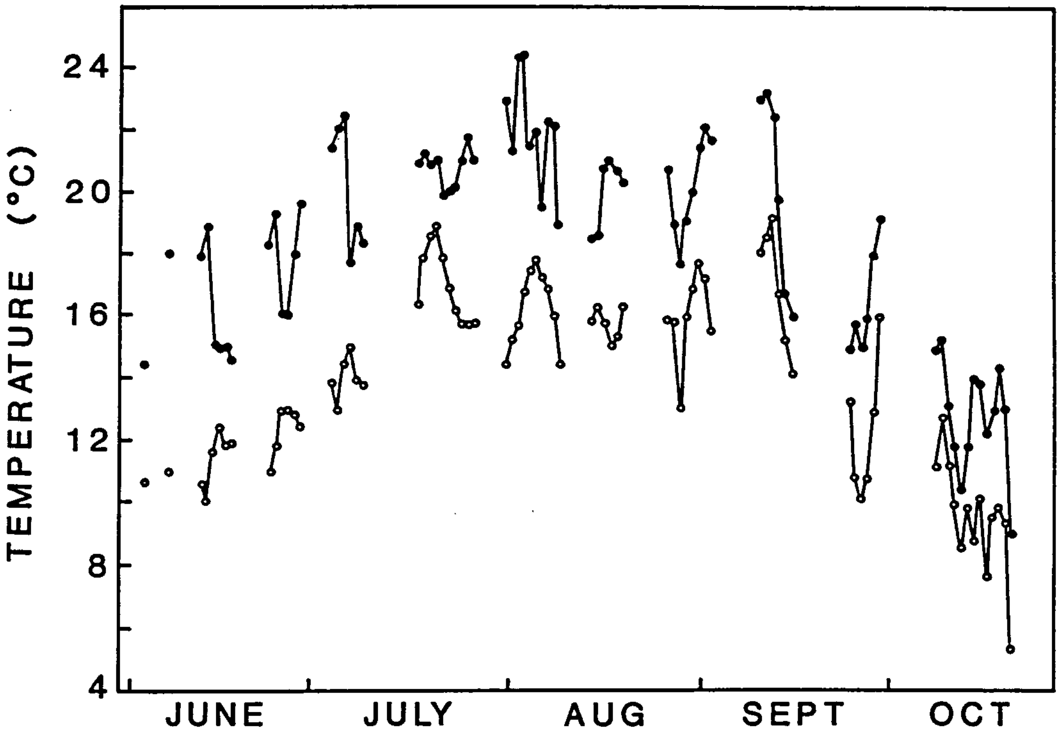

FIGURE 6. Daily high and low temperatures (°C) vs time. (Filled and open dots are high and low values respectively. Breaks indicate unrecorded days.)

TABLE 3. Summary of volumetric productivity and respiration ($g/m^3/day$), areal productivity and respiration ($g/m^2/day$), and P/R ratio

	Mean±S.E.M.	Range
Volumetric ($g/m^3/day$)		
Gross Primary Productivity	46.1±3.29	0.13-115.0
Community Respiration	79.1±5.39	17.86-202.1
Areal ($g/m^2/day$)		
Gross Primary Productivity	10.0±0.51	0.12-19.3
Community Respiration	18.2±0.73	6.84-35.1
P/R ratio	0.60±0.03	0.003-1.55

respiration was 18.2±0.73 g $O_2/m^2/day$.

Figure 7 shows a fairly high day to day variation in productivity, with no temporal trends. It appears that the productivity observed on any day is unrelated to the productivity occurring on the next day. Apparent respiration, on the other hand, shows a fairly small day to day variation, and a definite temporal trend (Figure 8). In early June the respiration rate was about 10 g $O_2/m^2/day$. By the end of August, however, the levels had risen to 30 g $O_2/m^2/day$. In late September, there was a drop in respiration back to around 10 g $O_2/m^2/day$.

Assay bottles for suspended algal productivity (light-dark bottle method) produced no oxygen concentration

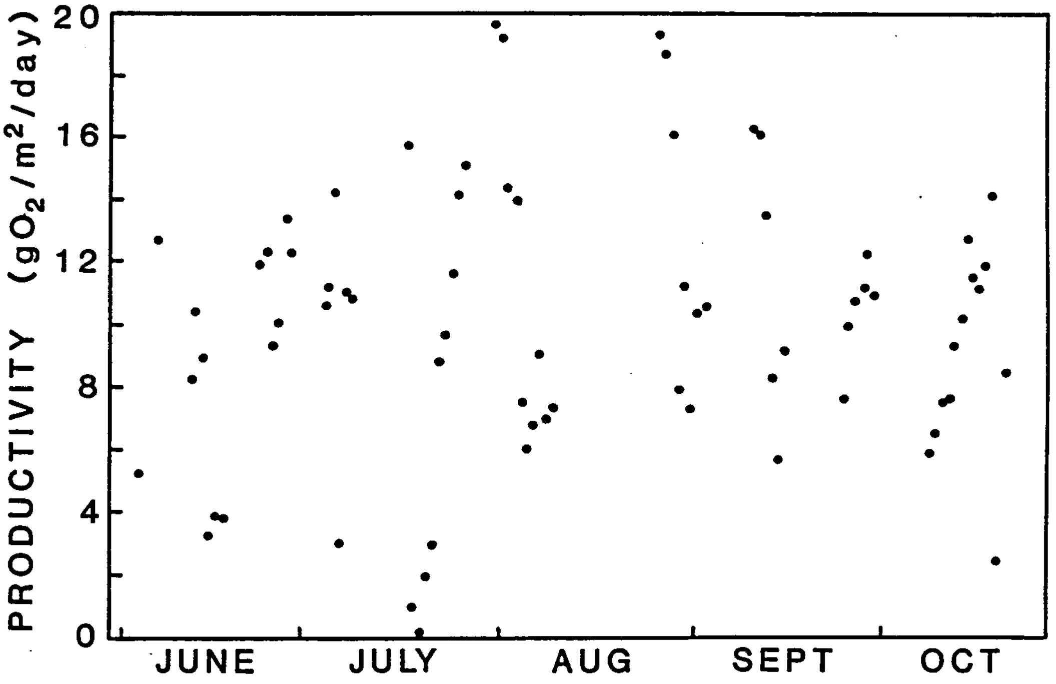

FIGURE 7. Gross primary productivity (g/m^2/day) vs time

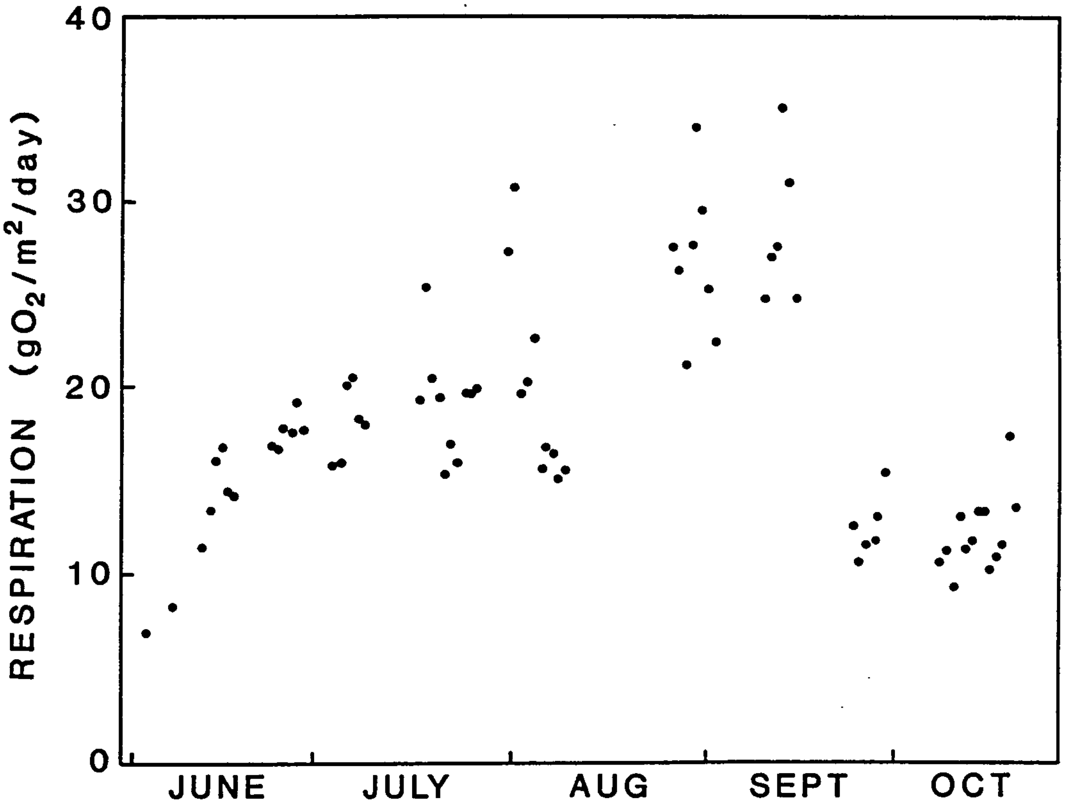

FIGURE 8. Community respiration (g/m^2/day)) vs time

changes. Even after 6 hours of incubation, both light and dark bottle oxygen concentrations showed no significant changes from the initial values. These assays produced similar results throughout the summer.

The daily ratio of gross primary productivity to community respiration (P/R ratio) was less than one on all but three days during the summer. The mean daily P/R ratio during the summer was 0.60, indicating that the rate of primary production is lower than the rate of breakdown of organic debris by respiration. The oxygen consumptive effcts of drainage accrual, however, may also have been responsible for these low P/R ratios. As pointed out by Minshall (1978), the interpretation of these P/R ratios can be difficult and misleading.

