Estimation of Community Metabolism in a Polluted Stream Using the Velz Oxygen Model

Richard G. Hunter and John H. Carroll
Environmental Resources Branch, U.S. Army Corps of Engineers, P.O. Box 61, Tulsa, OK 74121

The Velz method was used to predict dissolved oxygen concentrations in a stream receiving municipal and industrial effluents. Because the method ignores biological processes of reaeration, it was possible to estimate community metabolism using the difference between observed and predicted dissolved oxygen. Net productivity in the unpolluted reach was 34.9 g $O_2/m^2 \bullet$ day and ranged from 1.9 to 37.0 g $O_2/m^2 \bullet$ day in the polluted section. Community respiration showed little variation, with a value of 30.6 g $O_2/m^2 \bullet$ day in the unpolluted reach and values from 26.2 to 50.0 g $O_2/m^2 \bullet$ day in the polluted stretch. The P/R ratio decreased downstream from 1.14 in the unpolluted stretch to 0.06 in the polluted reaches, but these variations were not related to municipal waste input. Instead, the sharp decline in productivity downstream was correlated with increasing conductivity and was ultimately attributed to sodium chloride input.

INTRODUCTION

Although many techniques for measuring community metabolism in aquatic systems have been proposed (1), few have been applied to flowing waters. Methods involving changes in dissolved oxygen (DO) content of the water are difficult to apply to streams because of the influence of atmospheric reaeration.

Important factors in determining the rate of reaeration are the saturation deficit, water temperature, depth, occupied channel volume, velocity, and turnover rate (3). Atmospheric rearation provides the majority of oxygen in most streams; therefore, an incorrect reaeration coeffiicient can lead to large errors in estimates of community metabolism. Elaborate steps are necessary to estimate this coefficient of reaeration in streams. Heggen (2) used 20 well-established methods for estimating this coefficient and found that none yielded DO values consistent with observed DO over the entire stream. The method of determining stream reaeration proposed by Velz (3) appears to be well suited for use in community metabolism studies. The reaeration coefficient is replaced with a mix-interval value unique to a stream type. This mix-interval is used with several other factors in a graphical solution of the DO added per day. Oxygen assets are then combined with oxygen-demanding wastes in a ledger to provide net oxygen at that station. Effects of oxygen-demanding materials may be minimal in relatively unpolluted streams where most productivity studies have been conducted, but such effects have precluded similar sutdies in polluted streams.

Information on productivity in polluted streams would be useful because some states have moved to relax water quality requirements downstream from sewage treatment plants. The 1982 Oklahoma water quality standards now allow dissolved oxygen as low as 3 mg/L in reaches below some sewage treatment plants (4). Streams in this category are termed secondary warm-water fisheries and the biota is assumed to be less desirable than in other fisheries. The impacts of such discharges on the biota may be mixed because the elevated nutrients associated with sewage discharges result in high plankton densities; yet levels of some metals, such as copper, may reduce the biomass of plankton.

The purposes of the present study were to determine community metabolism in a stream receiving municipal and industrial wastes, to ascertain the impacts of such wastes on productivity and respiration rates, and to demonstrate the use of the Velz method in stream metabolism studies.

STUDY AREA

Cow Creek is a fifth-order stream with headwaters in Stephens County, Oklahoma. It flows southerly about 60 km through Jefferson County to its confluence with Beaver Creek (Fig. 1). A small tributary, Claridy Creek, joins Cow Creek near its headwaters. Claridy Creek is an effluent-dominated stream receiving wastes from the city of Duncan and an oil refinery. The towns of Comanche and Addington also discharge treated sewage into Cow Creek downstream of the Claridy Creek confluence. Chronic problems with low DO were identified by the U.S. Public Health Service in 1963 (5) and frequent violations of Oklahoma DO standards occur (6). Both Duncan and Comanche were noted by the Oklahoma State Department of Health (7) as violating discharge limits of 30 mg/L for 5-day biochemical oxygen demand (BOD). At normal flows of 0.1 to 0.3 m/sec near Waurika, Cow Creek is intermittent above Claridy Creek and forms a pool and riffle environment below Claridy Creek. The lower portion of the stream is 7 to 10 m wide and generally less than 1 m deep. A few pools exceed 2 m in depth.

