Effects of Land Use on Oxygen Uptake by Microorganisms on Fine Benthic Organic Matter in Two Appalachian Mountain Streams

by

Mary Alice Schaeffer

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APPROVED:

J.R. Webster, Chairman

E. F. Benfield

A.C. Hendricks

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(ABSTRACT)

Oxygen uptake rates by fine benthic organic matter were measured on samples from two Appalachian mountain streams to determine the effects of land use patterns on microbial respiration. Both Coweeta Creek in western North Carolina, and Wolf Creek in western Virginia, flow through national forest, agricultural land and scattered residential areas. Seven sites were sampled at six to ten week intervals over one year. Land use was determined using infrared aerial photographs. ARC/INFO was used to obtain land use areas for various land uses. Oxygen uptake rates were measured using a Gilson differential respirometer, at ambient temperature and 20°C. Temperature was the most important factor influencing oxygen uptake rates in both streams, with oxygen uptake rates consistently lower at ambient temperatures than 20°C. Oxygen uptake rates were higher in Wolf Creek than Coweeta Creek and were higher at sites that drained agricultural areas. Nitrates increased as the percent of agriculture increased in Wolf Creek, but not in Coweeta Creek. Nitrates were positively correlated with oxygen uptake

rates in Wolf Creek. The data suggest that clearing forests for agriculture results in increased microbial respiration in streams.

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INTRODUCTION

In this study I measured oxygen uptake rates by microorganisms on fine benthic organic matter (FBOM) from streams to use as an indicator of respiration. Oxygen uptake occurs as microorganisms respire and use oxygen for metabolic processes and is widely used to measure metabolic processes occurring in streams (e.g., Bott et al. 1985). Metabolic respiration on FBOM is a large component of the total community respiration occurring in streams. For example, Naiman (1983) found that 64% of the respiration in small streams in Quebec was associated with microorganisms residing on FBOM.

Respiration in stream communities is related to a variety of site specific factors including stream order: temperature, nutrients, organic content of detritus, and land use. Stream order was one site specific factor used in characterizing streams. Vannote et al. (1980) proposed change from heterotrophy to autotrophy in a downstream direction as stream order increased in temperate U.S. streams. Autotrophic sources of organic matter are more labile than heterotrophic sources (Hedin 1990, Petersen et al. 1989), thus oxygen uptake by microorganisms on FBOM should increase in a downstream direction.

Many investigators studied respiration to determine if it also follows the predictions of Vannote et al (1980) in increasing in the downstream direction.

Naiman (1983) found annual community respiration to be highly correlated with stream order in his study of four streams in Quebec. Peters et al. (1987) reported respiration increased in a downstream direction in streams in North Carolina and Virginia. Bott et al. (1985) also reported an increase in community respiration in a downstream direction for streams in Michigan, Pennsylvania, Idaho, and Oregon, although site specific factors influenced the trend.

Another factor affecting respiration is temperature, which usually increases in a downstream direction. Temperature affects respiration rates by increasing the metabolic rate of organisms. Peters et al. (1987) found a change of 5°C significantly altered metabolic rates of microbes on FBOM. In an analysis of several studies of oxygen uptake by benthic communities, Hargrave (1969, 1972) found sediment oxygen uptake was significantly correlated with temperature.

Nutrient concentrations, specifically nitrates and phosphates, are higher in drainage from disturbed watersheds (e.g. Vitousek et al. 1979) and increased nutrient levels have been shown to affect respiration in streams. Flemer (1970) showed streams receiving excess nutrients have higher community respiration, although Peters et al. (1987) found microorganisms on refractory organic matter were not limited by nitrate or phosphate in first order streams in North Carolina and Virginia.

Organic content of detritus also affects respiration rates. Respiration rates on a per unit mass basis were found by Cuffney et al. (1990) to be higher on leaves by an order of magnitude than on wood or benthic sediment. Detritus microbes consumed three orders of magnitude more oxygen per dry weight than microbes in sand, indicating oxygen uptake is related to organic content (Hargrave 1969).

Much of the degradation of water quality in U.S. streams is from nonpoint source pollution, which accounts for water quality disturbances in 38.4% of all stream length in the U.S. (van der Leeden et al. 1990). Nonpoint source disturbances were not considered to have a significant impact on water quality until the late 1960's (Novotny and Chesters 1981). The first major effort to control nonpoint source pollution occurred with the passage of the Water Pollution Control Act Amendments of 1972 (P. L. 92-500) which set a goal of zero discharge to surface waters by 1985 (Thillmann 1978). Studies have now shown 50% or more of the water quality problems can be attributed to nonpoint source pollution (Novotny and Chesters 1981). The 1987 amendment to the Clean Water Act emphasized the importance of nonpoint sources of pollution in surface waters (Foran et al. 1991).

Land use disturbances identified in the Water Pollution Control Act of 1972 that degrade water quality include agriculture, logging, and urbanization. Activities in all three land use categories increase sedimentation, which may be the single most important factor influencing water quality. Anderson et al.

(1976) estimates 80% of the decrease in water quality is due to suspended sediments, which decrease available light, increase turbidity, and decrease photosynthesis.

Forests that are not logged or otherwise disturbed have the least negative impact on water quality, and thus undisturbed forest streams may be used as a reference for comparison with other sites along a stream continuum to determine changes in water quality (Currier 1981). Disturbances in forested areas that affect streams include: logging, road and bridge construction, and skidding techniques (Chesters and Schierow 1985, Webster 1990, Golladay et al. 1987, and Webster et al. 1992). Logging affects streams by increasing temperature due to reduced vegetation canopy, increased availability of nitrate, and increased sediment loading from erosion of surface soils (Webster et al. 1992). Bridge and road construction for logging increase erosion by eliminating vegetation and disturbing soil (Chesters and Schierow 1985).

Residential and urban areas affect streams by increased runoff and subsequent increased sediment loading from construction sites and areas of reduced vegetative cover. The loss of vegetation in residential areas also increases stream temperature. Runoff from residential areas increases nutrient loading from fertilization of lawns and gardens (Chesters and Schierow 1985). Urbanization compacts ground surfaces and decreases infiltration to groundwater systems thereby increasing overland flow. Septic system overflows may also contribute to water quality change (Novotny and Chesters 1981).

Agricultural areas are the most pervasive source of nonpoint pollution (Meyers et al. 1985, Clark et al. 1985). Of 3.7 billion tons of sediment eroded each year in the U.S., 52% is attributed to agriculture (van der Leeden 1990). Agricultural areas affect streams by increasing organic content of drainage from pastures and feedlots and from direct access of cattle to streams (Chesters and Schierow 1985). Cattle may cause breakdown of stream banks and compaction of soil in riparian zones. This degrades the ability of the soil to absorb nutrients. Croplands contribute additional nutrients to streams from increased sediment runoff from some tillage practices and overuse of fertilizers (Fauss 1992).

Concern with water quality has prompted development of watershed monitoring programs that use spatial and temporal data including length and location of streams, soil type, changes over time, and land use. Land use characteristics are a major element of watershed monitoring programs due to impact of land use on temperature and sediment and nutrient loading. Geographic information systems (GIS) are used to analyze data and link land use to changes of hydrologic impacts (Fauss 1992). GIS, along with other analytical tools, provides a valuable method of identifying critical nonpoint source pollution areas. In Virginia GIS is used to assess pollution potential based on water quality impacts caused by erosion and sediment yield (Hamlett et al. 1992).

My objective was to determine if oxygen uptake changes as land use changes. I measured oxygen uptake by microorganisms on FBOM and compared the uptake rates at seven sites along two streams, one in Virginia draining a large agricultural area; and one in North Carolina that was predominately forested. The rates were related to land use patterns within the two watersheds.

METHODS

SITE DESCRIPTION

I studied two southern Appalachian Mountain streams, Wolf Creek and Coweeta Creek. Wolf Creek is a fifth order stream that flows through portions of Jefferson National Forest in Tazewell, Bland, and Giles Counties in western Virginia. Major tributaries of Wolf Creek include Hunting Camp Creek, Clear Fork, Laurel Creek, and Kimberly Creek (Fig. 1). Wolf Creek drains an area of 61,517 hectares and runs 86 kilometers from the headwaters to the confluence with New River at Narrows, Virginia. Wolf Creek has a mean annual flow of 34,828 L/sec (Water Resources Center, Blacksburg, Virginia) (Table 1). Wolf Creek flows in a trellis drainage pattern flowing between fault lines, except in the Burkes Garden area where the terrain is level and the stream follows a dendritic course.

Wolf Creek is located in the Valley and Ridge Geologic Province. The regional climate is temperate and continental with an average rainfall of 94-117 cm per year (USDA 1954). The Valley and Ridge Province is characterized as an area of broad open folds and thrust faults in sedimentary rocks of the Paleozoic Era. The Province is bounded by the Blue Ridge Province to the east and by the escarpment of the Appalachian Plateau to the west (Butts 1973).

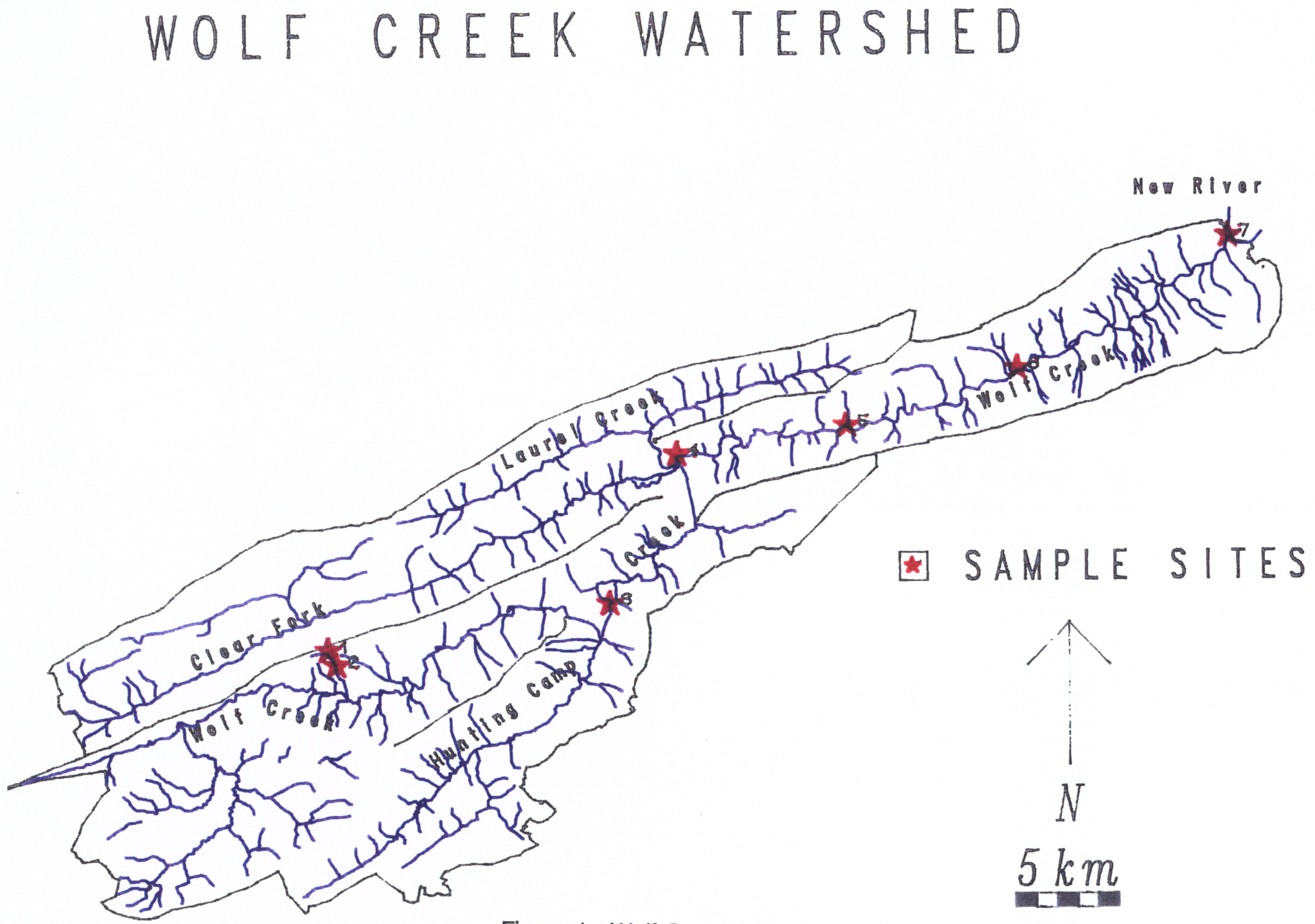

Figure 1. Wolf Creek watershed with major tributaries and sample sites.

Table 1. Characteristics of sample sites along Wolf Creek.

	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7
ELEVATION (m)	914	792	671	610	579	533	488
DISTANCE FROM SOURCE (km)	0.7	1.6	39.8	51.7	61.6	71.7	86.0
MEAN ANNUAL FLOW (L/sec)	-	-	-	-	-	-	34,828
DRAINAGE AREA (ha)	60	109	25,225	47,348	51,061	54,503	61,517

Flow was obtained from regression of flow versus watershed area using Water Resources Center data for flow during 1991.

Wolf Creek originates in rocks of Ordovician age that are primarily dolomite (Calver 1963). After passing down from Burkes Garden, Wolf Creek continues through alternating layers of Silurian and Devonian age formations. The Silurian age rocks are quartz sandstone and Devonian formations are alternating beds of shale, sandstone, limestone and chert (Cady 1963). Downstream from Rocky Gap to Narrows, Wolf Creek parallels the Narrows fault and is underlain by alluvial floodplain deposits of sand, gravel, and clay that cover Cambrian age Copper Ridge Formation dolomite composed of sandstone and chert (Schultz et al. 1986).