Factors Affecting Primary Productivity

Plotting primary productivity against light energy (Figure 9) results in an apparently random distribution of points, suggesting light levels have little effect on primary productivity in Big Creek. The correlation coefficient for this relationship was 0.31 (Table 4), which is statistically significant. The relationship between light and productivity is much poorer than might have been expected.

Rain events were thought to contribute to the low correlation between light and productivity. Heavy rains would be expected to increase discharge in the stream, and thereby increase stream turbidity. Under conditions of high turbidity, the sunlight reaching the macrophytes and the benthic algae, could have been reduced enough to decrease productivity. Daily precipitation values, however, showed no significant correlation with productivity (Table 4). Plotting only days without precipitation produced a correlation coefficient only slightly higher than when all of the days were used (Table 4). In a stream as clear and as shallow as Big Creek, rain events, and the increases in discharge which are associated with them, may have little effect on the amount of light reaching the stream bottom.

TABLE 4. Correlation coefficients of gross primary productivity and community respiration ($g/m^2/day$) versus light energy and precipitation

	Productivity	Respiration
Light	0.31^{**}	0.01^{NS}
Precipitation	-0.15^{NS}	0.11^{NS}
Light[a]	0.38^{**}	0.04^{NS}

[a] Using only days with zero precipitation.
** - $p < 0.01$
NS - Not Significant, $p > 0.05$

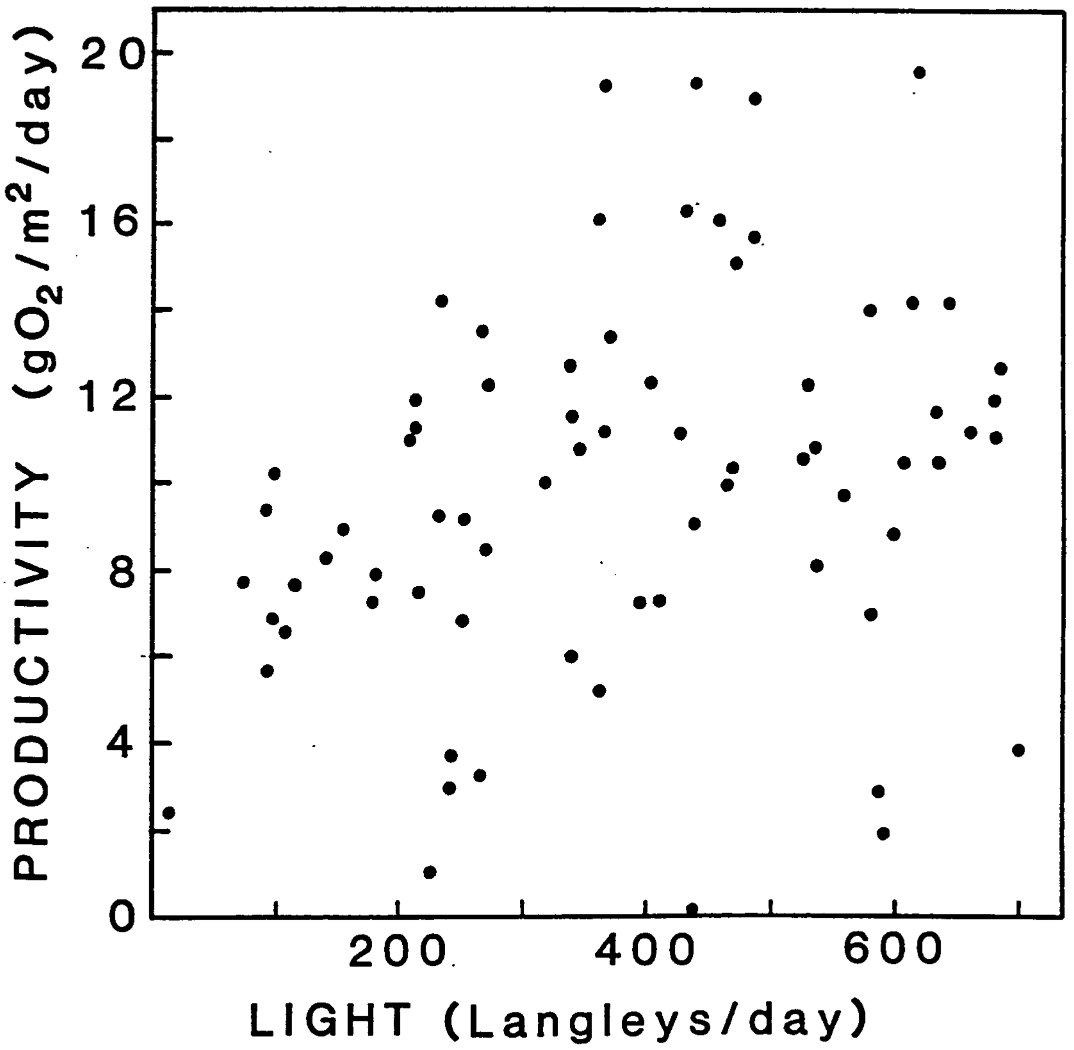

FIGURE 9. Areal gross productivity (g/m^2/day) vs light energy (Langleys/day)

No statistically significant correlations were found between primary productivity and respiration, and algal biomass, specific conductance, discharge, turbidity, and total phosphorus. Algal biomass may have too small a range to show a significant effect on productivity. In a system as dynamic as Big Creek, it is likely that solar radiation is not the only factor controlling the rate of primary production. While solar radiation may be an important factor influencing productivity (as indicated by the correlation coefficients in Table 4), even small changes in plant biomass, discharge, nutrients and other factors, though each showing insignificant effects alone, may interact to regulate primary production.

DISCUSSION

The diurnal changes in dissolved oxygen observed in Big Creek were much larger than had been expected. On the average, oxygen levels rose to 121% saturation by late afternoon before dropping to 55% saturation at night. Extreme values ranged from 24% saturation to 177% saturation. Fluctuations in dissolved oxygen would be expected to be minimal in small streams. The large surface area to volume ratio would be expected to maintain a dissolved oxygen concentration near saturation.

Large fluctuations in dissolved oxygen result from high metabolic rates occurring in the stream biota. During the night, respiring organisms consume oxygen at such a high rate that saturation cannot be maintained by diffusion. During the day, the rate of photosynthetic oxygen production is greater than the rate of diffusion, thereby allowing oxygen to supersaturate the stream water.

In an environment where dissolved oxygen levels rise to 121% saturation and then fall to 55% saturation in less than 12 hours, the aquatic organisms must be subjected to a great deal of stress. When oxygen concentrations become low, the activities of fishes and invertebrates may be severely restricted. In streams with large diurnal changes in oxygen, organisms which usually forage at dawn and dusk must modify their behavior to cope with these conditions. During early morning hours, these organisms may have to stop feeding because of the very low oxygen concentrations which occur at night.

It is likely that the organisms which inhabit Big Creek are primarily species which are tolerant of low oxygen concentrations, and of extreme changes in both oxygen and temperature. Many of these species probably evolved under similar conditions in the open streams of the prairies, and can therefore survive the harsh environment. Increased organic inputs, however, could create even more severe conditions, causing increased rates of respiration, which would result in lethally low levels of oxygen at night.

The estimates of primary production and respiration in Big Creek indicated that metabolic rates were high. Productivity values reported for other streams (Table 5) ranged from 1.96 g O_2/m^2/day in Honey Creek, Oklahoma (Reisen, 1976) to 16.6 g O_2/m^2/day in Silver Springs, Florida (Odum, 1957). Only three streams reported rates of production as large as those in Big Creek. Edwards and Owens (1962) and Prophet and Ransom (1974) reported productivity values very similar to those of Big Creek. Odum (1957) reported a productivity of 16.6 g O_2/m^2/day, which was much higher than Big Creek's.

The rate of respiration measured in Big Creek, 18.2 g O_2/m^2/day, was higher than any values reported in

TABLE 5. Observed values of gross primary productivity, community respiration ($g/m^2/day$), and P/R in streams

Site	GPP	CR	P/R
Honey Creek, Oklahoma	1.96	2.27	0.86
(Reisen, 1976)			
Pinto Creek, Arizona			
Polluted	3.45	3.84	0.90
Unpolluted	5.3	4.3	1.23
(Lewis and Gerking, 1979)			
Laboratory Stream	3.7	2.7	1.37
(McIntire et al., 1964)	(3.4-4.0)	(2.4-2.9)	
Spring Creek, Penn.	3.98	---	---
(McDonnell, 1982)			
White Clay Creek, Penn.	5.2	8.9	0.58
(Bott et al., 1978)			
Buffalo Creek, Penn.	5.62	2.16	2.60
(McDiffett et al., 1972)			
Blue River, Oklahoma	6.8	11.0	0.62
(Duffer and Dorris, 1966)	(10.1-48.0)		
Truckee River, Nevada	8.8	11.4	0.77
(Thomas and O'Connell, 1966)	(4.0-16.5)	(4.8-17.7)	
River Ivel, England	9.6	8.5	1.13
(Edwards and Owens, 1962)			
Big Creek, Iowa	10.0	18.2	0.60
(present study)	(0.12-19.3)	(6.84-35.1)	
Cedar Creek, Kansas	10.51	17.28	0.61
(Prophet and Ransom, 1974)			
Silver Springs, Florida	16.6	13.1	1.27
(Odum, 1957)			

the literature. Prophet and Ransom (1974) reported a respiration rate of 17.8 g $O_2/m^2/day$ in Cedar Creek, Kansas, which was the only value close to Big Creek's. Other investigations have found respiration rates ranging from 2.27 g $O_2/m^2/day$ in Honey Creek, Oklahoma (Reisen,

1976) to 13.1 g O_2/m^2/day in Silver Springs, Florida (Odum, 1957). It should be noted that the respiration rates presented in this study are rates of apparent respiration. The contribution of oxygen poor water from drainage accrual in Big Creek may have simulated the effects of respiration by reducing the levels of oxygen.

High productivity values are common to Iowa waters. Iowa's lakes are among the most eutrophic bodies of water in the world. Table 6 lists productivity values for several lakes in Iowa reported by Paulsen (1982). These range from a low of 7.68 g O_2/m^2/day in Little Wall Lake, to a high of 13.76 g O_2/m^2/day in Black Hawk Lake. The productivity in Big Creek is quite comparable to that of Iowa's very eutrophic lakes.

TABLE 6. A comparison between the mean daily gross productivity (g/m^2/day) of Big Creek and several Iowa lakes (Paulsen, 1982)

Site	Mean	S.E.M.	N	Max	Min
Big Creek (stream)	10.03	0.51	73	19.3	0.12
Little Wall Lake	7.68	1.09	8	12.16	4.16
Saylorville Res.	8.32	1.63	8	14.40	0.96
Union Grove Lake	9.28	0.99	9	14.08	4.16
Big Creek Lake	10.88	1.25	8	16.64	7.68
Black Hawk Lake	13.76	2.69	11	38.08	5.12

High rates of productivity in Big Creek may have been the result of large algal standing crops. The benthic algal biomass in Big Creek, 53.47 mg/m^2 of chlorophyll a, was much higher than that reported for Carnation Creek (Stockner and Shortreed, 1976), which was 1.6 mg/m^2. Swanson and Bachmann (1976), however, reported a benthic algal biomass three times higher than that of Big Creek in nearby Skunk River, Iowa.

TABLE 7. Observed values of suspended and attached chlorophyll a concentrations (mg/m^2)

Site	Attached	Suspended	Susp/Total
Carnation Creek	1.6	---	---
Ritherdon Creek (Stockner and Shortreed, 1976)	2.3	---	---
Blue River, Oklahoma (Duffer and Dorris, 1966)	20-39	4.0	0.17-0.09
Big Creek, Iowa (present study)	53.47	0.78	0.014
Skunk River, Iowa (Swanson and Bachmann, 1976)	160	40.0	0.20
Logan River, Utah (McConnell and Sigler, 1959)	300	---	---

While Big Creek supported a high benthic algal biomass, the suspended algal biomass was extremely low. The chlorophyll a content averaged 0.014 mg/m^2, which was only 1.4% of the total algal biomass collected. The low suspended algal biomass resulted in the low suspended primary productivity in Big Creek. With such a low concentration of algae in the water column, even high rates of production had little effect on the stream's oxygen content.

The majority of the production in Big Creek probably originates from the benthic algal community. The stream's shallowness, its extreme clarity, and a riparian vegetation composed almost entirely of short grasses, allow the benthic algal community to receive large amounts of sunlight. The high light intensities, combined with large standing crops of algae and macrophytes, result in high productivity values like those found in Big Creek.

The high rates of respiration in Big Creek may also be related to large benthic standing crops. Swanson (1973) found the benthic algae to be responsible for most of the oxygen consumption in the Skunk River. Edwards and Owens (1965) indicated that the consumption of oxygen by benthos is dependent on the depth of the river. In shallow streams, the benthos have a much greater impact on oxygen levels than in deeper streams.

The ratio of productivity to respiration (P/R ratio) in Big Creek was 0.60 (Table 3). Vannote et al. (1980)

describe a stream with a P/R ratio less than one as heterotrophic. Mann (1975), however, defines a heterotrophic stream as one which imports a majority of its primary production from outside the system. In a system with a P/R ratio of 0.60, 60% of the primary production originates from within the stream, and only 40% originates from outside the stream. By Mann's definition, Big Creek should be considered autotrophic because most of the primary production originates from within the stream system. Minshall (1978) emphasizes the difficulty of interpreting P/R ratios, and concludes that P/R values of less than one should not be considered convincing evidence that a stream is dependent on allochthonous material.

The very high values of respiration could be the result of an introduction of oxygen deficient drainage accrual. Deoxygenated water, upon entering the stream, acts to lower dissolved oxygen concentrations, which can simulate the effects of respiration. There may, however, be substantial inputs of allochthonous organic material entering the stream. The riparian vegetation along Big Creek may contribute much of this material in the form of coarse particulates, which consist mostly of wind blown plant parts. Dissolved organic material, originating from nearby agricultural fields, may also be entering the stream through surface runoff, groundwater seepage, and tile drainage.

The large day to day variation found in primary productivity in Big Creek (Figure 7) suggests that a single day's estimate of productivity may not be representative of the stream's actual average productivity. On September 10, the productivity was estimated to be 16.32 g O_2/m^2/day, but only 4 days later, on September 14, the estimate was 5.71 g O_2/m^2/day. This is a difference of over 10 g O_2/m^2/day. Several studies, however, have measured long term changes in productivity by taking measurements only once or twice a month (Duffer and Dorris, 1966; Hickman, 1974). It is apparent that this sampling frequency, at least in Big Creek, could have produced inaccurate results. In a system as dynamic as a stream, it may be necessary to measure production quite often to develop a complete understanding of metabolic rates.

Studies involving small streams in Iowa must also take into account the large diurnal changes which may occur in these streams. In Big Creek, the highest dissolved oxygen concentrations usually occurred around 1600 hours. If the study is concerned with periods of high oxygen concentrations, late afternoon would be the most appropriate time to sample. Studies dealing with the effects of low oxygen concentrations, however, should sample just prior to sunrise, when concentrations are lowest.

This study creates many questions concerning oxygen metabolism in small agricultural streams. How accurate are the estimates of productivity and respiration? How reliable are the equations of Owens (1974) for the estimation of diffusion rates? Are the assumptions made for the diurnal oxygen curve method valid? What are the effects of photorespiration in Big Creek? What is the primary source of allochthonous organic material? How much of the production is imported from upstream, or exported downstream? What are the effects of large diurnal fluctuations on the streams biota? Many of these questions are difficult to answer. Continued investigation is needed to fully understand the oxygen metabolism of small agriculturally impacted streams. Such streams make up a large part of the surface water in Iowa, and must be considered valuable resources worth studying and protecting.

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APPENDIX A:

EXPANDED PRODEDURES

Measurement of dissolved oxygen and temperature began on June 2, 1982, and continued until October 21, 1982. A YSI Model 56 Dissolved Oxygen-Temperature Monitor was used for these measurements. This meter records dissolved oxygen and temperature on a heat sensitive strip chart located within the meter itself. Recording is continuous (1 cm/hour), however, the meter had to be turned off periodically for battery recharging, meter calibration, and meter and probe maintenance.

The meter was placed on the stream bank 100 m downstream from the access road. The meter's probe was fastened to a metal fence post in the center of the stream, with the oxygen sensor about 15 cm from the stream bottom. A flow of water over the probe's membrane was ensured not only by the stream flow itself, but also by a stirring mechanism which was attached to the probe. The probe membrane was wiped clean every time the meter battery was recharged, and replaced periodically. The battery pack used with the monitor allowed 10 days of continuous operation before recharging was necessary. To recharge the unit, the battery pack was removed and returned to the laboratory for a 24-hour recharging period. The monitor was usually replaced within 3 or 4 days, after which the meter was recalibrated. The monitor was calibrated by setting the chart oxygen reading to dissolved oxygen concentrations determined using an azide modification of the Winkler method (A.P.H.A., 1975).

Water samples for meter calibration and suspended productivity assays were obtained using a Van Dorn sampling device. The sampler was placed under the water surface for several seconds to allow water to flow through it before hand tripping the closing mechanism. This water was then poured into triplicate 200 ml BOD bottles allowing at least three times the volume to overflow. Dissolved oxygen concentrations were then determined using the Winkler method. The samples were fixed in the field with 2 ml of manganous sulfate and 2 ml of alkali-iodide azide reagent. After returning to the laboratory, 2 ml of concentrated sulfuric acid were added to 200 ml of each of the fixed samples. The samples were titrated with 0.025 N phenylarsine oxide (PAO, Hach Chemical Co.).

On October 21, 1982 the strip chart was removed from the monitor. Reading the data from the strip chart was aided by using a transparent template placed over the chart. The template allowed the dissolved oxygen and temperature values to be read for each hour. These data were then entered into a computer file for analysis. Dissolved oxygen and temperature were recorded in mg/l and °C respectively.

These data can be found in microfiche at the Iowa State University Library Media Center.

An estimation of gross primary productivity and community respiration can be made from diurnal changes in dissolved oxygen (Hall and Moll, 1975). The rate of change in dissolved oxygen in a stream (q) is assumed to be determined by 4 parameters. These are the rate of gross primary production (p), the rate of community respiration (r), the rate of oxygen diffusion across the air-water interface (d), and the rate of drainage accrual (a). The The relationship between the rate of change of oxygen and the parameters given above can be shown by Equation 1.

$$(1) \quad q = p - r \pm d + a$$

For the purpose of determining primary productivity and respiration the rate of drainage accrual (a) must be negligible. If this is the case, Equation 2 results.

$$(2) \quad q = p - r \pm d$$

Before the values of primary production (p) and respiration (r) can be determined, the volume of oxygen diffused (d) must be estimated, and its effects removed.