Wolf Creek flows through deciduous forests, agricultural, lands and scattered small residential areas (Fig. 2). Vegetation consists primarily of scarlet oak (*Quercus coccinea*), chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), and red oak (*Quercus rubra*). Yellow poplar (*Liriodendron tulipifera*) and sycamore (*Platanus occidentalis*) are also found in abundance in the area (L. Brossy, personal conversation). Elevation is 1070 m at the headwaters and 488 m at the confluence with the New River. Seven sites were chosen along an elevational gradient from Indianfield Creek, a tributary of Wolf Creek, to just before the junction with the New River. The first two sites are on Indianfield Creek in the Jefferson National Forest. The third site receives drainage from Burkes Garden and Hunting Camp Creek. Site 4 receives additional drainage from Laurel Creek and Clear Fork. Sites 5 and 6 were situated evenly between

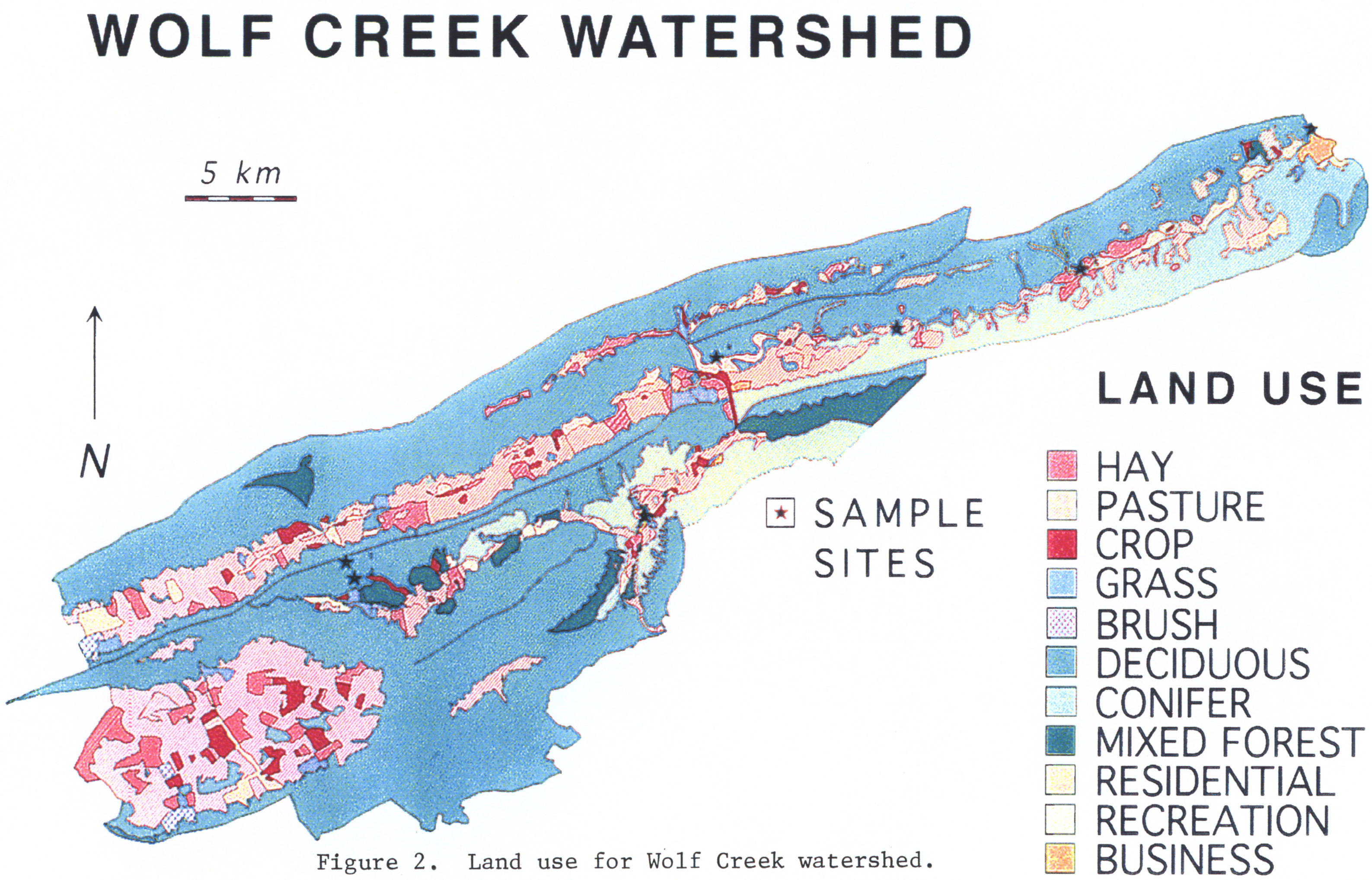

Figure 2. Land use for Wolf Creek watershed.

Sites 4 and 7. Site 7 was approximately 100 meters from the New River (Fig. 1).

Wolf Creek is a moderately hardwater stream with a total hardness ranging from 80 to 100 ppm $CaCO_3$ except at the two headwater sites where hardness is below detection. Ortho-phosphate was at or below the detection limit of 10 ppb throughout the year at all elevation sites, however nitrates varied from zero to 3.3 ppm.

Coweeta Creek is a fifth order stream located in the Nantahala Mountains in western North Carolina. Ball Creek, the headwaters of Coweeta Creek, is in the Coweeta Hydrologic Laboratory, a research facility of the USDA Forest Service.

Major tributaries of Coweeta Creek include Shope, Dryman, and North Forks (Fig. 3). Coweeta Creek is a dendritic stream draining an area of 4,397 hectares. The total length of the stream from headwaters to the Little Tennessee River is approximately 13.4 km (Fig. 3). Climate is characterized as marine, humid, and temperate (Swank and Bolstad 1993). Average monthly temperatures range from 3°C to 21.6°C. Annual rainfall ranges from 180 to 250 cm. Elevation is 1070 m at the headwater site (WS27) and 650 m at CC4 at the confluence of Coweeta Creek with the Little Tennessee River (Table 2). Coweeta Creek is located in a syncline in the eastern Blue Ridge Geologic Province. The Blue Ridge Province is bordered to the south by Brevard fault

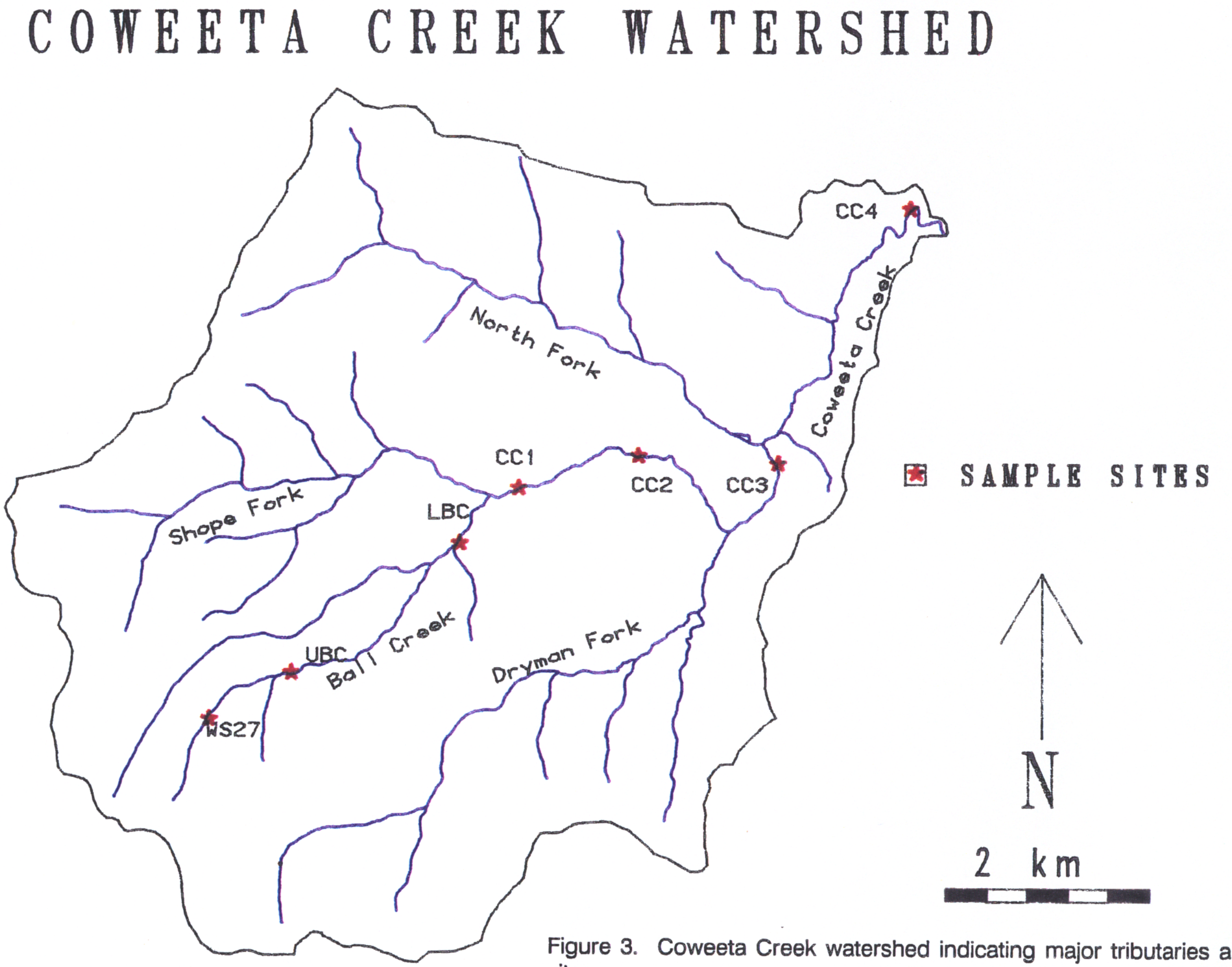

Figure 3. Coweeta Creek watershed indicating major tributaries and sample sites.

Table 2. Characteristics of sample sites along Coweeta Creek.

	WS27	UBC	LBC	CC1	CC2	CC3	CC4
ELEVATION (m)	1070	922	716	685	670	655	650
DISTANCE FROM SOURCE (km)	0.95	2.60	3.85	5.55	6.70	9.40	13.4
MEAN ANNUAL FLOW (L/sec)	21	85	279	600	680	1,159	1,642
DRAINAGE AREA (ha)	38	199	723	1,587	1,804	3,095	4,397

and the Inner Piedmont Province (Hatcher 1988). The area is characterized by extensive faults. Drainage is controlled by the structural geology of the formations (Hatcher 1988).

The Coweeta Creek watershed consists of Proterozoic age basement rocks and metasedimentary rocks. The Tallulah Falls Formation consist of metasandstones with volcanic rocks. Overlying the Tallulah Falls rocks, the Otto Formation is quartz-rich metasandstones. Of the three formations in the Coweeta Group, the older Persimmon Creek Gneiss Formation is a diorite gneiss. The Coleman River Formation and the Ridgepole Mountain Formation are comprised of metasandstone with layers of quartzite (Hatcher 1988). Quaternary colluvium and alluvium deposits are found throughout the watershed.

Vegetation of the Coweeta Creek watershed is comprised primarily of oaks (*Quercus spp.*), red maple (*Acer rubrum*), yellow poplar, dogwood (*Cornus florida*), and rhodendron (*Rhododendron maximum*) (Swank and Crossley 1988).

Seven sites were chosen, four within the Coweeta Hydrologic Laboratory and three beyond the laboratory boundaries. Within the laboratory area, the stream receives drainage from virtually only forested area. Beyond the laboratory area, the stream receives drainage from agricultural, recreational, residential, and forested areas. Non-forest land contributes less than 6% of the drainage for any site (Swank and Bolstad 1993) (Fig. 4).

Coweeta Creek is one sixth the length of Wolf Creek, however both creeks are classed as fifth order streams following the method of Strahler. The mean annual flow of Coweeta Creek is also considerably less than Wolf Creek, 1,642 L/sec versus 34,828 L/sec in 1991. Land use in the two streams is also significantly different. Much of the agriculture along Wolf Creek is near the headwaters and Coweeta Creek has very little agriculture even at the most downstream site. Coweeta Creek in its entirety falls within the distance of the first three sites of Wolf Creek on a longitudinal scale. Site comparisons may lead to misinterpretations of the data, though the trends may be examined. Coweeta Creek was analyzed as it is a relatively unimpacted stream for comparison with Wolf Creek which has much more agriculture and residential area within the watershed.

FIELD STUDIES

Fine benthic organic matter (FBOM) was collected at each site using a hand vacuum pump with 1-mm mesh over the intake port. Approximately 1-liter slurry of FBOM was collected from a variety of patches at each location. Three water samples were also collected at each site. Alkalinity, pH, and hardness were measured on-site with a LaMotte water testing kit. Water temperature and dissolved oxygen were measured with a YSI Model 57 oxygen meter. Samples

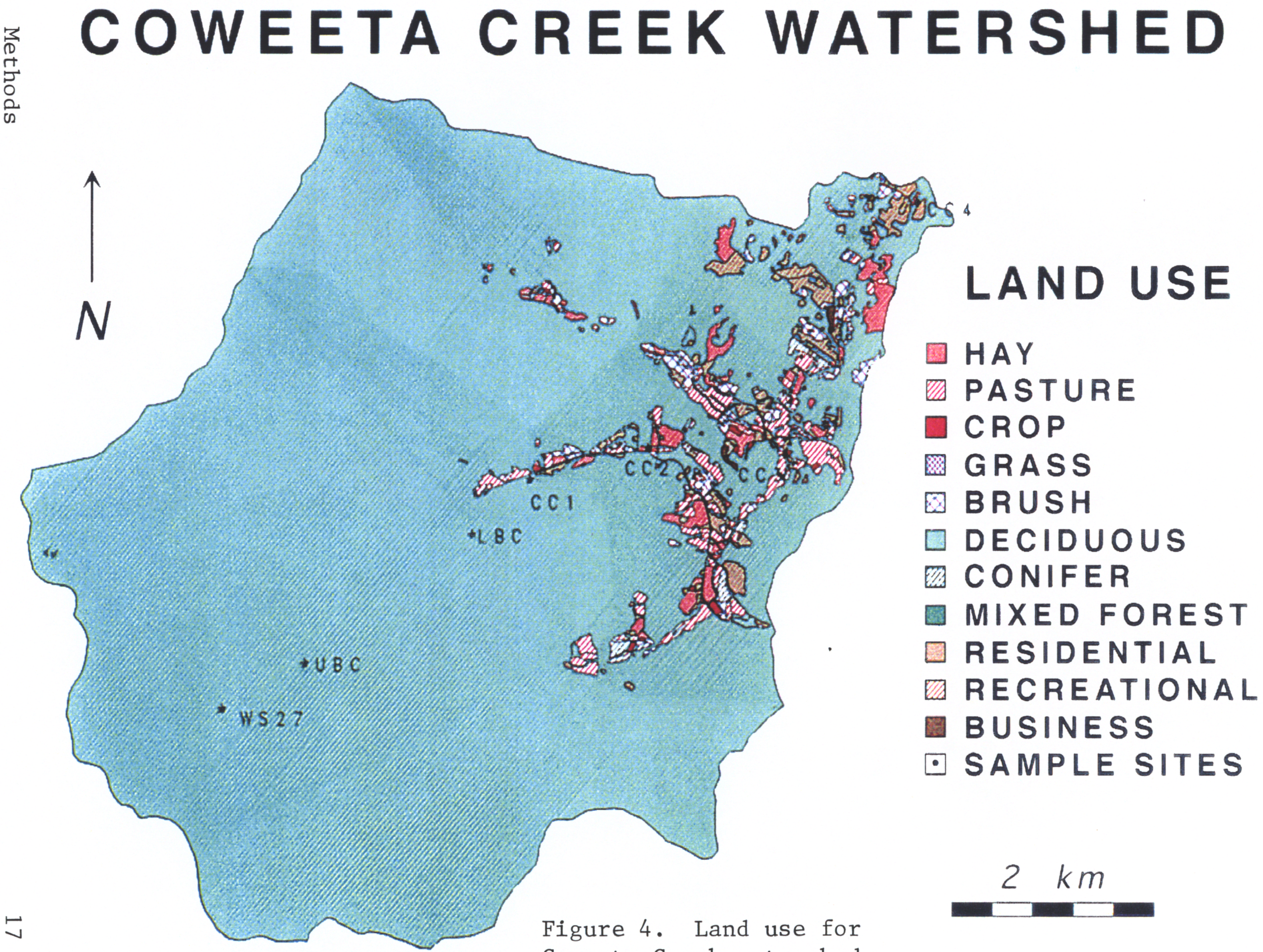

Figure 4. Land use for Coweeta Creek watershed.

were put on ice and transported to the laboratory for further analysis.