Owens (1974) provides a series of equations for the estimation of the rate of diffusion across the air-water interface. These equations can be summarized by Equation 3.

$$(3)\quad D = \frac{50.8\ V^{0.67}}{Z^{0.85}}\ 1.024^{(T - 20)}\ ((Cs - C) / 100)$$

where D is the rate of oxygen diffusion in g $O_2/m^2/hr$, V is the velocity of the stream in cm/sec, Z is the mean depth of the stream in cm, T is the water temperature in °C, Cs is the concentration of dissolved oxygen at 100% saturation (at temperature T), and C is the dissolved oxygen concentration observed. Both oxygen concentrations are in mg/l (g/m^3). Dividing the areal rate of diffusion (D) by the mean depth (Z) of the stream converted to meters (multiply Z by 0.01) provides an estimate of the volumetric rate of oxygen diffusion (d) in g $O_2/m^3/hr$ as in Equation 4.

$$(4)\quad d = \frac{D}{Z}$$

Now that a value for d is known, the gross primary productivity (p) and community respiration (r) can be estimated. For this estimation, the change in dissolved oxygen is calculated for each hour. This is done by taking each dissolved oxygen value (one per hour) and subtracting the dissolved oxygen value of the previous hour from it. The d value obtained previously is then subtracted from each hour's change in oxygen to produce the corrected hourly change in dissolved oxygen (q'). These calculations result in Equations 5 and 6.

$$(5)\quad q' = q \pm d$$

$$(6)\quad q' = p - r$$

The resulting twenty-four data points are then plotted against time (in hours) as seen in the two lower plots in Figure A1.

The second assumption of this method is that the rate of community respiration (r) remains constant. If this is the case then community respiration can be estimated at night, when the value of primary productivity is zero due to lack of light, as shown in Equations 7 and 8.

$$(7)\quad q' = -r$$

$$(8)\quad r = -q'$$

If respiration is constant, the best estimate of daytime respiration would be provided by drawing a straight line between the dissolved oxygen values occurring at sunrise and sunset as is line a in Figure A1. This is an accurate estimation only if respiration is constant, and the sunrise and sunset point represent times when the effects of primary production are negligible.

It is possible that daytime respiration is higher than nighttime respiration due to higher oxygen levels and photorespiration. If this is true, the line should be curved downward, as does line c in Figure A1. There is

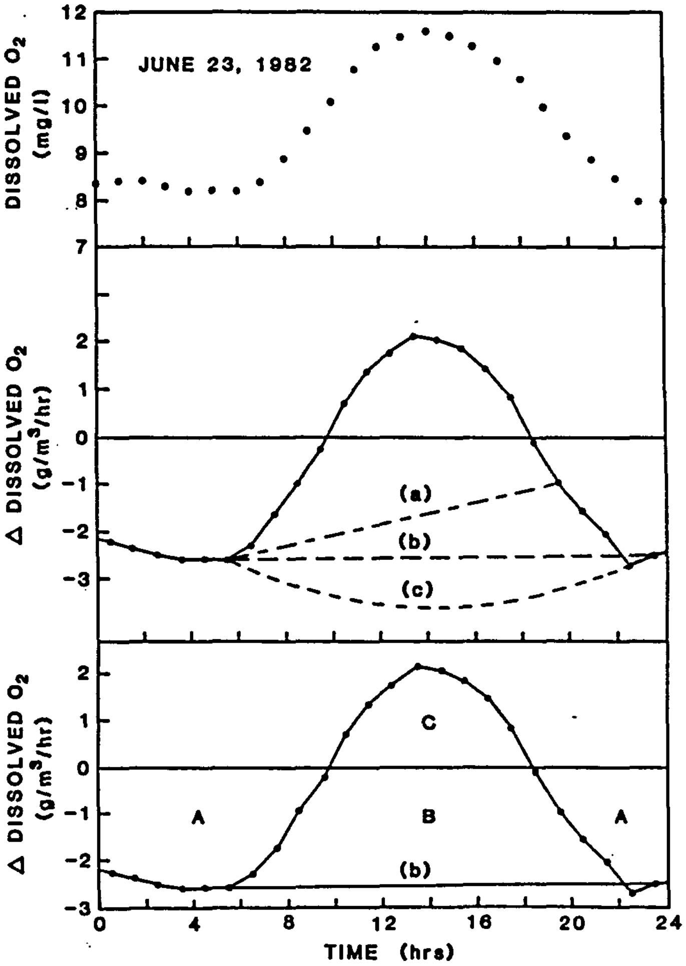

FIGURE A1. Graphical analysis of gross primary productivity and community respiration using a diurnal oxygen curve. (The top graph is dissolved oxygen versus time. The middle and bottom graphs are identical. These plot the changes in dissolved oxygen per hour, corrected for diffusion, versus time. Lines a, b, and c represent the various ways lines could be drawn to estimate productivity and respiration. Line b was used to create the bottom plot. Respiration is estimated by the sum of areas A and B. Productivity is estimated by the sum of areas B and C.)

evidence, however, that such an increase in daytime respiration may not occur (Kelly et al., 1974). Until this matter is settled it may be best to use the straight line (line a in Figure A1) as a possibly conservative, yet objective method.

Upon plotting the data obtained from Big Creek, it became apparent that the dissolved oxygen value at sunset was usually not one of the lowest values observed. This suggests that the sunset value does not represent a time when the effects of primary productivity are negligible. The effects of primary productivity are seen for 4 to 5 hours after sunset. To correct for this lag, the midnight dissolved oxygen value was chosen instead (line b in Figure A1). Midnight was often the time of the greatest decrease in dissolved oxygen during each 24 hour period. The decrease in dissolved oxygen should be greatest when the effect of production is least.

After the "respiration line" is drawn, an estimate of gross primary productivity and community respiration can be made. The area below the "zero line", and above the "respiration line", is an estimate of community respiration. This is a summation of area A (nighttime respiration) and area B (daytime respiration) in Figure A1. If respiration is indeed constant, this represents the r value in Equation 8.

Because the rate of respiration is known, Equations 9 and 10 are true during daylight hours.

$$(9) \quad q' = p - r$$

$$(10) \quad p = q' + r$$

Primary productivity can be estimated by the summation of area C (daytime change in dissolved oxygen corrected for diffusion (q')) and area B (daytime respiration) in Figure A1. These rates are in volumetric units (g O_2/m^3/day). Areal rates (g O_2/m^2/day) can be obtained by multiplying the volumetric rates by the mean depth (Z) expressed in meters.

This procedure for the estimation of gross primary productivity and community respiration was adapted into a computer program written by Dr. Roger W. Bachmann and myself, which is presented in Appendix B. The rates presented in this study were determined using this program. Appendix C contains a sample of the data used in the program.

Equation 3 requires the measurement of the stream's rate of flow (V) and mean depth (Z). These parameters were estimated twice a week from June to July, and once a week during September and October, while measuring the stream discharge. Discharge was determined by measuring the stream channel dimensions, and the rate of stream flow. The channel dimensions were calculated by measuring the water depth at three points spaced evenly across the stream, and the length of the 4 resulting interval segments. Each segment's mean depth was estimated by summing the depths at each end of the interval and dividing by 2. Rate of stream flow was determined by timing the travel of fluorescein dye over a known distance at 3 points spaced evenly across the stream, and obtaining a mean value. This value was the stream velocity (V) used in Equation 3. Multiplication of each segment's mean depth, width, and the mean rate of flow resulted in an estimate of discharge for each segment. These values were then summed for an estimate of total stream discharge. The mean depth (Z) used in Equation 3 was obtained by dividing the sum of the three measured water depths by 4, which has the same effect as averaging the mean depths of the 4 interval segments.

It must be noted that Owens' equation can only be used in streams with a rate of flow of 0.03-1.50 m/sec, and a mean depth of 0.12-3.35 m. Big Creek did meet these requirements throughout the study.

Suspended algal primary productivity was measured using the dissolved oxygen light-dark bottle technique described by Vollenweider (1969). Nine 200-ml BOD bottles were filled with stream water using a Van Dorn sampler. Three of these bottles were treated to prevent entry of light. The remaining bottles were left transparent. Three of the "light" bottles were immediately fixed with 2 ml of manganous sulfate and 2 ml of alkali-iodide azide reagent. The other six bottles, three "light" and three "dark", were placed on the stream bottom in midstream (0.5-1 m deep) and incubated for 4 hours. Any sedimentation on the bottles was removed as it occurred, yet this proved to be no real problem. Upon removal from the stream the sample were fixed and the dissolved oxygen concentrations were determined.

Suspended chlorophyll a and phaeophyton were measured twice weekly until September, when measurments were taken once weekly. Sample water was collected by immersing a 1 liter nalgene bottle under the water surface, and allowing it to fill. Samples were then kept in an ice chest while being transported to the laboratory. For chlorophyll a and phaeophyton determinations, known volumes of water were filtered through Whatman GF/C glass fiber filters and stored with desiccant in a freezer for a maximum of 3 months. The filters were pulverized using a tissue grinder and pigments were extracted using 90% acetone. Concentrations of chlorophyll a and phaeophyton were determined according to Richards with Thompson (1952) and Yentsch and Menzel (1963), using the equations of Strickland and Parsons (1968).

An approximation of benthic chlorophyll a and phaeophyton biomass was made by allowing algae to colonize on bricks located on the stream bottom. Ten bricks were placed two abreast along the center of the stream. Sampling two bricks every week allowed them five weeks to colonize. After the period of colonization, the bricks were gently rinsed with stream water. The attached algae were then scraped off of the top surface with a razor blade. The remaining algal material was then removed using a toothbrush. All scraping and brushing was done in as uniform a manner as possible. Scraped bricks were then returned to the stream bed to colonize again. Water was added to the algal sample to a volume of 1 liter. This sample was then vigorously shaken and analyzed in the same manner as the suspended algae.