LABORATORY ANALYSES

Oxygen uptake rates of microbes on FBOM were measured using a Gilson differential respirometer. Three to four 5-ml subsamples of FBOM from each site were placed in 5-ml Gilson flasks containing 0.2-ml of potassium hydroxide in the center well to absorb carbon dioxide. The samples were run twice: once in a water bath at an average of ambient stream temperature and once at 20°C after an acclimation period of 24 hours. The controls were FBOM samples that had been autoclaved for 30 minutes.

Samples were run until readings were sufficient to measure accurately. The length of the run varied with the temperature at which the samples were tested, ranging from three to six hours. After the runs FBOM samples were filtered through Gelman 0.45 μm glass fiber filters and oven dried at 50°C overnight. They were then desiccated for at least twenty minutes and weighed and ashed for 30 minutes at 550°C. The samples were then re-wetted to restore water of hydration, dried in the drying oven, and weighed to obtain total ash free dry mass (AFDM).

Oxygen uptake rates were calculated using the formula below and expressed on an AFDM basis (Umbreit et al. 1964);

where X is oxygen taken up (μL), V_g is the change in volume of the respirometer

$$X = (\Delta V_g) \frac{P-P_w}{P_1} \frac{T_1}{T}$$

in (μL), P is total gas pressure within respirometer, (mm Hg), P_w is vapor pressure of water at temperature T (mm Hg), P_1 is standard pressure (760 mm Hg), T_1 is standard temperature (273.15 K), and T is the temperature of the water bath (K).

Water samples were analyzed for nitrate and phosphate. These were measured on a Dionex 2000i/SP ion chromatograph with an AS4A anion column. Ortho-phosphate was measured on the Dionex or Perkin Elmer UV/VIS Spectrophotometer using the ascorbic acid method (Standard Methods 1991).

GEOGRAPHIC ANALYSIS OF THE WATERSHEDS

Within each of the two watersheds, area for each category of land use was calculated using ARC/INFO, a geographic information system. Land use polygons for Wolf Creek were plotted on 1:24,000 scale 7.5' series U. S. Geological Survey (USGS) topographic maps (Garden Mountain, Tiptop, Hutchinson Rock, Big Bend, Cove Creek, Bastian, Rocky Gap, Bluefield, Princeton, Oakvale, and Narrows quadrangles of Virginia) using 1:40,000 scale leaf-off infrared aerial photographs dated April 1991. Areas of less than one hectare were not digitized for Wolf Creek. Verification was done by field inspection of 152 of 351 polygons.

I used Coweeta Creek land use data collected by Swank and Bolstad (1993). These data were interpreted on screen from digitally rectified scanned photography. Leaf-off 1:58,000 color infrared photography was scanned at 50 μm on an Optronics rotating drum scanner which was then used as a base onto which 1991 1:60,000 leaf-on color infrared photos were interpreted (Swank and Bolstad 1993). I derived twelve land use classes from the 32 classes originally defined by Swank and Bolstad (1993). Four watersheds within the Coweeta Hydrologic Laboratory contain white pine (*Pinus strobus*), but are not included in Figure 4 as the 32 original land use classes identified tree age classes, not type of tree.

Three basic spatial data layers were developed for Wolf Creek and Coweeta Creek, including watershed boundaries, hydrography, and landcover. All data were converted to a vector digital format and co-registered to the UTM Zone 17 coordinate system. A root mean square error of 12 m was established as acceptable for digitization of Wolf Creek. An error limit of 15 m was established for both digitization and registration of all data layers for Coweeta Creek (Swank and Bolstad 1993).

STATISTICS

Data for both Wolf Creek and Coweeta Creek were analyzed using

Statistical Analysis System (SAS) Version 6 (SAS 1991). SAS General Linear Model (GLM) is a procedure which can analyze classification variables having discrete levels, as well as continuous variables for regressions and analysis of variance (SAS 1991). GLM analysis was used with respiration as the dependent variable and site, nitrate, phosphate, transformed land use and stream temperature as independent variables.

Land use areas (as percentages) were transformed using the arc sine transformation. These were then used in a General Linear Model with respiration as the dependent variable and land use, site, and nitrate as independent variables. Multiple regressions of these variables were also done. T-tests were used to determine differences in respiration rates among sites. Regressions using GLM with nitrate as the dependent variable and land use and stream temperature as independent variables were also run.

RESULTS

CHANGE IN LAND USE ALONG THE STREAM GRADIENT

At Coweeta Creek, land used for agriculture increased in the downstream direction from no agriculture at WS27 to a maximum of 3.3% at CC4, and residential area increased from zero to 1.9% at CC4. The percentage of forest decreased from 100% at WS27 to 94% at CC4, near the Little Tennessee River (Table 3).

Land in agriculture in the Wolf Creek watershed varied from zero at Site 1 in the headwaters to 27% at Site 3 and then decreased to 22.6% at Site 7. Area devoted to residential use varied from zero at the headwaters to 3.3% at Site 7. Area devoted to forest decreased from 100% at Site 1 to 64.6% at Site 6 and then increased slightly to 72.6% at Site 7 as the stream flowed through primarily forested area in Giles County on its way to the New River (Table 4).

STREAM TEMPERATURE

Average temperature in Coweeta Creek increased in a downstream direction from 11.0°C at WS27 to 15.5°C at CC4. Temperature at CC4, the site nearest the Little Tennessee River, was normally 3 to 4°C higher than the headwaters. Temperature ranged seasonally from a maximum of 22°C in July 1992 to a minimum of 6°C in January 1992. The average temperature in Wolf

Table 3. Percent land use for sample sites along Coweeta Creek.

	WS27	UBC	LBC	CC1	CC2	CC3	CC4
Forest	100.0	100.0	100.0	99.8	98.9	96.6	94.0
Deciduous	00.0	100.0	100.0	99.8	98.9	96.3	93.4
Conifer						0.2	0.3
Mixed							
Agriculture				0.2	0.6	2.2	3.3
Hay					0.2	0.9	1.3
Pasture				0.2	0.4	1.2	1.8
Crop					T	0.1	0.2
Residential					0.2	0.8	1.9
Residential					0.2	0.7	1.8
Recreation							
Business						T	0.1
Other							
Grass							
Brush					0.2	0.4	
Water							0.1

T = Less than 0.1 but greater than zero

Table 4. Percent land use for sample sites along Wolf Creek.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Forest	100.0	99.0	69.0	70.9	71.0	64.6	72.6
Deciduous		99.0	62.8	62.9	60.9	60.3	65.1
Conifer			3.2	5.5	6.4	8.3	4.4
Mixed			3.1	3.8	3.6	3.4	3.1
Agriculture		1.0	27	24.7	24.5	24	22.6
Hay		1.0	3.8	4.0	3.8	3.8	3.7
Pasture			20.7	18.5	18.7	18.0	17.1
Crop			2.8	2.3	2.2	2.1	1.9
Residential			2.0	2.7	2.5	2.6	3.3
Residential			1.6	2.3	2.4	2.2	2.9
Recreation			0.5	0.2	0.2	0.2	0.2
Business			T	T	0.1	0.1	0.3
Other							
Grass			1.0	1.0	1.2	1.1	1.0
Brush			0.6	0.5	0.5	0.5	0.4
Water			T	T	T	T	T

T = Less than 0.1 but greater than zero

Creek at the time samples were taken was usually 2.5°C higher at Site 7 than at the headwater sites. Seasonal variation of stream temperature in Wolf Creek ranged from a maximum of 25°C to a minimum of 2°C. For both streams the least amount of variation between sites occurred in winter, increasing only 1°C downstream. The maximum difference was 6°C in the summer.

GENERAL CHEMICAL CHARACTERISTICS

Total hardness of Coweeta Creek was very low ranging from below the limit of detection at the headwaters to 12.5 ppm downstream. Alkalinity varied from 8 ppm to 20 ppm with no downstream trend. The pH was between 6.3 and 6.8 with a slight increase in the downstream direction. Dissolved oxygen was near saturation throughout the year at all seven sites (Table 5).

Total hardness in Wolf Creek increased from below detection limits at the two headwater sites to 86 ppm at the most downstream site. Most of the increase occurred downstream of Site 2 where total hardness increased to 80 ppm. Alkalinity increased from 16 ppm at the headwaters to 124 ppm at Site 7. At the two headwater sites, pH averaged 6.0 but was 8.0 downstream of Site 2. These trends are probably the result of changing geology from mineral to carbonate rock. Dissolved oxygen was near saturation levels at all sites throughout the year, except in October 1992. At that time flow was negligible at the headwater sites, and dissolved oxygen was 3.8 mg/L at Site 1 and Table

5. Mean values of water chemistry at sites on Coweeta Creek. The values are means of samples taken on all dates and are reported in parts per million (ppm).

SITE	HARDNESS	ALKALINITY	pH
WS27	2.0	12.6	6.3
UBC	4.0	18.6	6.5
LBC	9.45	14.9	6.7
CC1	11.5	14.3	6.7
CC2	11.0	13.3	6.8
CC3	10.0	16.0	6.8
CC4	12.5	17.7	6.8

Table 6. Mean values of water chemistry at sites on Wolf Creek. The values are means of samples taken on all dates and are reported in parts per million (ppm).

SITE	HARDNESS	ALKALINITY	pH
SITE 1	D	14.7	5.9
SITE 2	D	15.0	6.1
SITE 3	70.3	82.3	7.7
SITE 4	68.9	81.7	7.8
SITE 5	71.7	93.7	7.9
SITE 6	82.3	94.9	8.1
SITE 7	85.7	108.6	8.0

D Below limits of detection

5.2 mg/L at Site 2 (Table 6). Overall, anion levels for Coweeta Creek were very low as compared to levels measured in Wolf Creek (Table 7). Nitrate levels in Coweeta Creek were highest at WS27 with an average of 0.30 mg/L and then decreased to an average of 0.22 mg/L throughout the rest of the stream. These were similar to those reported for Coweeta Creek by Swank and Bolstad (1993). Phosphate levels were at or below detection limits for all sites in Coweeta Creek throughout the year, which corresponded with phosphate reported by Swank and Bolstad (1993). Nitrate for Wolf Creek was lowest at Sites 1 and 2 at 0.16 mg/l and 0.14 mg/L, respectively. Nitrate was highest at Site 3 at 2.11 mg/L. Nitrate then decreased downstream, averaging 1.65 mg/L at the remaining sites.

Phosphate for Wolf Creek averaged 0.025 mg/L (Table 7).

OXYGEN UPTAKE RATES

Factors affecting oxygen uptake rates on FBOM included stream temperature, amount of land use for agriculture, housing and forest, site, and nitrate levels. These factors were related to each other. As forested area decreased, area for agriculture and residential use increased. The greatest single effect on oxygen uptake rates was stream temperature. This effect was removed by running all FBOM samples at 20°C throughout the year. When stream temperature was removed from analysis, land use and nitrate levels were the next most significant factors influencing oxygen uptake rates.

Table 7. Mean nitrate and phosphate concentrations (mg/L) for Wolf Creek and Coweeta Creek.

				WOLF CREEK			
	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7
NO_3-N	0.038	0.032	0.477	0.328	0.359	0.400	0.411
PO_4-P	0.040	0.040	0.010	0.040	0.017	0.023	0.003
				COWEETA CREEK			
	WS27	UBC	LBC	CC1	CC2	CC3	CC4
NO_3-N	0.068	0.036	0.052	0.054	0.047	0.061	0.045
PO_4-P	0.007	0.003	D	0.003	0.003	0.003	0.003

D Below limits of detection

EFFECTS OF TEMPERATURE ON OXYGEN UPTAKE RATES

Oxygen uptake rates increased as stream temperature increased for both streams at all sites. Both streams had low oxygen uptake rates approximately the same rate less than 0.1 μL O_2/mg AFDM/h in winter when temperatures averaged 6° C and increased rates in summer when temperatures were higher. However Coweeta Creek oxygen uptake rates did not increase as much as those of Wolf Creek (Fig. 5). Coweeta Creek oxygen uptake rates averaged 0.04 μL/mg AFDM/h at low temperatures and increased to 0.095 μL/mg AFDM/h at higher temperatures during the summer (Fig. 6). When measured at ambient temperature, oxygen uptake rates increased significantly with temperature in Coweeta Creek. Regression of oxygen uptake rates and stream temperature was significant (GLM, $r^2 = 0.12$, $n = 218$, $p < 0.0001$) (Fig. 7).