Once a month a portion of both suspended and attached algal samples were preserved in 10% Lugal's solution and allowed to settle for determination of suspended algal taxon.

Macrophyte biomass was determined in mid-August when density appeared highest. Representative quadrats of vegetation were collected at the meter site, 5 m upstream, and then every 10 m upstream for 80 m. The samples were separated by taxon, air-dried, and weighed. An approximation of the percent areal coverage for each genus of macrophyte was made during collection.

At the same time, water samples were collected for suspended chlorophyll a and phaeophyton determinations, samples were collected to measure several other parameters.

These water samples were collected in acid washed nalgene bottles, placed on ice, and returned to the laboratory for analysis. Water samples were analyzed for turbidity, specific conductance, and total phosphorus.

Turbidity was measured using a Hach Model 2100 Turbidimeter. Specific conductance was measured using a Hach Model 2511 Conductivity Meter. The total phosphorus concentration was determined using the persulfate digestion and ascorbic acid determination (A.P.H.A., 1975). Samples were centrifuged after digestion to remove suspended particles.

Values for total daily light energy, as measured in Ames, Iowa, were obtained from the Agronomy Department at Iowa State University. These measurements are in Langleys/day. Daily rainfall estimates were obtained from the Des Moines Register.

APPENDIX B:

COMPUTER PROGRAM FOR CALCULATING GROSS PRIMARY PRODUCTIVITY AND COMMUNITY RESPIRATION USING THE DIURNAL OXYGEN CURVE METHOD

The following is a FORTRAN (WATFIV) program which will calculate gross primary productivity and community respiration in volumetric (g O_2/m^3/day) and areal (g O_2/m^2/day) units, as well as the P/R ratio. This program was written by Dr. Roger W. Bachmann and myself, and was adopted for use in this study. Input data columns include site, week, Julian date, hour, dissolved oxygen concentration (mg/l), temperature (°C), stream velocity (m/sec), and mean depth (m). Note that the longitude and time zone variables must be changed to coincide with the location of the stream. A sample of the data used with this program is included.

```
C  STREAMS-- A PROGRAM TO CALCULATE VOLUMETRIC AND AREAL
C  PRIMARY PRODUCTIVITY AND COMMUNITY RESPIRATION FOR
C  SMALL STREAMS ARE BASED ON 24 HOUR RECORDINGS OF
C  DISSOLVED OXYGEN AND TEMPERATURE.
C  NOTE-- THE DIFFUSION CORRECTION EQUATIONS IN THE PROGRAM
C  WILL WORK ONLY WITH MEAN DEPTH BETWEEN 0.12 AND 3.35 M,
C  AND VELOCITY BETWEEN 0.03 AND 1.50 M/SEC (SEE WESTLAKE,
C  1974).
C
C  DATA CARDS (RECORDS) WILL HAVE THE FOLLOWING INFORMATION:
C  HOUR, SITE, WEEK NO.(NOT USED FOR CALCULATIONS), JULIAN
C  DATE, DISSOLVED OXYGEN (MG/L), TEMPERATURE (C), VELOCITY
C  (M/SEC), MEAN DEPTH (M).  THERE WILL BE ONE RECORD PER
C  HOUR STARTING WITH MIDNIGHT (HOUR=0).  THERE MAY BE ONE
C  OR MORE DAYS OF RECORD (24 RECORDS EACH).  EACH WILL END
C  WITH A READING AT MIDNIGHT.  WHERE A NEW STRING OF DAYS
C  STARTS THERE WILL BE TWO MIDNIGHT READINGS IN A ROW.
C  THE SITE, WEEK, DAY, VELOCITY, AND DEPTH NEED ONLY BE ON
C  THE SECOND CARD (HOUR=1) AND WILL BE USE FOR ALL
C  24 RECORDS (CARDS).
C  VARIABLES:
C  K1=DIFFUSION COEFFICIENT   VEL=WATER VELOCITY (M/SEC)
C  Z=WATER DEPTH (M)  SITE=SITE   WEEK = WEEK NO.
C  DAY=JULIAN DATE  HOUR=HOUR (NUMBERED FROM 0 TO 23 WITH
C  0 AS THE MIDNIGHT READING)
C  DO(25) ARRAY TO STORE HOURLY DISSOLVED OXYGEN
C  DOX=TEMPORARY VARIABLE TO STORE OXYGEN READING
C  DDO(24) ARRAY TO STORE CHANGES IN DISSOLVED OXYGEN PER
C  HOUR
C  CDO(24) ARRAY TO STORE CHANGES IN DISSOLVED OXYGEN
C  CORRECTED FOR DIFFUSION
C  RESP(24) ARRAY TO STORE HOURLY VALUES OF RESPIRATION
C  TEMP(25) ARRAY TO STORE HOURLY WATER TEMPERATURES
C  TEMPX=TEMPORARY VARIABLE TO STORE TEMPERATURE READING
C  SAT(25) ARRAY TO STORE HOURLY VALUES FOR OXYGEN
C  SATUARATION
C  LLOC=LONGITUDE OF THE SITE
C  LSTC=STANDARD LONGITUDE FOR LOCAL TIME ZONE
C       EASTERN   LST=75
C       CENTRAL   LST=90
C       MOUNTAIN  LST=105
C       PACIFIC   LST=120
C  TSR=TIME OF SUNRISE
C  TSS=TIME OF SUNSET
C
C
       REAL DO(25), DDO(24),CDO(24), RESP(24),TEMP(25),K1,
      1SAT(25),DIF(24)
       INTEGER TSR,TSS,SITE,WEEK,DAY,HOUR
       DO(25)=10
```

```
      TEMP(25)=30
C
      WRITE(6,3)
    3 FORMAT(' ','   S  WK DAY  GPRM3  GRSM3  GPRM2  GRSM2
     1   P/R')
C
    5 READ(5,6,END=100)SITE,WEEK,DAY,HOUR,DOX,TEMPX,VEL,Z
    6 FORMAT(I1,1X,I2,1X,I3,1X,I2,1X,F4.1,1X,F4.1,1X,F5.3,
     11X,F5.3)
C
      DO(1)=DO(25)
      TEMP(1)=TEMP(25)
C
C   THE FOLLOWING STEP WILL BRANCH IF THIS RECORD IS FOR
C   1 AM ((HOUR=1)
C   RATHER THAN MIDNIGHT.  IF IT IS MIDNIGHT (HOUR=0) WE
C   NEED TO READ IN
C   THE NEW VALUES FOR OXYGEN AND TEMP, OTHERWISE WE USE
C   THE MIDNIGHT
C   VALUE READ FOR THE PREVIOUS DAY'S CALCULATIONS.
C
      IF(HOUR.EQ.1) GO TO 10
      DO(1)=DOX
      TEMP(1)=TEMPX
      READ(5,6)SITE,WEEK,DAY,HOUR,DOX,TEMPX,VEL,Z
C
   10 DO(2)=DOX
      TEMP(2)=TEMPX
C
      DO 11 N=3,25
   11 READ(5,12) DO(N),TEMP(N)
   12 FORMAT(12X,F4.1,1X,F4.1)
C
C  THE FOLLOWING STEP CALCULATES THE TSR AND TSS FOR
C  DAYLIGHT SAVINGS TIME.
C
      B=2*3.1415927*(284+DAY)/365
      B2=B*2
      B3=B*3
      B4=B*4
      EX=(-103.9*SIN(B)-429.6*COS(B)+596.3*SIN(B2)-2*COS
     1(B2)+4.3*SIN(B3)
     1-12.7*COS(B4))/60
      XA=360*(284+DAY)/365*0.0174533
      XB=SIN(XA)
      XC=23.45*XB*0.0174533
      XD=-0.900404*TAN(XC)
      WS=ARCOS(XD)/0.0174533
C
C  BE THE NEXT EQUATION IS XL=4*(LLOC-LST).  THESE VALUES MUST
```

```
C  BE INSERTED AS WERE LLOC=94 AND LST=90.
C
      XL=4*(94-90)
      XTSR=(12-(WS/15))-(((EX-16)/60)-1)
      XTSS=(12+(WS/15))-(((EX-16)/60)-1)
      TSR=XTSR+0.5
      TSS=XTSS+0.5
C
C  THESE STEPS MODIFY THE DEPTH AND VELOCITY VALUES AS
C  NEEDED FOR THE DIFFUSION CORRECTION FORMULAS.
C
      ZC=Z*100
      VEL=VEL*100
C
C  THE FOLLOWING LOOP CALCULATES THE CHANGES IN DISSOLVED
C  OXYGEN FOR THE 24 HOURLY PERIODS.
C
      DO 15 N=1,24
      K=N+1
   15 DDO(N)=DO(K)-DO(N)
C
C  IN THE FOLLOWING LOOP, WE WILL CALCULATE THE SATURATION
C  VALUE OF OXYGEN FOR HOUR T AND T+1.  WE WILL THEN
C  CALCULATE THE DIFFUSION RATE FOR THOSE TWO HOURS AND
C  AVERAGE THEM.  WE THEN CALCULATE THE CORRECTED OXYGEN
C  CHANGE.
C
      DO 18 N=1,24
      K=N+1
      SAT(N)=14.587-0.3937*TEMP(N)+0.007549*TEMP(N)**2-
     10.0000606*TEMP(N)**3-0.00000038*TEMP(N)**4
      SAT(K)=14.587-0.3937*TEMP(K)+0.007549*TEMP(K)**2-
     10.0000606*TEMP(K)**3-0.00000038*TEMP(K)**4
C
C  SEE OWENS, 1974 FOR THE FOLLOWING FORMULAS.
C
      D1=((0.508/Z)*(VEL**0.67)*(1.024**(TEMP(N)-20)))/
     1(ZC**0.85)
      D1=D1*(SAT(N)-DO(N))
      D2=((0.508/Z)*(VEL**0.67)*(1.024**(TEMP(K)-20)))/
     1(ZC**0.85)
      D2=D2*(SAT(K)-DO(K))
      DIF(N)=(D1+D2)/2.
      CDO(N)=DDO(N)-DIF(N)
C
C  THE FOLLOWING CALCULATES THE GROSS PRIMARY PRODUCTIVITY
C  AND THE COMMUNITY RESPIRATION.
   18 RESP(N)=CDO(N)

C  THE FOLLOWING STEP MODIFIES THE PROGRAM TO "DRAW THE
```

```
C  LINE" TO THE LAST VALUE.
C
   29 TSS=24
C
      DO 30 N=TSR,TSS
   30 RESP(N)=((CDO(TSS)-CDO(TSR))/(TSS-TSR))*(N-TSR)
     1+CDO(TSR)
      GPR=0.
      GRESP=0.
      DO 40 N=1,24
      GPR=GPR+(CDO(N)-RESP(N))
      GRESP=GRESP+(0.-RESP(N))
      K=N+1
   40 CONTINUE
      GPR2=GPR*Z
      GRESP2=GRESP*Z
      PR=GPR/GRESP
      WRITE(6,50) SITE,WEEK,DAY, GPR,GRESP,GPR2,GRESP2,PR
   50 FORMAT(' ',3I4,5F7.2)
      GO TO 5
  100 STOP
      END
$ENTRY
1  1 154  0  9.7 10.8 0.224 0.265
1  1 154  1  9.8 10.8 0.224 0.265
1  1 154  2  9.7 10.8 0.224 0.265
1  1 154  3  9.6 10.8 0.224 0.265
1  1 154  4  9.7 10.8 0.224 0.265
1  1 154  5  9.8 10.8 0.224 0.265
1  1 154  6  9.7 10.8 0.224 0.265
1  1 154  7  9.9 10.8 0.224 0.265
1  1 154  8 10.2 10.8 0.224 0.265
1  1 154  9 10.6 11.0 0.224 0.265
1  1 154 10 10.9 11.0 0.224 0.265
1  1 154 11 11.0 11.0 0.224 0.265
1  1 154 12 11.4 11.2 0.224 0.265
1  1 154 13 12.0 12.2 0.224 0.265
1  1 154 14 12.2 13.3 0.224 0.265
1  1 154 15 12.0 14.2 0.224 0.265
1  1 154 16 11.8 14.5 0.224 0.265
1  1 154 17 11.5 14.2 0.224 0.265
1  1 154 18 11.2 13.3 0.224 0.265
1  1 154 19 10.7 12.7 0.224 0.265
1  1 154 20 10.4 11.8 0.224 0.265
1  1 154 21 10.0 11.3 0.224 0.265
1  1 154 22  9.8 11.0 0.224 0.265
1  1 154 23  9.7 10.7 0.224 0.265
1  1 155  0  9.8 10.4 0.224 0.265
1  2 158  0  9.0 12.7 0.224 0.265
1  2 158  1  9.1 12.0 0.224 0.265
```

```
1  2 158  2   9.2 12.4 0.224 0.265
1  2 158  3   9.3 11.1 0.224 0.265
:  :   :  :    :    :    :     :
:  :   :  :    :    :    :     :
:  :   :  :    :    :    :     :
1  2 158 21  10.5 13.5 0.224 0.265
1  2 158 22   9.8 12.4 0.224 0.265
1  2 158 23   9.4 11.8 0.224 0.265
1  2 159  0   9.3 11.1 0.224 0.265
1  2 163  0   8.0 11.7 0.471 0.643 (NOTE WHEN DAYS ARE
1  2 163  1   8.0 11.5 0.471 0.643  SKIPPED, THE PROPER
1  2 163  2   7.9 11.2 0.471 0.643  MIDNIGHT VALUES MUST
1  2 163  3   7.9 11.1 0.471 0.643  BE INSERTED)
:  :   :  :    :    :    :     :
:  :   :  :    :    :    :     :
:  :   :  :    :    :    :     :
1  2 163 21   9.0 13.2 0.471 0.643
1  2 163 22   8.4 12.6 0.471 0.643
1  2 163 23   8.1 11.9 0.471 0.643
1  3 164  0   8.0 11.1 0.471 0.643
1  3 164  1   8.0 10.9 0.471 0.643
1  3 164  2   8.1 10.5 0.471 0.643
1  3 164  3   8.1 10.5 0.471 0.643
:  :   :  :    :    :    :     :
:  :   :  :    :    :    :     :
:  :   :  :    :    :    :     :
1  3 164 21   9.0 14.1 0.471 0.643
1  3 164 22   8.4 13.1 0.471 0.643
1  3 164 23   8.0 12.6 0.471 0.643
1  3 165  0   7.7 12.1 0.471 0.643
1  3 165  1   7.6 12.0 0.471 0.643
1  3 165  2   7.6 12.0 0.471 0.643
1  3 165  3   7.6 11.9 0.471 0.643
1  3 165  4   7.6 11.9 0.471 0.643
1  3 165  5   7.7 11.8 0.471 0.643
1  3 165  6   7.7 11.7 0.471 0.643
```