In Wolf Creek, oxygen uptake rates averaged 0.078 μL O_2/mg AFDM/h during winter, when temperatures averaged 5°C, and increased to an average of 0.524 μL O_2/mg AFDM/h in the summer, when temperatures peaked at 24°C (Fig. 8). Regression of Wolf Creek oxygen uptake rates measured at ambient stream temperature versus stream temperature was also highly significant (GLM, $r^2 = 0.38$, $n = 173$, $p < 0.0001$) (Fig. 9). Data from both streams for oxygen uptake rates, stream, and stream temperature were combined and a GLM with oxygen uptake as the dependent variable and stream and stream temperature as independent variables, indicated both stream and stream temperature were

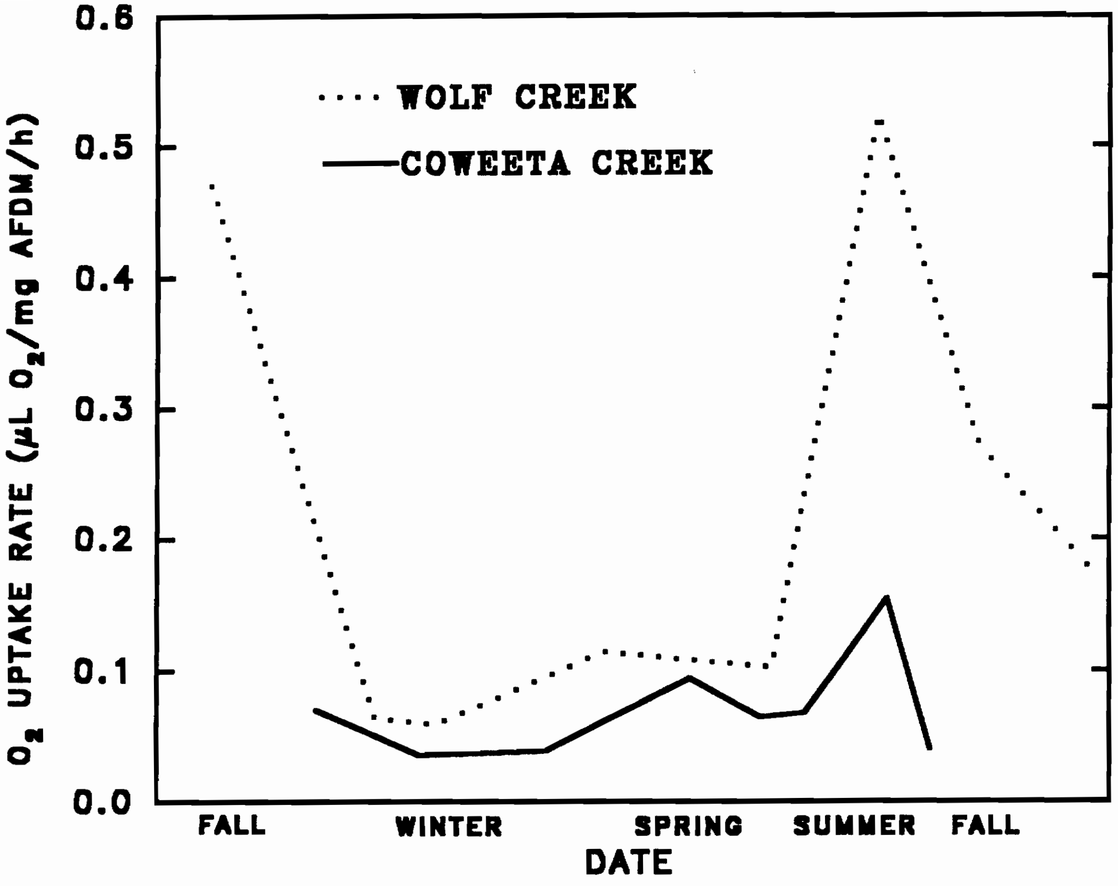

Figure 5. Comparison of mean FBOM oxygen uptake rates measured at ambient temperature for Coweeta Creek and Wolf Creek plotted by date.

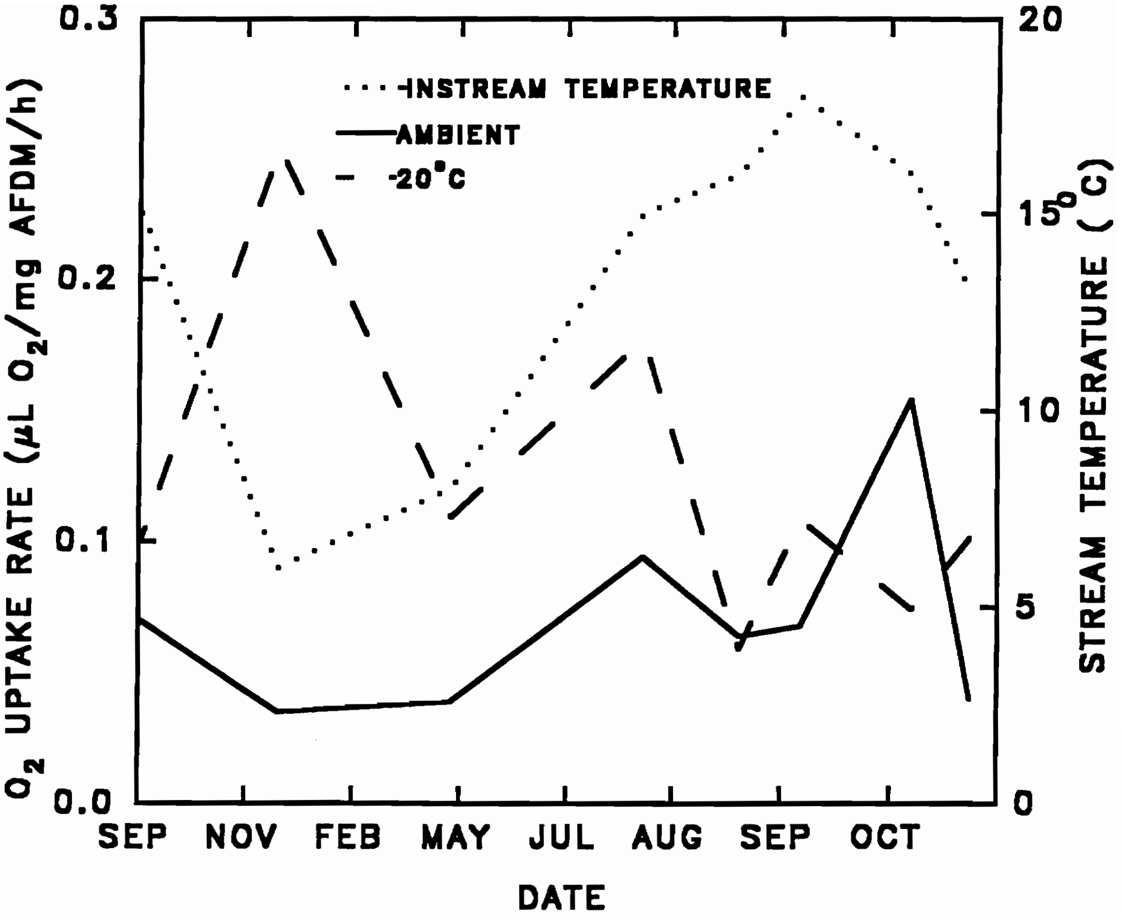

Figure 6. FBOM oxygen uptake rates measured at ambient temperature and at 20°C for Coweeta Creek with temperature plotted by date.

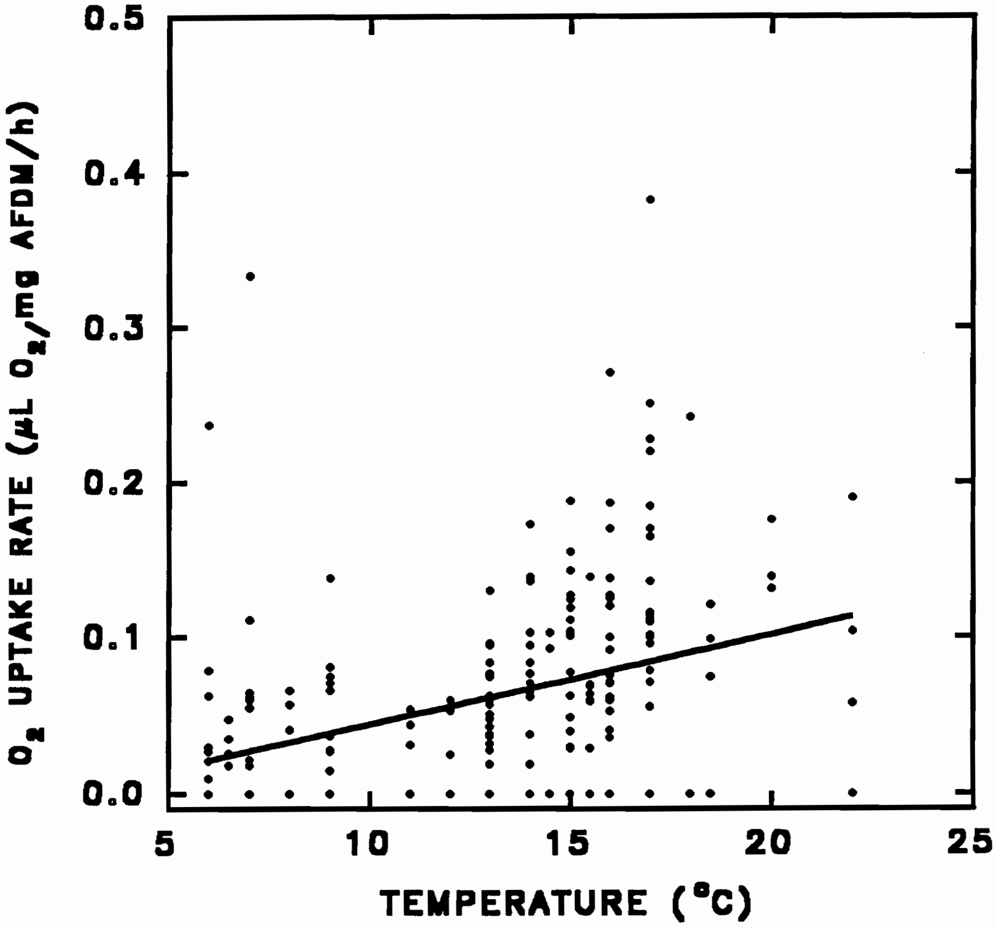

Figure 7. Mean FBOM oxygen uptake rates measured at ambient temperature for Coweeta Creek plotted by temperature. Regression of oxygen uptake rate versus temperature was statistically significant (r^2 = 0.12, n = 218, p < 0.0001).

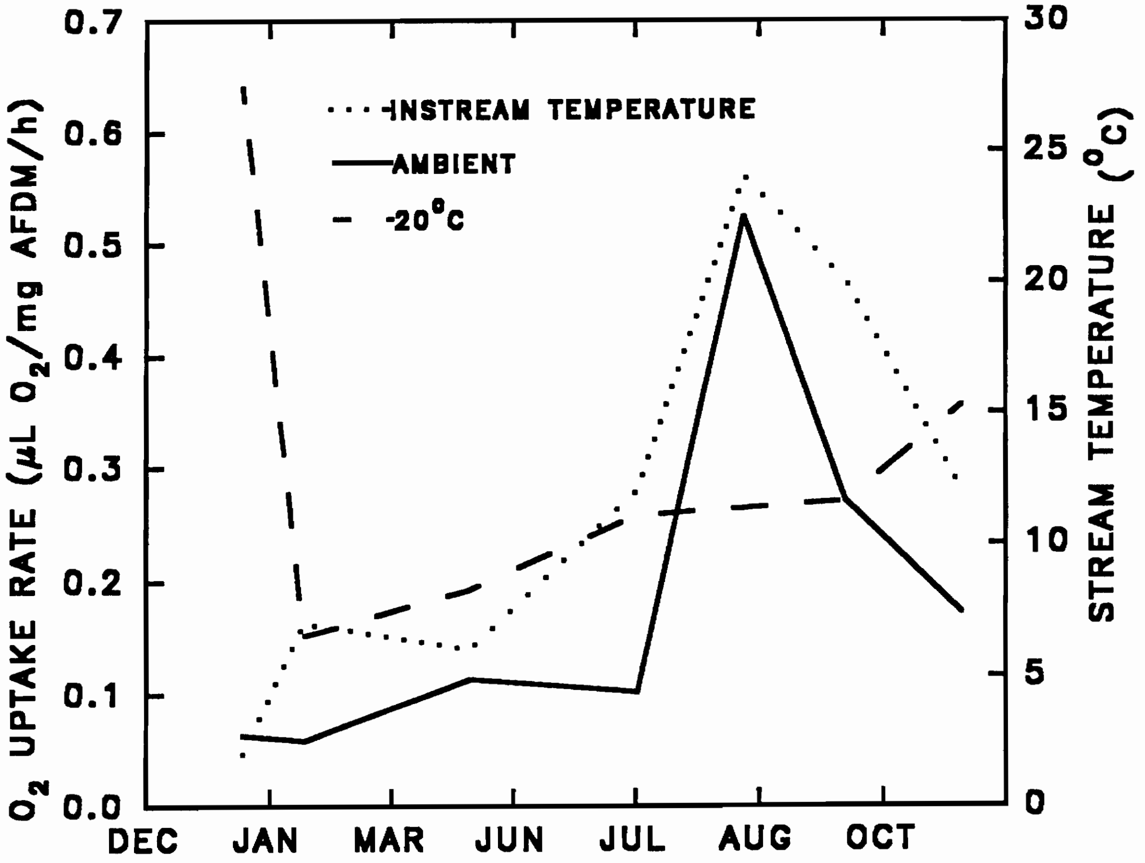

Figure 8. Comparison of mean FBOM oxygen uptake rates for Wolf Creek measured at ambient temperature and at 20°C and temperature plotted by distance downstream.

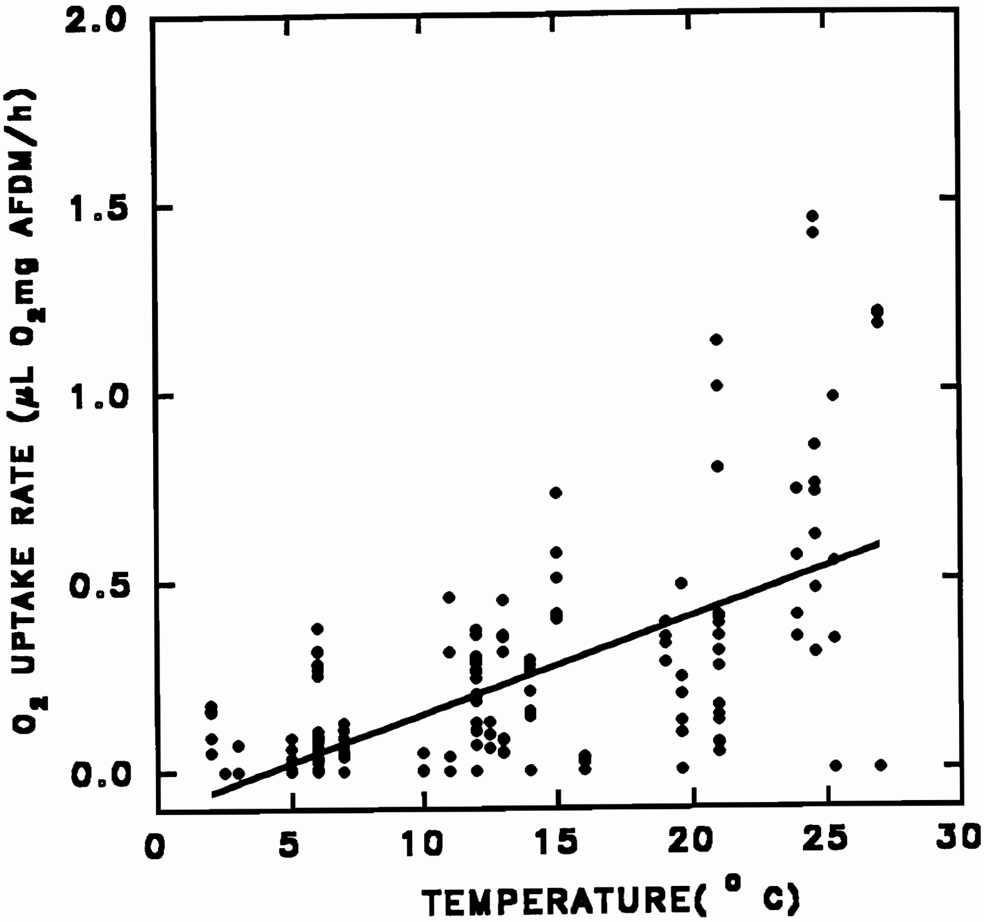

Figure 9. Oxygen uptake rates measured at ambient temperatue for Wolf Creek plotted by temperature. The regression of oxygen uptake rates versus temperature was statistically significant (r^2 = 0.38, n = 174, p < 0.0001).

significant (GLM $r^2 = 0.38$, $n = 182$, $p < 0.0001$). Examining the two streams separately, the slope of the regression line for Wolf Creek oxygen uptake rate versus temperature was almost ten times that of Coweeta Creek, 0.0256 and 0.0057, respectively.

Respiration may be expressed as a function of temperature using a Q_{10} function:

$$R = R_0 Q_{10}^{(T-T_0)/10}$$

where R equals respiration rate and T equals temperature. A linear regression of the natural logarithm of oxygen uptake versus temperature was used to find Q_{10} values for FBOM oxygen uptake (Tank 1992). The Q_{10} for Coweeta Creek was 2.5 and that of Wolf Creek was 2.6. These are similar to Q_{10}'s for oxygen uptake obtained by Tank (1992) for respiration of microbes on rhododendron leaves of 2.2 and on sticks of 2.4. Hargrave (1969) reported a Q_{10} of 2.2 for respiration of a benthic microbial community on Marion Lake, British Columbia, and White et al. (1991) obtained a Q_{10} of 2.1 - 3.9 for respiration in a variety of habitats in freshwater and marine systems.

INFLUENCE OF NUTRIENTS ON OXYGEN UPTAKE RATES

Regression of the data for Wolf Creek with oxygen uptake rates measured at 20°C as the dependent variable and nitrate as the independent variable was significant ($r^2 = 0.14$, $n = 145$, $p < 0.0001$) (Fig. 10). Adding stream temperature as a second independent variable, multiple regression of oxygen uptake rates measured at 20°C versus nitrate and stream temperature increased the amount of variance explained ($r^2 = 0.23$, $p < 0.0003$). Regression for Wolf Creek oxygen uptake data measured at ambient temperatures versus stream temperature was significant ($r^2 = 0.13$, $n = 196$, $p < 0.0033$). Multiple regression of oxygen uptake rates measured at ambient stream temperatures versus stream temperature and nitrate increased the amount of variance explained ($r^2 = 0.41$). Nitrate was negatively correlated with stream temperature for Wolf Creek (Fig. 11). Nitrate was highest when temperature was low, probably a result of less nitrate immobilized in plant and animal tissue in winter. The effects of increased nitrate on oxygen uptake rates were probably masked by the effects of decreased temperature.

Nitrate did not affect oxygen uptake in Coweeta Creek ($p = 0.31$) (Fig. 12). Multiple regression of oxygen uptake measured at 20°C versus nitrate and stream temperature for Coweeta Creek data also had no statistical significance ($p = 0.33$).

Phosphate was not correlated with oxygen uptake rates for either stream. Regression of phosphate woth oxygen uptake rate for Wolf Creek was not statistically significant (GLM, $r2 = 0.01$, $n = 145$, $p = 0.31$).

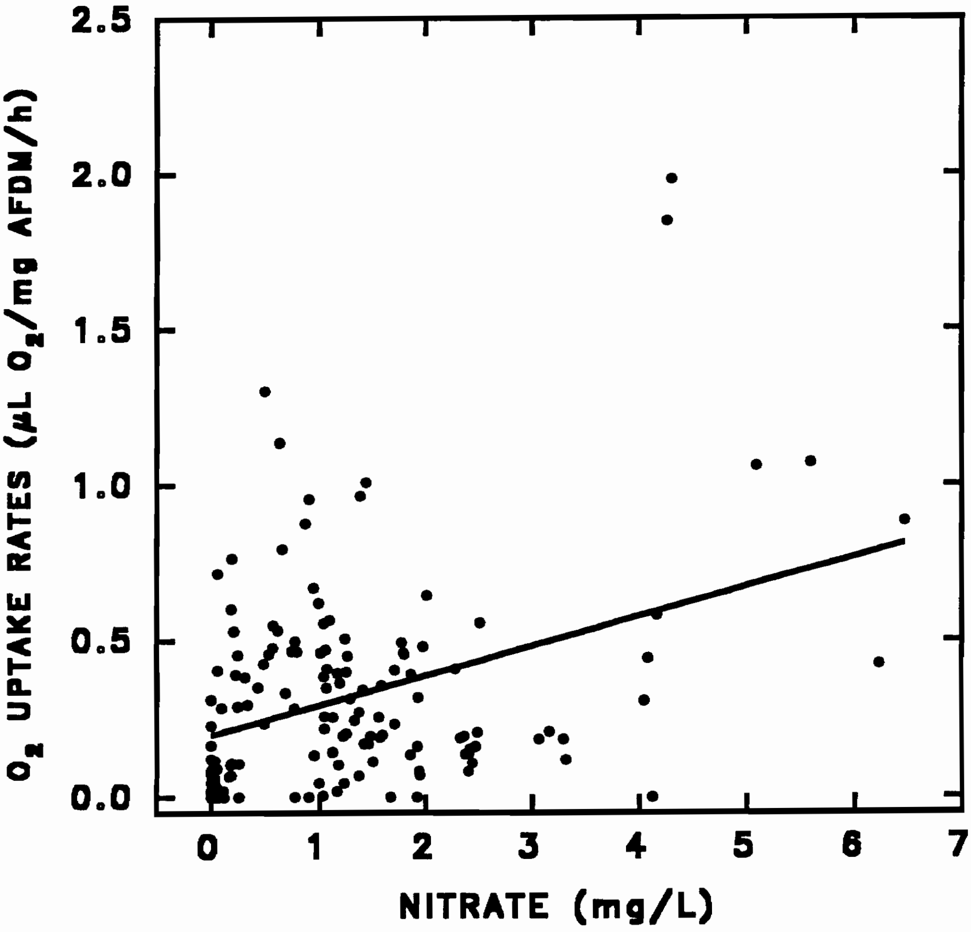

Figure 10. Oxygen uptake rates at 20°C plotted by nitrate for Wolf Creek. Regression of oxygen uptake rates versus nitrate was statistically significant ($r^2 = 0.14$, $n = 146$, $p < 0.0001$).

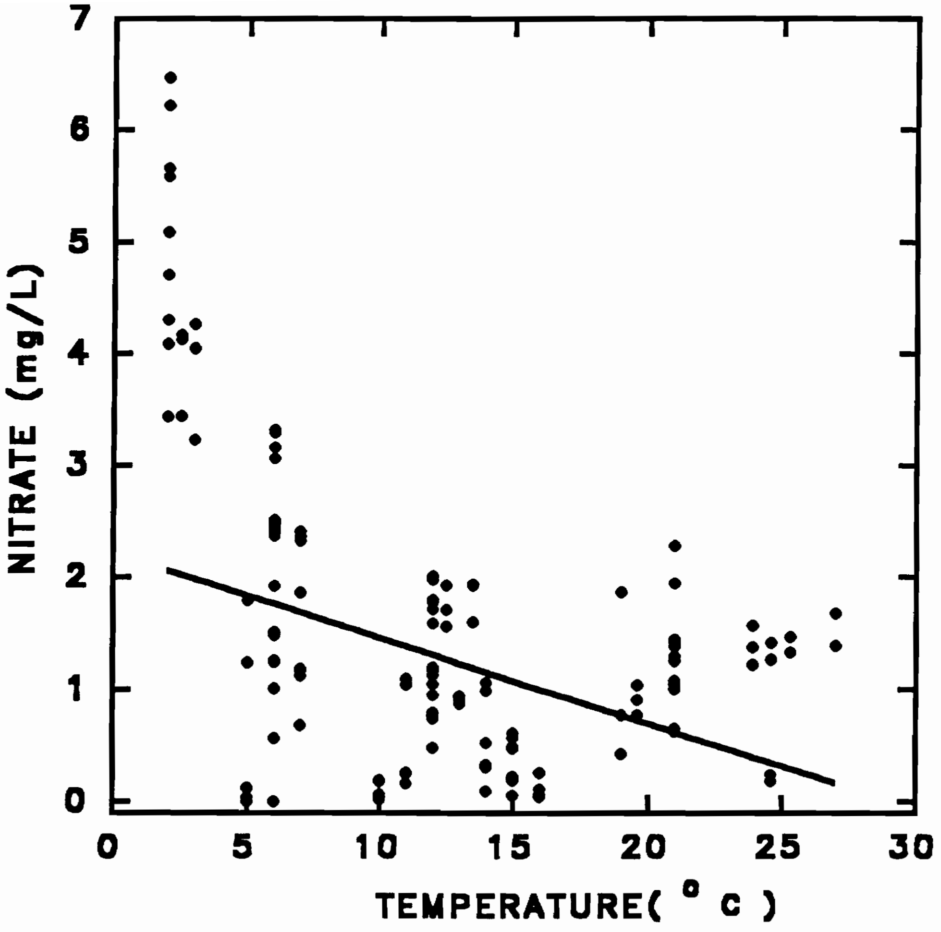

Figure 11. Nitrate plotted by stream temperature for Wolf Creek.

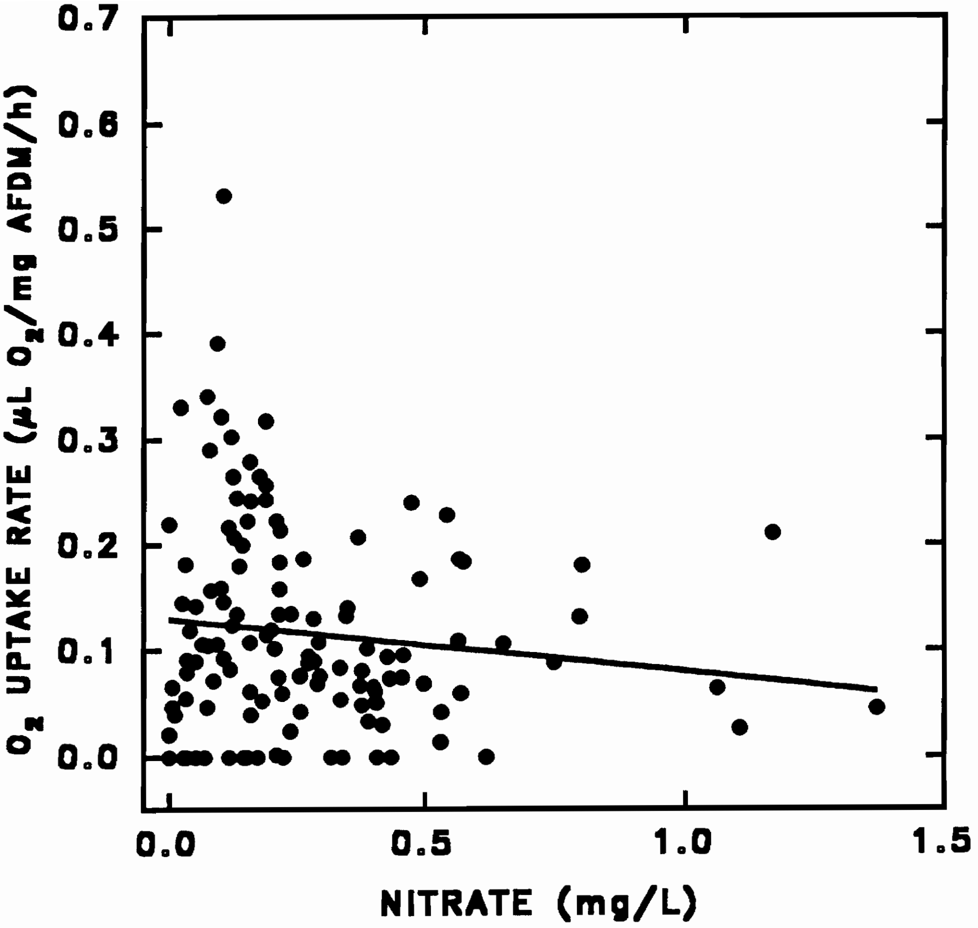

Figure 12. Oxygen uptake rates at 20°C plotted against nitrate for Coweeta Creek. Regression of oxygen uptake rates versus nitrate was not significantly different from zero.

SITE AS A FACTOR IN OXYGEN UPTAKE RATES

Oxygen uptake rates were related to site for both streams (analysis of variance for Wolf Creek, $r^2 = 0.23$, $n = 173$, $p < 0.0001$, and Coweeta Creek, $r^2 = 0.15$, $n = 218$, $p < 0.0001$).

Because Coweeta Creek is one-sixth the length of Wolf Creek, comparison of oxygen uptake rates by site is not relevant except for the first two sites that are comparable in elevation and land usage. The first two sites on both streams had approximately the same oxygen uptake rates for both temperature treatments. The most downstream site on Coweeta Creek, CC4, is only 13.4 km from the headwaters, compared to Site 3 on Wolf Creek, which is 39 km from the headwaters. A comparison of oxygen uptake rates by site for both streams on a longitudinal scale (Figs. 13 and 14), indicated there was an increase in oxygen uptake in the downstream direction. This graph also showed a comparison of the oxygen uptake rates between streams and that the entire length of Coweeta Creek is comparable only to Wolf Creek up to Site 3.