APPENDIX C:

DAILY HIGH AND LOW OXYGEN VALUES

Included are the high and low oxygen values in mg/l and % saturation for each day, and the hours during which they occurred (midnight=0). Also included are the daily ranges of these parameters.

Date	High			Low			Range	
	Conc	% Sat	Hr	Conc	% Sat	Hr	Conc	% Sat
6/03/82	12.2	115.8	14	9.6	86.2	3	2.6	29.6
6/07/82	14.2	148.6	15	9.1	84.0	1	5.1	64.7
6/12/82	12.9	134.8	14	7.9	71.6	2	5.0	63.2
6/13/82	12.4	130.1	14	8.0	72.3	0	4.4	57.7
6/14/82	11.8	116.4	17	7.3	69.0	21	4.5	47.4
6/15/82	7.5	72.0	13	6.3	61.4	7	1.2	10.6
6/16/82	8.8	86.1	13	7.2	66.7	0	1.6	19.4
6/17/82	9.1	87.9	14	7.3	67.4	0	1.8	20.5
6/23/82	11.6	121.4	14	8.0	75.3	23	3.6	46.1
6/24/82	11.8	124.3	14	7.7	74.2	23	4.1	50.0
6/25/82	11.6	116.1	15	7.2	67.9	5	4.4	48.2
6/26/82	11.9	118.9	16	7.5	71.2	1	4.4	47.7
6/27/82	11.8	123.5	16	7.2	67.9	2	4.6	55.6
6/28/82	12.0	124.4	14	7.0	66.0	2	5.0	58.3
7/03/82	11.5	125.9	14	6.5	64.0	0	5.0	61.9
7/04/82	11.7	127.6	14	7.0	66.8	2	4.7	60.8
7/05/82	11.6	131.1	15	6.8	68.4	0	4.8	62.8
7/06/82	7.6	78.8	17	6.0	59.4	7	1.6	19.3
7/07/82	11.0	116.5	15	7.0	68.9	0	4.0	47.6
7/08/82	11.1	116.7	14	7.1	68.1	4	4.0	48.5
7/17/82	12.8	141.5	15	6.7	68.5	3	6.1	73.0
7/18/82	6.5	70.5	7	4.4	48.9	21	2.1	21.6
7/19/82	4.8	51.7	13	4.3	47.0	0	0.5	4.8
7/20/82	5.6	62.0	16	4.3	46.0	6	1.3	16.0
7/21/82	7.4	79.6	17	5.4	58.7	0	2.0	21.0
7/22/82	9.4	102.1	15	5.9	60.5	6	3.5	41.6
7/23/82	10.1	108.7	14	6.0	60.6	8	4.1	48.1
7/24/82	11.0	120.2	15	6.0	60.3	5	5.0	59.9
7/25/82	11.5	128.8	16	6.4	64.2	6	5.1	64.6
7/26/82	12.0	131.6	15	6.4	64.3	5	5.6	67.3
7/31/82	12.6	141.9	15	5.5	54.7	2	7.1	87.2
8/01/82	12.0	133.1	17	5.0	50.3	4	7.0	82.9
8/02/82	12.6	147.8	16	4.4	44.9	4	8.2	103.0
8/03/82	12.3	144.3	16	4.3	44.8	4	8.0	99.5
8/04/82	9.1	98.5	17	3.8	39.8	5	5.3	58.7
8/05/82	9.8	110.6	17	3.2	34.1	4	6.6	76.5
8/06/82	9.1	97.5	14	4.3	44.4	7	4.8	53.1
8/07/82	10.7	119.8	16	4.6	47.1	6	6.1	72.7
8/08/82	10.2	114.9	16	4.5	46.3	3	5.7	68.6
8/09/82	10.7	114.2	16	4.4	43.9	4	6.3	70.4
8/26/82	13.2	145.6	16	4.2	42.2	6	9.0	103.4
8/27/82	13.4	143.1	16	3.8	39.7	4	9.6	103.4
8/28/82	13.8	143.9	17	5.6	53.2	6	8.2	90.7