For Coweeta Creek t-tests showed oxygen uptake rates for WS27 were statistically different than those for sites CC2, CC3, and CC4. Oxygen uptake rates for CC2 were statistically different than those for CC4 (Table 8). For Wolf Creek, t-tests run for site differences indicated oxygen uptake rates for Site 1 were statistically different than oxygen uptake rates for sites from Site 3 through

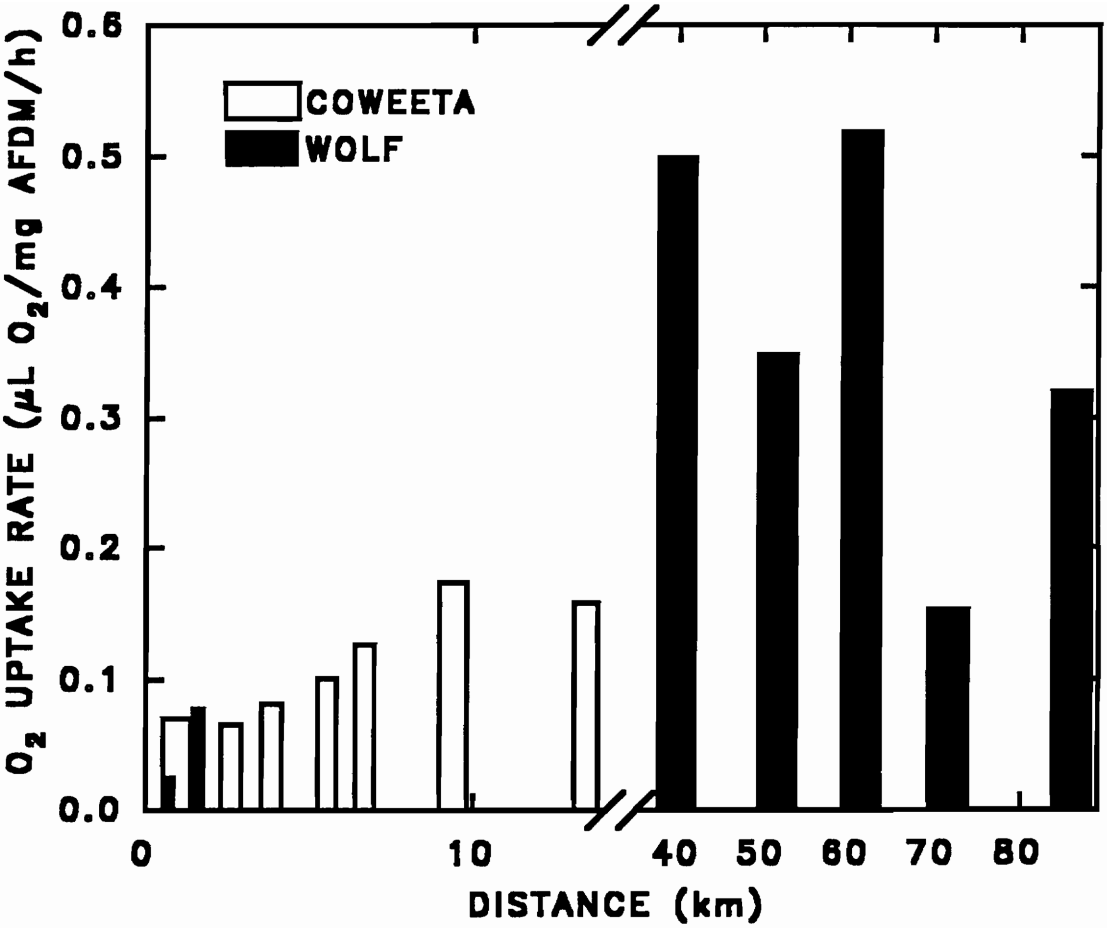

Figure 13. Comparison of mean FBOM oxygen uptake rates for Coweeta Creek and Wolf Creek measured at 20°C plotted by distance downstream.

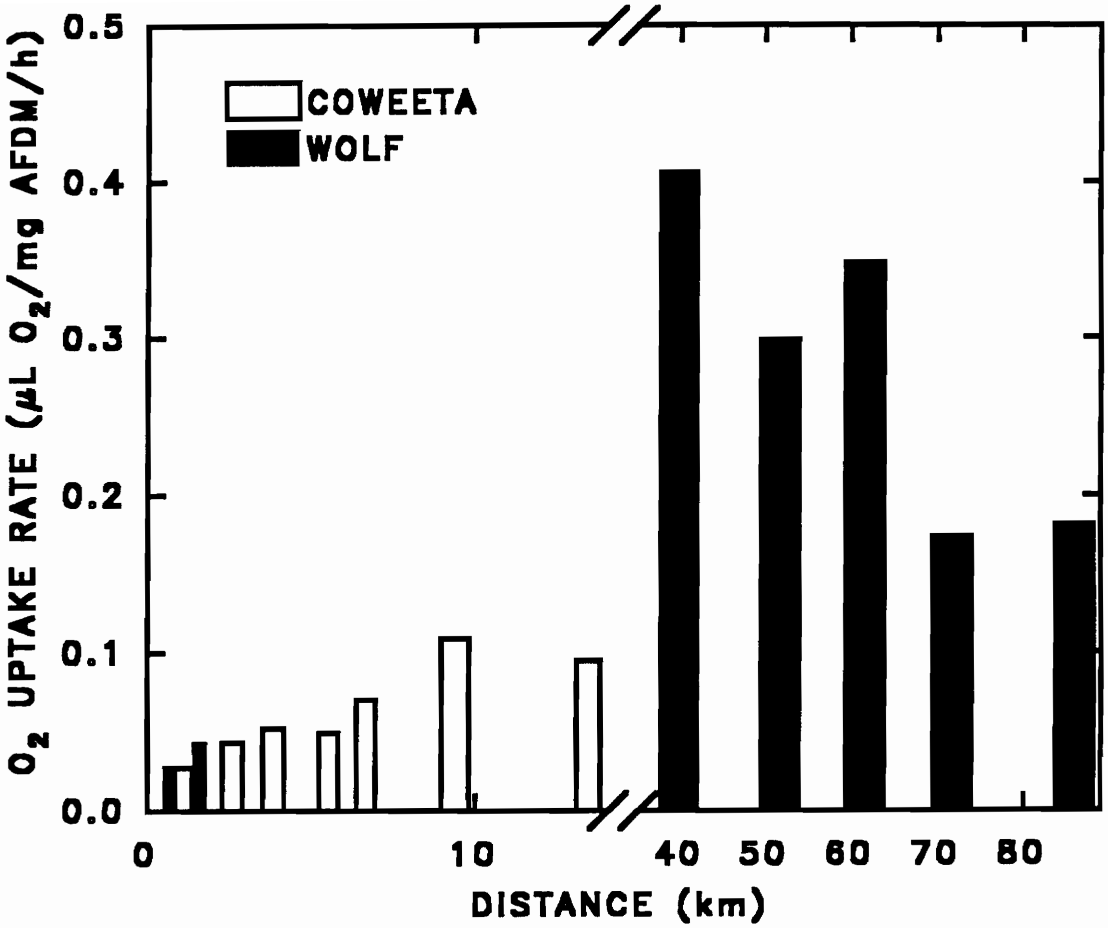

Figure 14. Comparison of mean FBOM oxygen uptake rates for Coweeta Creek and Wolf Creek measured at ambient temperatures plotted by distance downstream.

Table 8. Annual mean FBOM oxygen uptake rates for Wolf Creek and Coweeta Creek. Values with the same letter are not significantly different ($p < 0.05$).

SITE	μL O_2/mg AFDM/h	WOLF CREEK	SITE	μL O_2/mg AFDM/h	COWEETA CREEK
1	0.025	A	WS27	0.027	A
2	0.044	A B	UBC	0.043	A B
3	0.407	D	LBC	0.052	A B
4	0.300	C D	CC1	0.049	A B
5	0.350	D	CC2	0.070	B C
6	0.175	B C	CC3	0.109	D
7	0.183	B C	CC4	0.087	C D

Site 7. Oxygen uptake rates for Site 3 were statistically different than Site 7 (Table 8).

IMPACT OF LAND USE ON OXYGEN UPTAKE RATES

In Wolf Creek, oxygen uptake rates increased significantly as the amount of area that drained agricultural land use increased (GLM, $r^2 = 0.24$, $n = 187$, $p < 0.0001$). In Coweeta Creek this trend was also significant (GLM, $r^2 = 0.159$, $n = 208$, $p < 0.0001$). Regression of oxygen uptake rates on FBOM for Wolf Creek versus amount of residential land use indicated a significant positive effect on oxygen uptake rates (GLM, $p < 0.0001$). Regression of oxygen uptake rates and forested land showed forest had a negative impact on oxygen uptake rates as well (GLM, $p < 0.0001$). In Coweeta Creek, forest and housing did not affect oxygen uptake rates.

To determine whether stream nitrate concentration was affected by the percent of land used in agriculture, I did a regression of nitrate versus agriculture. For Wolf Creek the amount of land in agriculture had a significant effect on nitrate concentration in the stream (GLM, $r^2 = 0.26$, $n = 154$, $p < 0.0001$) (Fig. 15). Nitrate in Coweeta Creek was low throughout the stream and was not affected by the amount of land in agriculture (Fig. 16).

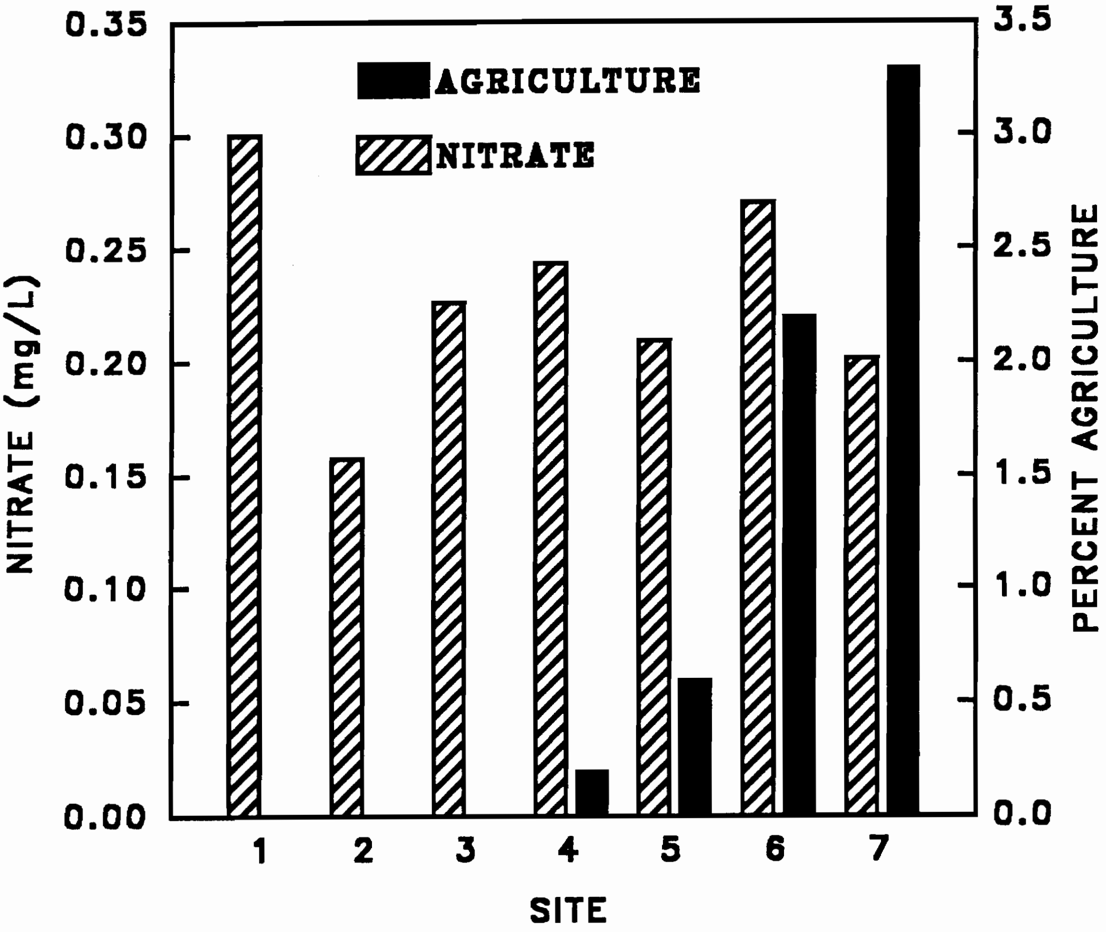

Figure 15. Mean nitrate and percent agriculture for Coweeta Creek plotted by site. Regression of nitrate versus agriculture was not significant. Sites 1-7 for Coweeta Creek are WS27, UBC, LBC, CC1, CC2, CC3, and CC4, respectively.

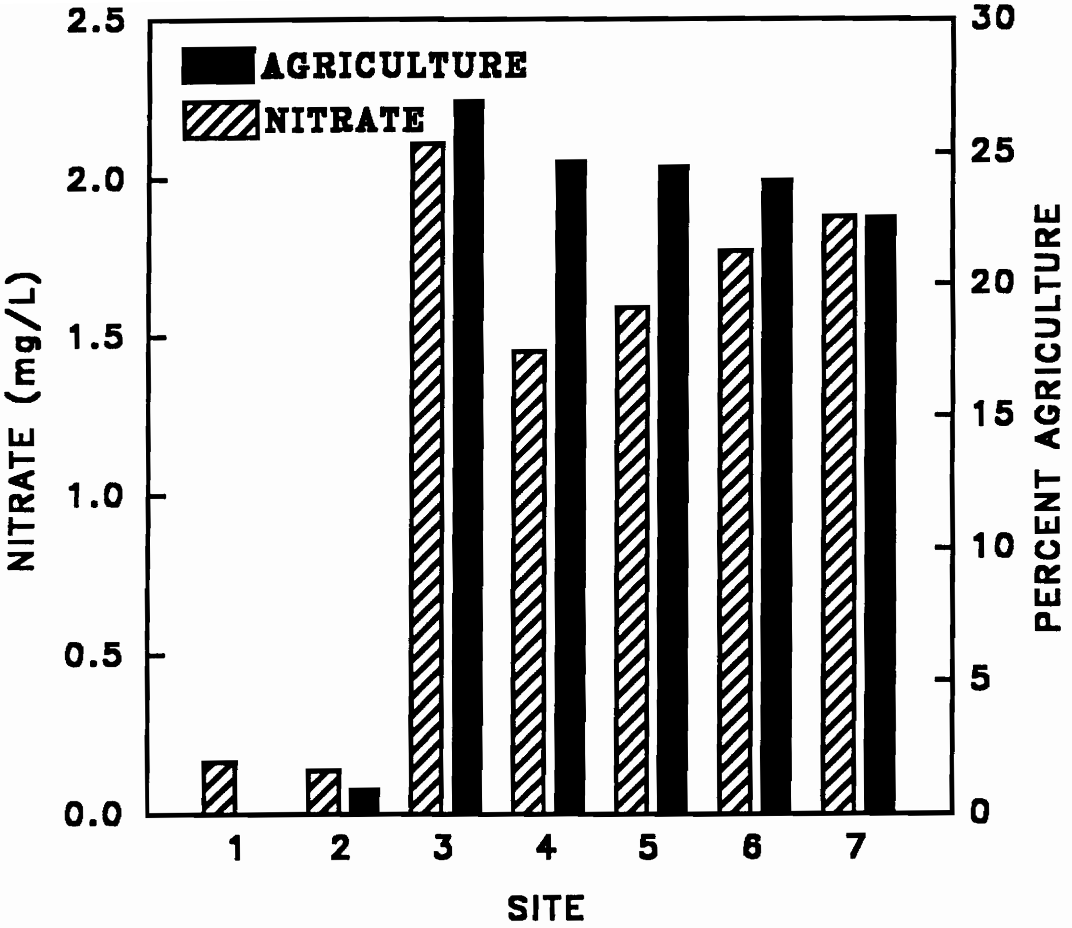

Figure 16. Nitrate and percent agriculture plotted by site for Wolf Creek. Regression of nitrate versus agriculture was significant ($r^2 = 0.26$, $n = 154$, $p < 0.0001$).