Date	High			Low			Range	
	Conc	% Sat	Hr	Conc	% Sat	Hr	Conc	% Sat
8/29/82	10.8	115.5	13	4.3	45.0	20	6.5	70.5
8/30/82	9.2	100.1	17	3.0	31.4	7	6.2	68.7
8/31/82	8.0	89.4	17	2.3	24.1	10	5.7	65.4
9/01/82	9.8	109.8	16	4.7	49.2	4	5.1	60.6
9/02/82	10.7	116.9	16	4.8	51.4	1	5.9	65.5
9/10/82	12.3	139.8	15	4.1	43.3	6	8.2	96.6
9/11/82	11.6	134.1	16	3.7	39.6	5	7.9	94.5
9/12/82	10.8	123.0	16	3.3	35.6	5	7.5	87.4
9/13/82	7.8	82.1	15	3.5	36.8	6	4.3	45.4
9/14/82	8.1	82.4	16	4.8	47.6	7	3.3	34.9
9/15/82	10.6	106.6	17	5.2	51.7	3	5.4	54.8
9/24/82	13.0	126.4	17	6.1	58.7	5	6.9	67.7
9/25/82	15.1	148.7	15	7.2	66.6	4	7.9	82.1
9/26/82	16.1	158.9	17	7.1	63.6	6	9.0	95.2
9/27/82	15.7	157.8	17	6.8	61.8	5	8.9	96.1
9/28/82	15.5	160.6	16	6.0	56.7	7	9.5	103.9
9/29/82	14.3	153.3	17	4.6	46.4	8	9.7	106.8
10/08/82	13.8	133.6	17	6.8	61.8	5	7.0	71.8
10/09/82	12.8	123.1	17	5.2	51.4	4	7.6	71.7
10/10/82	14.7	139.0	17	6.6	60.1	7	8.1	78.9
10/11/82	13.7	123.0	18	7.0	62.7	7	6.7	60.3
10/12/82	15.0	132.9	16	8.0	68.8	7	7.0	64.1
10/13/82	15.9	145.1	17	7.4	65.1	8	8.5	80.0
10/14/82	16.4	158.1	17	7.4	64.0	7	9.0	94.0
10/15/82	15.8	151.0	18	6.7	60.5	5	9.1	90.6
10/16/82	16.9	157.0	18	7.7	65.2	7	9.2	91.8
10/17/82	17.2	162.3	18	7.0	61.6	8	10.2	100.7
10/18/82	18.2	176.6	18	6.6	58.2	8	11.6	118.4
10/19/82	10.5	99.3	0	5.8	53.3	7	4.7	46.0
10/20/82	15.8	136.4	18	7.4	59.4	10	8.4	77.0

APPENDIX D:

DAILY HIGH AND LOW TEMPERATURE VALUES

Included are the high and low temperature values (°C) for each day observed and the hours during which they occurred (midnight=0). The daily ranges are also included.

Date	High		Low		Rng
	Temp	Hr	Temp	Hr	
6/03/82	14.5	16	10.7	23	3.8
6/07/82	18.0	15	11.0	4	7.0
6/12/82	17.9	14	10.6	6	7.3
6/13/82	18.9	16	10.1	6	8.8
6/14/82	15.1	16	11.7	6	3.4
6/15/82	15.0	5	12.4	23	2.6
6/16/82	15.0	15	11.9	6	3.1
6/17/82	14.6	17	11.9	4	2.7
6/23/82	18.3	15	11.0	6	7.3
6/24/82	19.3	16	11.9	6	7.4
6/25/82	16.1	16	13.0	3	3.1
6/26/82	16.0	17	13.0	5	3.0
6/27/82	18.0	16	12.9	6	5.1
6/28/82	19.6	18	12.5	6	7.1
7/03/82	21.4	16	13.9	6	7.9
7/04/82	22.0	16	13.0	5	9.0
7/05/82	22.4	16	14.5	5	7.9
7/06/82	17.7	16	15.0	11	2.7
7/07/82	18.8	16	14.0	8	4.8
7/08/82	18.3	15	13.8	4	4.5
7/17/82	20.9	16	16.4	7	4.5
7/18/82	21.2	20	17.9	0	3.3
7/19/82	20.8	19	18.6	9	2.2
7/20/82	21.0	17	18.9	8	2.1
7/21/82	19.9	0	17.9	23	2.0
7/22/82	20.0	16	16.9	8	3.1
7/23/82	20.1	16	16.2	7	3.9
7/24/82	21.0	17	15.8	8	5.2
7/25/82	21.7	17	15.8	7	5.9
7/26/82	21.0	16	15.8	8	5.2
7/31/82	22.9	17	14.5	7	8.4
8/01/82	21.3	18	15.3	7	6.0
8/02/82	24.3	17	15.7	7	8.6
8/03/82	24.4	17	16.8	7	7.6
8/04/82	21.5	0	17.5	8	4.0
8/05/82	21.9	17	17.8	6	4.1
8/06/82	19.5	18	17.3	4	2.2
8/07/82	22.2	18	16.9	5	5.3
8/08/82	22.1	17	16.0	7	6.1
8/09/82	19.0	16	14.5	8	4.5
8/26/82	20.7	16	15.9	7	4.8
8/27/82	19.0	16	15.9	23	3.1
8/28/82	17.8	17	13.1	8	4.7

Date	High		Low		Rng
	Temp	Hr	Temp	Hr	
8/29/82	19.1	13	16.0	7	3.1
8/30/82	20.0	17	16.9	0	3.1
8/31/82	21.4	17	17.7	12	3.7
9/01/82	22.1	18	17.3	8	4.8
9/02/82	20.7	17	15.6	9	5.1
9/10/82	23.0	16	18.1	8	4.9
9/11/82	23.2	16	18.6	8	4.6
9/12/82	22.4	16	19.2	8	3.2
9/13/82	19.8	0	16.8	24	3.0
9/14/82	16.8	0	15.3	7	1.5
9/15/82	16.0	0	14.2	23	1.8
9/24/82	15.0	1	13.3	9	1.7
9/25/82	15.8	17	10.9	9	4.9
9/26/82	15.1	17	10.2	8	4.9
9/27/82	16.0	17	10.8	8	5.2
9/28/82	18.0	18	13.0	8	5.0
9/29/82	19.2	17	16.1	9	3.1
10/08/82	15.0	22	11.2	6	3.8
10/09/82	15.3	2	12.8	23	2.5
10/10/82	13.2	16	11.2	9	2.0
10/11/82	11.9	0	10.0	23	1.9
10/12/82	10.5	18	8.6	8	1.9
10/13/82	11.9	16	9.9	8	2.0
10/14/82	14.1	18	8.8	9	5.3
10/15/82	13.9	17	10.2	9	3.7
10/16/82	12.3	18	7.7	10	4.6
10/17/82	13.0	17	9.6	10	3.4
10/18/82	14.4	19	9.9	9	4.5
10/19/82	13.1	0	9.4	23	3.7
10/20/82	9.1	17	5.4	6	3.7

APPENDIX E:

GROSS PRIMARY PRODUCTIVITY, COMMUNITY RESPIRATION, P/R RATIO, SOLAR RADIATION AND PRECIPITATION DATA

Gross primary productivity and community respiration data were calculated using the computer program in Appendix B. They are listed in both volumetric (g O_2/m^3/day) and areal (g O_2/m^2/day) units. Light energy data is in Langleys/day, and were obtained from the I.S.U. Agronomy Department. The precipitation data were taken from the Des Moines Register, and are in cm.

Date	Volumetric		Areal		P/R	Light	Precip
	Prod	Resp	Prod	Resp			
6/03/82	19.63	25.81	5.20	6.84	0.76	363	0.10
6/07/82	47.97	30.93	12.71	8.20	1.55	686	trace
6/12/82	12.64	17.86	8.13	11.48	0.71	536	0.00
6/13/82	16.39	20.78	10.54	13.36	0.79	607	0.38
6/14/82	13.93	24.91	8.95	16.02	0.56	221	0.00
6/15/82	5.05	26.08	3.24	16.77	0.19	265	0.00
6/16/82	6.01	22.46	3.86	14.44	0.27	701	1.42
6/17/82	5.74	22.14	3.69	14.24	0.26	245	0.00
6/23/82	43.03	60.92	11.96	16.93	0.71	681	0.00
6/24/82	46.72	63.82	12.29	16.78	0.73	529	0.00
6/25/82	35.59	67.94	9.36	17.87	0.52	234	0.00
6/26/82	38.17	66.90	10.04	17.59	0.57	317	0.05
6/27/82	50.96	72.73	13.40	19.13	0.70	371	0.03
6/28/82	48.59	70.14	12.29	17.75	0.69	403	0.00
7/03/82	41.87	62.95	10.59	15.93	0.67	636	0.30
7/04/82	44.36	63.10	11.22	15.97	0.70	661	2.69
7/05/82	22.80	32.39	14.20	20.18	0.70	645	trace
7/06/82	4.78	33.01	2.98	20.57	0.14	243	0.00
7/07/82	17.86	29.39	11.13	18.31	0.61	683	4.75
7/08/82	33.84	55.95	10.93	18.07	0.60	535	0.00
7/17/82	48.77	59.82	15.75	19.32	0.82	488	2.95
7/18/82	3.09	78.28	1.00	25.29	0.04	227	trace
7/19/82	0.13	26.08	0.10	20.42	0.00	435	3.12
7/20/82	2.43	24.88	1.90	19.48	0.10	591	0.03
7/21/82	3.75	19.64	2.93	15.38	0.19	587	0.00
7/22/82	11.36	21.72	8.90	17.00	0.52	598	0.00
7/23/82	12.47	20.46	9.77	16.02	0.61	562	0.00
7/24/82	39.74	67.03	11.65	19.64	0.59	633	0.00
7/25/82	48.28	67.31	14.15	19.72	0.72	617	0.00
7/26/82	51.45	68.38	15.08	20.04	0.75	471	0.00
7/31/82	75.99	105.75	19.60	27.28	0.72	625	0.00
8/01/82	74.38	119.22	19.19	30.76	0.62	369	0.00
8/02/82	62.31	86.33	14.21	19.68	0.72	615	0.00
8/03/82	61.41	89.01	14.00	20.29	0.69	580	0.00
8/04/82	32.99	99.28	7.52	22.64	0.33	216	trace
8/05/82	16.91	43.58	6.05	15.60	0.39	341	1.37
8/06/82	19.12	47.07	6.84	16.85	0.41	251	4.75
8/07/82	25.42	46.22	9.10	16.55	0.55	437	trace
8/08/82	29.49	63.46	7.02	15.10	0.46	580	0.00
8/09/82	30.97	65.80	7.37	15.66	0.47	410	0.00
8/26/82	115.01	164.21	19.32	27.59	0.70	441	0.00
8/27/82	111.20	156.48	18.68	26.29	0.71	487	0.00
8/28/82	95.75	125.98	16.09	21.16	0.76	364	0.00

Date	Volumetric		Areal		P/R	Light	Precip
	Prod	Resp	Prod	Resp			
8/29/82	47.17	164.29	7.92	27.60	0.29	183	0.00
8/30/82	67.03	202.07	11.26	33.95	0.33	215	1.07
8/31/82	36.62	148.89	7.25	29.48	0.25	395	0.56
9/01/82	52.43	127.85	10.38	25.31	0.41	470	3.35
9/02/82	53.52	113.98	10.60	22.57	0.47	525	0.03
9/10/82	100.15	152.30	16.32	24.83	0.66	431	trace
9/11/82	98.99	166.00	16.14	27.06	0.60	458	0.00
9/12/82	83.12	169.76	13.55	27.67	0.49	268	0.00
9/13/82	46.64	197.27	8.30	35.11	0.24	141	0.00
9/14/82	32.08	165.40	5.71	29.44	0.19	94	2.34
9/15/82	51.75	139.73	9.21	24.87	0.37	251	0.38
9/24/82	43.03	70.98	7.66	12.63	0.61	116	trace
9/25/82	56.42	59.99	10.04	10.68	0.94	465	0.00
9/26/82	60.79	64.51	10.82	11.48	0.94	346	0.00
9/27/82	71.90	76.02	11.22	11.86	0.95	428	0.00
9/28/82	79.04	84.12	12.33	13.12	0.94	272	0.00
9/29/82	70.62	99.41	11.02	15.51	0.71	210	trace
10/08/82	45.25	69.26	6.92	10.60	0.65	99	0.00
10/09/82	43.00	73.90	6.58	11.31	0.58	107	0.13
10/10/82	48.04	60.86	7.35	9.31	0.79	179	0.76
10/11/82	50.23	86.26	7.69	13.20	0.58	73	trace
10/12/82	61.65	74.41	9.43	11.39	0.83	93	trace
10/13/82	66.84	77.12	10.23	11.80	0.87	99	0.00
10/14/82	83.34	87.92	12.75	13.45	0.95	340	0.00
10/15/82	75.55	87.73	11.56	13.42	0.86	340	0.00
10/16/82	73.12	67.51	11.19	10.33	1.08	367	0.00
10/17/82	77.93	71.56	11.92	10.95	1.09	215	0.00
10/18/82	92.82	76.39	14.20	11.69	1.22	236	trace
10/19/82	15.60	114.70	2.39	17.55	0.14	15	0.00
10/20/82	55.87	89.02	8.55	13.62	0.63	268	0.25

APPENDIX F:

CHLOROPHYLL AND PHAEOPHYTON DATA

Date	Suspended				Attached	
	Chl a	Phaeo	Chl a	Phaeo	Chl a	Phaeo
	(mg/m^3)		(mg/m^2)		(mg/m^2)	
6/04/82	0.748	0.692	0.198	0.183	.	.
6/08/82	4.394	1.155	2.803	0.743	.	.
6/15/82	2.459	0.797	1.581	0.512	.	.
6/22/82	1.181	0.295	0.328	0.082	.	.
6/25/82	1.361	0.676	0.358	0.178	.	.
6/29/82	1.285	1.266	0.325	0.320	.	.
7/02/82	0.790	0.289	0.200	0.073	.	.
7/06/82	8.706	1.159	5.424	0.722	.	.
7/09/82	0.988	1.088	0.319	0.351	.	.
7/13/82	0.451	0.439	0.142	0.146	.	.
7/16/82	0.525	0.253	0.170	0.082	.	.
7/22/82	0.835	0.109	0.654	0.085	20.48	0.71
7/27/82	0.612	0.296	0.179	0.087	.	.
7/30/82	0.947	0.486	0.244	0.125	114.28	5.87
8/03/82	1.170	1.352	0.264	0.308	.	.
8/06/82	0.899	0.926	0.322	0.332	81.64	2.66
8/10/82	1.372	0.985	0.327	0.234	.	.
8/13/82	1.827	1.414	0.548	0.424	60.38	1.82
8/17/82	0.558	1.943	0.094	0.326	.	.
8/20/82	1.132	2.494	0.430	0.948	54.59	1.61
8/27/82	1.459	2.598	0.245	0.436	56.06	1.83
9/03/82	1.216	1.436	0.241	0.284	69.10	2.10
9/09/82	1.208	1.752	0.197	0.286	42.62	1.50
9/16/82	1.497	1.188	0.266	0.211	42.23	1.67
9/23/82	0.748	0.692	0.133	0.123	28.72	0.91
9/30/82	17.073	6.745	2.663	1.052	25.92	0.92
10/07/82	13.004	5.529	1.990	0.846	34.74	1.89
10/14/82	7.710	2.795	1.180	0.428	36.98	1.25

APPENDIX G:

MACROPHYTE BIOMASS AND % COVER DATA

Distance Upstream (m)	Potomogeton Biomass (g/m²)	Potomogeton % Cover	Polygonum Biomass (g/m²)	Polygonum % Cover
1	254	30	tr	5
5	403	70	tr	5
10	221	25	tr	1
20	255	35	71	35
30	676	50	tr	50
40	450	75	tr	5
50	250	75	11	5
60	40	5	tr	tr
70	270	60	9	20
80	184	35	40	35

Note that the area 60 m upstream is where cattle cross the stream.

APPENDIX H:

TAXON OF THE SUSPENDED AND ATTACHED ALGAE

The algal samples were identified by David Millie of the I.S.U. Botany Department. The numbers in parentheses are the dates the algal samples were collected.

Suspended Genera

Caloneis (6/22)
Cocconeis (8/27, 9/23)
Cyclotella (9/23)
Nitzschia (6/22, 7/20)
Synedra (7/20)

Attached Genera

Achnanthes (8/6, 8/27, 9/30)
Cladophora (8/6, 8/27)
Cocconeis (8/6, 8/27, 9/30)
Cyclotella (8/6, 9/30)
Cymatopleura (9/30)
Cymbella (9/30)
Eunotia (9/30)
Gomphonema (8/6)
Gyrosigma (9/30)
Meridion (8/6)
Navicula (8/6, 9/30)
Nitzschia (8/6, 9/30)
Oedogonium (8/6, 8/27, 9/30)
Pinnularia (9/30)
Rhizoclonium (8/6, 8/27)
Rhoicosphenia (8/6, 9/30)
Spirogyra (9/30)
Surirella (8/27)
Synedra (8/6, 9/30)

Epiphytes of Macrophytes, *Cladophora*, or *Rhizoclonium*

Achnanthes lanceolatum var. *dubia*
Chamaesiphon sp.
Cocconeis placentula var. *lineata*
Coleochaete sp.
Gomphonema parveulum
Gyrosigma sp. (*curvula*?)
Rhoicosphenia curvata
Stigeoclonium sp.

APPENDIX I:

TURBIDITY, SPECIFIC CONDUCTIVITY, STAGE, DISCHARGE, AND TOTAL PHOSPHORUS

Turbidity (JTU), specific conductivity (uM HO),stage (m), discharge (m^3/sec), and total phosphorus (mg/l).

Date	Turb	Spec Cond	Stage	Disch	Total Phosph
6/04/82	.		0.485	.	.
6/08/82	1.8	775	0.452	0.382	.
6/15/82	1.7	625	0.880	.	.
6/22/82	2.0	775	0.465	0.450	.
6/25/82	2.4	770	0.450	0.235	.
6/29/82	2.2	780	0.440	0.268	.
7/02/82	1.6	775	0.440	0.253	.
7/06/82	7.4	425	0.810	1.943	0.510
7/09/82	5.2	750	0.510	0.485	.
7/13/82	2.8	800	0.530	0.582	0.079
7/16/82	2.4	800	0.510	0.483	0.080
7/20/82	3.8	480	.	.	0.360
7/21/82	1.3	600	0.970	2.171	0.195
7/27/82	2.5	785	0.480	0.418	0.099
7/30/82	2.9	775	0.445	0.347	0.085
8/03/82	1.5	810	0.415	0.155	0.072
8/06/82	1.6	775	.	0.377	0.099
8/10/82	3.5	825	0.425	0.127	0.081
8/13/82	1.3	860	0.415	0.125	0.147
8/17/82	1.4	910	0.395	0.057	0.081
8/20/82	3.7	1150	0.380	0.063	0.123
8/27/82	1.4	870	0.355	0.030	0.125
9/03/82	1.5	850	0.385	0.062	0.157
9/09/82	1.8	910	0.350	0.036	0.153
9/16/82	1.8	890	0.365	0.060	0.170
9/23/82	1.8	890	.	0.044	0.130
9/30/82	2.1	940	0.343	0.034	0.134
10/07/82	3.3	890	0.340	0.025	0.121
10/14/82	1.7	870	0.340	0.025	0.108