Nitrate was negatively correlated with forested area ($r = -0.51$, $p < 0.0001$) and positively correlated with both agriculture ($r = 0.51$, $p < 0.0001$) and housing ($r = 0.50$, $p < 0.0001$). There was no correlation of nitrate with housing or forest for Coweeta Creek.

DISCUSSION

COMPARISONS WITH OTHER STUDIES

Oxygen uptake rates by microorganisms on FBOM from Coweeta Creek and Wolf Creek were in the same range as those found for similar streams (Table 9). Average oxygen uptake rate by microorganisms on FBOM for Coweeta Creek measured 2.14 mg O_2/g AFDM/d at ambient temperature. Average oxygen uptake rate measured at ambient temperature for Wolf Creek was 7.58 mg O_2/g AFDM/d. This oxygen uptake rate was similar to microbial metabolism of FBOM measured by Naiman (1983) in streams within the Matamek River watershed and the Moisie River near Quebec, Canada. Total oxygen metabolism measured on FBOM in eastern Quebec ranged from 1.0 to 7.0 mg O_2/g AFDM/d (Naiman 1983). Bott et al. (1985) found respiration rates of fine particulate organic matter for streams in Idaho ranged from 1.44 to 10.57 mg O_2/g AFDM/d and in Oregon streams from 0.36 to 2.50 mg O_2/g AFDM/d. They noted eastern streams in Michigan and Pennsylvania had higher metabolic rates than the western streams studied. The eastern stream community respiration rates were not separated by particle size, but total respiration rates for Michigan streams were between 1.03 and 11.63 mg O_2/g AFDM/d, while those of Pennsylvania were 4.52 to 33.44 mg O_2/g AFDM/d (Bott et al. 1985). Microbial respiration for fine particulate organic matter in Augusta Creek,

Table 9. Comparison of average annual oxygen uptake rates from various streams in the United States.

SITE	PARTICLE SIZE	mg O_2/g ADFM/d	g O_2/ m^2/d	REFERENCE
Augusta Creek, MI	FPOM	3.92		Petersen et al.1989
Augusta Creek, MI	CR			King and Cummins 1989
Smith			0.56	
B Avenue			0.53	
Upper 43rd			1.79	
Nagel			1.88	
Kellogg Forest			0.75	
Tombigbee, MS	CR		0.60-6.00	Naimo et al. 1988
Buttahatchie, MS			0.24-1.04	
Chippewa River, MI	CR			Brown & King 1987
Main Branch			2.13	
Site B			0.10	
Site C			1.05	
Vermillion River, IL	CR		0-177.0	Wiley et al. 1990
Salt Fork				
Middle Fork				
McKenzie River, OR	FBOM	0.36-2.50		Bott et al. 1985
Salmon River, ID	FBOM	0.05-0.22		
White Clay Ck., PA	CR	4.52-33.44		
Augusta Creek, MI	CR	0.85-11.63		
Hubbard Brook, NH	CR		0.28	Hedin 1989
First Choice, Quebec	FPOM	1.0-7.0	161.0	Naiman 1983
Beaver Creek, Quebec			288.7	
Muskrat River, Quebec			58.3	
Matamek River, Quebec			136.3	
Moisie River, Quebec			211.5	
Stillhouse Branch WS 54, NC			2.20	Cuffney and Wallace unpub.
Satellite Branch WS 55, NC			1.90	
Coweeta, NC	Sticks	0.24		Tank 1992
	Rhododendron	2.16		
	Birch	2.88		
Coweeta Creek, NC	FBOM	2.14		This study
Wolf Creek, VA	FBOM	7.58		

CR	Community Respiration
MPOM	Medium-sized particulate organic matter, 0.25 - 1.0 mm
SPOM	Small particulate organic matter, 0.075 - 0.25 mm
UPOM	Ultrafine particulate organic matter 0.0005 - 0.075 mm
FPOM	Fine particulate organic matter less than 1.0 mm

Michigan, averaged between 2.95 and 5.21 mg O_2/g AFDM/d (Petersen et al. 1989).

In another study of Coweeta Creek with four of the same sites (WS27, UBC, LBC, and CC1), Tank (1992) measured mean microbial respiration rates for sticks and two types of leaves. Mean respiration rates on birch leaves averaged 2.88 mg O_2/g AFDM/d for the four sites, while mean respiration rates on rhododendron leaves averaged 2.16 mg O2/g AFDM/d. Average respiration rate for microbes on sticks was 0.24 mg O_2/g AFDM/d (Table 9). A comparison of an average microbial respiration rate on FBOM of 0.98 mg O_2/g AFDM/d for the first four sites in my study of Coweeta Creek to respiration rates measured on sticks and leaves by Tank (1992), suggests that oxygen uptake on FBOM at these sites may be related to the quality of organic matter used. FBOM seems to be more refractory than leaves but more labile than wood.

SEASONAL TRENDS OF OXYGEN UPTAKE RATES

There was a strong positive relationship between stream temperature and oxygen uptake rates in both streams, resulting in a strong seasonal pattern (Fig. 5). Many investigators have noted community respiration rates follow seasonal variation, with low rates in winter and peaks during summer (e.g., Naimo et al. 1988, Bott et al. 1985, Hargrave 1969, Peters et al. 1987). Naimo et al. (1988) found temperature accounted for 46% of the variation in community respiration in the Tombigbee River in Mississippi. Naiman (1983), however, found no significant seasonal trends in metabolism per unit mass on FBOM in his studies of streams in Quebec.

Seasonal patterns in oxygen uptake are the result of temperature differences throughout the year. Many investigators have found community respiration rates are highly correlated with temperature (King and Cummins 1989, Bott et al. 1985, Peters et al. 1987). Peters et al. (1987) found a 5°C difference in temperature always resulted in significant metabolic differences on FBOM from Virginia and North Carolina streams. I found consistently higher oxygen uptake rates for FBOM measured at 20°C than at average ambient temperature except when ambient stream temperature was higher than 20°C (Figs. 6 and 8). Regressions of FBOM oxygen uptake versus stream temperature for Coweeta Creek and Wolf Creek were significant. This suggests the major cause of increased microbial oxygen uptake rates was increased temperature increasing metabolic rates. This was similar to findings by Tank (1992) that microbial respiration rates increased with increasing incubation temperature for leaves and sticks in Coweeta Creek. King and Cummins (1989) also found community respiration measured *in situ* was significantly correlated with temperature. Respiration rates were lowest in first order heterotrophic streams which were heavily shaded and cooler, and higher in second and third order autotrophic streams having more sunlight and higher temperatures.

Oxygen uptake rates for both Coweeta Creek and Wolf Creek followed a similar pattern, with lowest average rates at the headwaters, increasing downstream as the canopy opened and temperature of the stream increased.

CHANGES IN OXYGEN UPTAKE ALONG AN ELEVATIONAL GRADIENT

The streams were sampled on an elevational gradient to determine any variation in respiration rates in the downstream direction. Respiration rates generally increased in a downstream direction, as predicted by Vannote et al. (1980). Eastern montane streams fit the River Continuum Concept (RCC) model very well, as headwaters are usually forested and cooler, with allochthonous inputs that tend to be more refractory and downstream sites that tend to be warmer and more open with more labile autochthonous inputs. This is well illustrated with data from Coweeta Creek, where respiration was 0.027 μL O_2/mg AFDM/h at the headwaters and 0.087 μL O_2/mg AFDM/h at the confluence with the Little Tennessee River (Fig. 13 and 14).

Wolf Creek data do not show such a clear trend (Fig. 13 and 14), though the headwater sites fit the RCC description and have low microbial respiration rates, the downstream sites do not show the same uniform increase in respiration rates found at Coweeta Creek downstream sites. This is probably a result of a major increase in agricultural drainage at Site 3, and subsequent dilution of the agricultural effects by tributaries draining primarily forested areas.

Coweeta Creek oxygen uptake rates fall within the range of oxygen uptake rates at the first three sites of Wolf Creek where elevation is similar.

IMPACT OF NUTRIENTS

As agriculture increased along Wolf Creek, nitrate in the stream also increased (Fig. 15). Nitrate, a major component of fertilizers, is carried into streams by runoff. Myers et al. (1985) indicated nitrogen from excessive fertilization was a major contributor to accelerated eutrophication of bodies of water. However, not all croplands contribute equal amounts of nutrients to surface waters. Site characteristics, slope, climate, proximity to stream, crop type, and tillage affect amounts of nutrients that enter the stream. Croplands close to the stream contribute more nutrients including nitrates than those further away. Closely sown crops such as wheat produce less erosion and loss of nutrients than row crops like corn (Myers et al. 1985).

Nitrate concentration in the stream varied with season and temperature. Nitrate had an inverse relation to temperature, with high nitrate during winter and low nitrate during spring and summer when nitrate was immobilized in biomass (Fig. 17). The negative relationship of temperature to nitrate may negate the effect of nitrate on respiration during the rest of the year. Nitrate was positively correlated with oxygen uptake rates in Wolf Creek. Oxygen uptake was significantly related to nitrate in Wolf Creek. On three sampling dates: December 1991 (GLM, $p < 0.05$); June 1992 (GLM, $p < 0.0023$); and October 1992 (GLM, $p < 0.0064$). Wiley et al. (1990) found nitrate in the Vermilion River was high during periods of seasonal fertilizer application, November through December and May through June. These correspond to dates nitrate was significantly related to oxygen uptake rates in Wolf Creek. In Wolf Creek nitrates most likely affected oxygen uptake by stimulating primary production, which increased the amount of labile FBOM available for metabolic use. During summer, temperature was the major factor in increased oxygen uptake rates.

Nitrate did not contribute to oxygen uptake rates in Coweeta Creek. There was also no relationship of nitrate to agriculture as nitrate was stable and very low throughout the entire length of the stream. Coweeta Creek watershed had so little agriculture it was probably insufficient to contribute enough nitrates or sediments to the stream to affect oxygen uptake rates by microorganisms on FBOM.

Phosphates appeared to have no affect on oxygen uptake rates in either stream. These streams may not be phosphate limited, or may not have high enough phosphates to stimulate production.

RELATIONSHIP OF LAND USE AND OXYGEN UPTAKE RATES

Nonpoint disturbances in land adjacent to the streambed have been

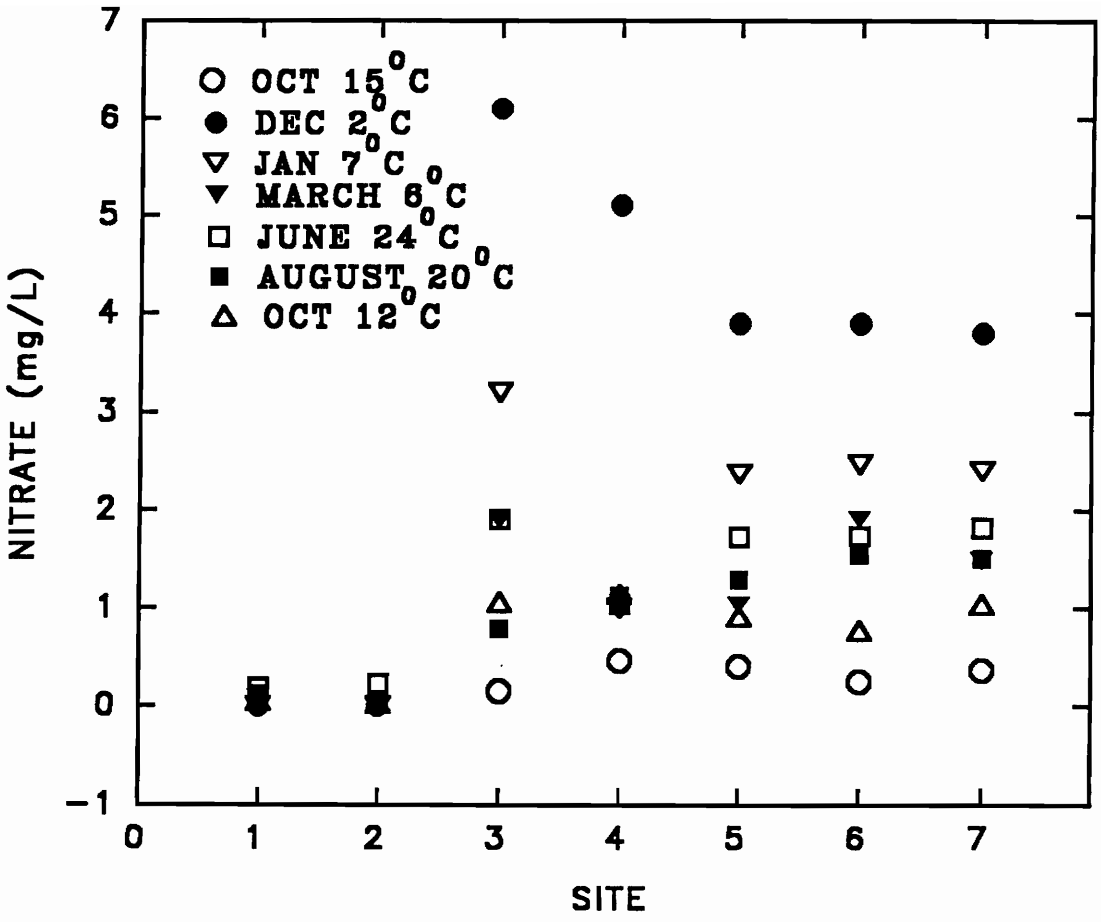

Figure 17. Nitrate in Wolf Creek plotted by date versus site. Stream temperature recorded for each sample date given in legend.

studied as to their impact on water quality. Suspended matter may be the single most important factor influencing water quality (Anderson et al. 1976 as cited by Gosz 1982). Vegetation removal for agricultural purposes causes increased sediment load, increased nutrients, and increased temperature. Turbidity increases with increased sediment load, which decreases available light and may decrease the amount of photosynthesis. These changes have been noted in relation to disturbances from three major land use categories: agriculture (Chesters and Schierow 1985), residential areas (Gosz 1982), and forested lands (Swank and Bolstad 1993, Swank and Crossley 1988, Webster et al. 1990). When there is a wide riparian buffer strip along a stream, the effects of land use disturbances are mitigated, as the vegetation prevents erosion and takes up nutrients including nitrates. When these riparian buffer strips are disturbed, the streams are more subject to the effects of disturbance. Other factors mentioned earlier, including distance from stream, type of crop, and site characteristics, contribute to the overall impact of land use disturbance. Oxygen uptake rates were significantly impacted by the drainage from agricultural and housing areas along Wolf Creek but were not affected by drainage from farmland or housing as land use changed along Coweeta Creek. The level of agriculture and housing along Coweeta Creek is minimal and probably insufficient to affect oxygen uptake rates. Along Wolf Creek the greatest increase in oxygen uptake rates occurred at Site 3, which had the greatest amount agriculture, 27%, of all sites along the stream (Table 2). After Site 3 land use in agriculture decreased to 22.6%, allowing some recovery as Wolf Creek flowed through mainly forested area downstream of Site 3. Most of the land in agriculture was in pasture because the area is montane and not suited to row crops (USDA 1954). The maximum area devoted to hay was 3.8%, and that devoted to crops was 2.8%, both at Site 3. Although streams in many agricultural areas have high oxygen uptake rates from nutrient loading caused by heavy fertilization of croplands, as in the Vermillion River in Illinois (Table 9) where land use is 100% agriculture and is mainly planted in corn and soybeans rather than pasture, Wolf Creek has a relatively small amount of cropland. Nitrate was higher in Wolf Creek than Coweeta Creek and may have increased oxygen uptake rates. However, the oxygen uptake rates are most likely increased mainly by loss of canopy and increased light and temperature in the agricultural areas increasing primary production and labile FBOM, with some contribution by runoff of nutrients from drainage of agricultural areas.

The amount of area along Wolf Creek in residential use, including recreational, residential, and business areas, is greatest at Site 7, but only 3.3 % of the total area. FBOM from Site 7 had lower oxygen uptake rates than Sites 3, 4, and 5, making it unlikely that residential areas in the Wolf Creek watershed have much impact on oxygen uptake rates.

With 94% of the land in forest, Coweeta Creek showed no increase in oxygen uptake rates related to agriculture or housing impacts at any site. The small increase in oxygen uptake rates in the downstream direction for Coweeta Creek may be explained by increased availability of light and increased temperature in the downstream direction as the stream widened. In this study oxygen uptake by microorganisms on FBOM changed with land use changes on Wolf Creek but not on Coweeta Creek. The amount of disturbed land in proportion to undisturbed land is the likely key to differences in the two streams. As mentioned earlier, some factors affecting this threshold include distance of disturbance from the stream, tillage practices, type of crop, and site characteristics.

Increased oxygen uptake rates indicate greater community respiration and higher productivity of the stream. This may be beneficial or detrimental, depending on the amount of productivity. If productivity increases without depleting dissolved oxygen, the increased productivity will support a greater stream biota. FBOM is an important food source for many stream organisms, measurement of oxygen uptake by microorganisms on FBOM is a way of assessing the impact of land use differences on benthic community metabolism.

LITERATURE CITED

Anderson, J.R., E.E. Hardy, J.T. Roack, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey professional paper 964.

Bott, T.L., J.T. Brock, C.S. Dunn, R.J. Naiman, R.W. Ovink, and R.C. Petersen. 1985. Benthic community metabolism in four temperate stream systems: an inter-biome comparison and evaluation of the river continuum concept. Hydrobiologia 123:3-45.

Brown, S.S., and D.K. King. 1987. Community metabolism in natural and agriculturally disturbed riffle sections of the Chippewa River, Isabella County, Michigan. Journal of Freshwater Ecology 4:39-51.

Butts, C. 1973. Geology of the Appalachian Valley in Virginia. Commonwealth of Virginia Department of Conservation and Economic Development, Division of Mineral Resources. Bulletin 52, Charlottesville, Virginia.

Cady, R.C. 1936. Ground-water resources of the Shenandoah Valley, Virginia with analyses by E.W. Lohr. Commonwealth of Virginia, State Commission on Conservation and Development. Charlottesville, Virginia.

Calver, J.L. 1963. Virginia Geologic Map. Calver, J.L., and C.R.B. Hobbs, Jr., (editors). Division of Mineral Resources, Commonwealth of Virginia.

Chesters, G. and L. Schierow. 1985. A primer on nonpoint pollution. Journal of Soil and Water Conservation 40:9-13.

Clark, E.H., II, J.A. Haverkamp, and W. Chapman. 1985. Eroding soils: the off-farm impacts. Conservation Foundation, Washington, D.C.

Cuffney, T.F., J.B. Wallace, and G.J. Lugthart. 1990. Experimental evidence quantifying the role of benthic invertebrates in organic matter dynamics of headwater streams. Freshwater Biology 23:281-299.

Currier, J.B. 1981. Evaluation of nonpoint sources associated with silvicultural activities. Pages 311-334 *in* M.R. Overcash (editor). Environmental impact of nonpoint source pollution. Ann Arbor Science Inc. Ann Arbor, Michigan.

Fauss, L.M. 1992. Linking the effects of land use change with water quality and discharge: an integrated approach. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Flemer, D.A. 1970. Primary productivity of the North Branch of the Raritan River, New Jersey. Hydrobiologia 35:273-293.

Foran, J.A., P. Butler, L.B. Cleckner, and J.W. Bulkley. 1991. Regulating nonpoint source pollution in surface waters: A proposal. Water Resources Bulletin 27:479-484.

Golladay, S.W., J.R. Webster, and E.F. Benfield. 1987. Changes in stream morphology and storm transport of organic matter following watershed disturbance. Journal of the North American Benthological Society, 6:1-11.

Gosz, J.R. 1982. Non-point source pollution of water by recreation: research assessment and research needs. Eisenhower Consortium for Western Environmental Forestry Research Bulletin 13. Fort Collins, Colorado. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Hamlett, J,M., D.A. Miller, R.L. Day, G.W. Peterson, G.M. Baumer, and J. Russo. 1992. Statewide GIS-based ranking of watersheds for agricultural pollution prevention. Journal of Soil and Water Conservation 47:399-404.

Hargrave, B.T. 1969. Similarity of oxygen uptake by benthic communities. Limnology and Oceanography 14:801-805.

Hargrave, B.T. 1972. Aerobic decomposition of sediment and detritus as a function of particle surface area and organic content. Limnology and Oceanography 17:583-596.

Hedin, L.O. unpublished. Aerobic decomposition in sediments: are woodland streams different from other aquatic ecosystems?

Hatcher, R.D., Jr. 1988. Bedrock geology and regional geologic setting of Coweeta Hydrologic Laboratory in the Eastern Blue Ridge. Pages 81-92 *in* W.T. Swank and D.A. Crossley, Jr. (editors). Forest hydrology and ecology at Coweeta. Springer-Verlag, New York.

Hedin, L.O. unpublished. Aerobic decomposition in sediments: are woodland streams different from other aquatic ecosystems?

Hedin, L.O. 1990. Factors controlling sediment community respiration in woodland stream ecosystems. Oikos 57:94-105.

King, D.K., and K.W. Cummins. 1989. Factors affecting autotrophic-heterotrophic relationships of a woodland stream. Journal of Freshwater Ecology 5:219-230.

Myers, C.F., J. Meek, S. Tuller, and A. Weinberg. 1985. Nonpoint sources of water pollution. Journal of Soil and Water Conservation 40:14-18.

Naiman, R.J. 1983. The annual pattern and spatial distribution of aquatic oxygen metabolism in boreal forest watersheds. Ecological Monographs 53:73-94.

Naimo, T.J., J.B. Layzer, and A.C. Miller. 1988. Benthic community metabolism in two northern Mississippi streams. Journal of Freshwater Ecology 4:503-515.

Novotny, V. and G. Chesters. 1981. Handbook of nonpoint pollution. Sources and Management. Van Nostrand Reinhold Company. New York.

Peters, G.T., J.R. Webster, and E.F. Benfield. 1987. Microbial activity associated with seston in headwater streams: effects of nitrogen, phosphorus and temperature. Freshwater Biology 18:405-413.

Petersen, R.C., Jr., K.W. Cummins, and G.M. Ward. 1989. Microbial and animal processing of detritus in a woodland stream. Ecological Monographs 59:21-39.

SAS Institute, Inc. 1991. SAS User's guide: statistics, version 6. 4th edition. SAS Institute, Inc. Cary, North Carolina.

Schultz, A.P., C.B. Stanley, T.M. Gathright, II, E.K. Rader, M.J. Bartholomew, S.E. Lewis, and N.H. Evans geologists. 1986. Geologic Map of Giles County, Virginia [Geological]. Virginia Division of Mineral Resources.

Standard methods for the examination of water and wastewater. 17th ed. 1989. L.S. Clesceri, A.E. Greenberg, and R.R. Trussell (editors). American Public Health Association, American Water Works Association, Water Pollution Control Federation. Baltimore, Maryland.

Swank, W.T., and P.V. Bolstad. In press. Cummulative effects of land use practices on water quality. Hydrochemistry 93.

Swank, W.T., and D.A. Crossley, Jr. 1988. Forest Hydrology and Ecology at Coweeta. Springer-Verlag, New York, New York.

Tank, J.L. 1992. Microbial respiration on decaying leaves and sticks along an elevational gradient of a southern Appalachian stream. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Thillmann, J.H. 1978. Nonpoint source water pollution and land use. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Umbreit, W.W., R.H. Burris, and J.F. Stauffer. 1964. Manometric Techniques. Burgess, Minneapolis, Minnesota.

U.S. Department of Agriculture, Soil Conservation Service in cooperation with the Virginia Agricultural Experiment Station and the Tennessee Valley Authority. 1954. Soil Survey: Bland County, Virginia. Series 1940.

van der Leeden, F., F.L. Troise, and D.K. Todd. 1990. The water encyclopedia. Lewis. Chelsea, Michigan.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Vitousek, P.M., J.R. Gosz, C.C. Grier, J.M. Melillo, W.A. Reiners, and R.L. Todd. 1979. Nitrate losses from disturbed ecosystems. Science 204:469-474.

Wallace, J.B., J.R. Webster, and R.L. Lowe. 1992. High-gradient streams of the Appalachians. Pages 133-191 *in* Hackney, C.T., S.M. Adams, and W.A. Martin, editors. Biodiversity of southeastern United States aquatic communities. John Wiley & Sons, Inc. New York.

Webster, J.R., S.W. Golladay, E.F. Benfield, D.J. D'Angelo, and G.T. Peters. 1990. Effects of forest disturbance on particulate organic matter budgets of small streams. Journal of North American Benthological Society 9:120-140.

Webster, J.R., S.W. Golladay, E.F. Benfield, J.L. Meyer, W.T. Swank, and J.B. Wallace. 1992. Catchment disturbance and stream response: an overview of stream research at Coweeta Hydrologic Laboratory. Pages 231-253 *in* Boon, P.J., P. Calow, and G.E. Petts. River Conservation and Management. Wiley, New York.

White, P.A., J. Kalff, J.B. Rasmussen, and J.M. Gasol. 1991. The effect of temperature and algal biomass on bacterial production and specific growth rate in freshwater and marine habitats. Microbial Ecology 21:99-118.

Wiley, M.J., L.L. Osborne, and R.W. Larimore. 1990. Longitudinal structure of an agricultural prairie river system and its relationship to current stream ecosystem theory. Canadian Journal of Fisheries and Aquatic Sciences 47:373-384.

CURRICULUM VITAE

of

Mary Alice Schaeffer

June 14, 1993

Address:	Department of Biology Virginina Polytechnic Institute and State University, Blacksburg, Virginia 24061 (703) 231-8948
Personal Data:	Date of Birth: 10 October 1945 Place of Birth: Elmhurst, Illinois

Education:

1963-66	Indiana University, Bloomington, Indiana, B.A. in Zoology.
1966-67	Indiana University, School of Dentistry
1971	San Antonio College, San Antonio, Texas
1979	Christopher Newport College, Newport News, Virginia.
1990-present	VPI & SU, Blacksburg, Virginia. M.S. in Biology. Thesis topic: Effects of land use on oxygen uptake by microorganisms in the stream benthos. Major Advisor: Dr. J.R. Webster.

Professional Experience:

1980-85	Engineering Coordinator, Newport News Shipbuilding and Dry Dock Co., 4101 Washington Ave., Newport News, Virginia.
1986-1990	Office Manager for Concord College Library, Concord College, Athens, West Virginia.
1988-90	German Teacher, Concord College, Athens, West Virginia.

1991-present	Teaching Assistant, General Biology, VPI & SU, Blacksburg, Virginia.
1992-present	Research Assistant, VPI & SU, Blacksburg, Virginia.

Memberships in Professional Associations:

Virginia Academy of Science
North American Benthological Society
American Water Resources Association

Manuscripts in Preparation:

M.A. Schaeffer, J.R. Webster, and P.V. Bolstad. Effects of land use on aerobic respiration by benthic microorganisms in two Appalachian streams.

Abstracts and Presentations:

Presentation to the Bland County Board of Supervisors to request funding in support of research on Wolf Creek.

Presentation to the Giles County Board of Supervisors to request funding in support of research on Wolf Creek.

M.A. Schaeffer and J.R. Webster, Correlation of oxygen uptake by microorganisms in stream sediments with land use in the watershed, American Water Resources Association Symposium. March 15, 1993.

M.A. Schaeffer, J.R. Webster, and P.V. Bolstad, Effects of land use on aerobic respiration by benthic microorganisms in two Appalachian streams, presented March 17, 1993.

M.A. Schaeffer, J.R. Webster, and E.F. Benfield, Relation of aerobic respiration on fine benthic organic matter and land use changes along two Appalachian streams, North American Benthological Society, presented May 27, 1993.

J.R. Webster, E.F. Benfield, T.P. Ehrman, J.J. Hutchens, J.L. Meyer, M.A. Schaeffer, J.L. Tank, P.A. Turner, and J.B. Wallace, Organic matter processes along a 1st to 4th order stream gradient in the Southern Appalachian Mountains, presented May 27, 1993.

References:

Dr. J.R. Webster, Dept. of Biology, VPI & SU, Blacksburg, Virginia 24061, (703)-231-8941.

Dr. E.F. Benfield, Department of Biology, VPI & SU, Blacksburg, Virginia 24061, (703)-231-5802.

Dr. A.C. Hendricks, Department of Biology, VPI & SU, Blacksburg, Virginia 24061, (703) 231-5256.