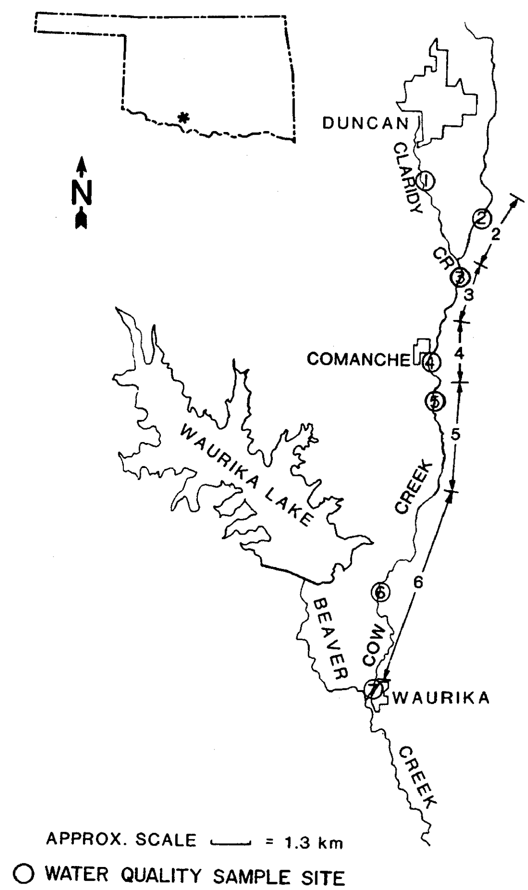

Figure 1. Map of Cow Creek study area showing sample sites.

MATERIALS AND METHODS

While many good models exist for predicting DO levels downstream from pollution sources, the Velz method was chosen for its simplicity and disregard for biological processes of reaeration. Instead, the model emphasizes deoxygenation from biochemical oxygen demand and reaeration through physical processes and upstream input. It was hypothesized that biological processes could be estimated as the difference between observed and modeled DO levels. The Velz method has been found to be particularly accurate for predicting DO in streams, such as Cow Creek, where reaches vary greatly in depth and velocity (2).

Six stations on the Cow Creek system where sampled at 3-hr intervals on July 20 and 21, 1982. A Hydrolab (Austin, TX) Model 4041 water quality instrument, calibrated prior to use in accordance with the manufacturer's instructions, was used to measure DO and temperature at each sample time. Flow and a series of measurements of 20 °C - BOD were determined one time at each station. Biochemical oxygen demand was measured according to the techniques of Standard Methods (8) using a calibrated YSI (Yellow Springs, OH) dissolved oxygen meter and bottle probe. Information obtained from BOD measurements made at 6-hr increments was averaged and deoxygenation rate coefficients calculated using Phelps' (9) law:

$$L_t/L = 10^{-kt}$$

where k = rate of deoxygenation, t = time in days L_t = oxidizability at time t, and L = initial oxidizability of organic material. The above formula was adjusted for temperature by using:

$$\bar{K} = K_{20\,°C} \times 1.047^{(T-20)}$$
$$(T = \text{Celsius temperature})$$

The values obtained were adjusted to the time of passage for each run.

Velocity was measured with a current meter at the 60% depth. Stage - discharge relationships were calculated for each station based on detailed cross-sectional measurements of the channel. A trapezoidal channel was assumed and velocity determined from the Newton-Raphson method of solution of Manning's equation (10):

$$Q = (1.49/n)\ A\ R^{0.667}\ S^{0.5}$$

where Q = flow, n = Manning's roughness coefficient A = cross-sectional area, R = hydraulic radius = area/wetted perimeter, and S = slope of channel The mix-interval, which controls the diffusion of atmospheric oxygen into the water, was calculated from the formula for shallow (less than 1 m) streams developed by Velz (3);

$$\text{mix-interval} = 0.721(\text{depth in feet}) + 2.279.$$

The total oxygen added per day is the amount added per mix-interval times the number of mixes per day. This percentage was high due to the short, 2 to 4-min mix-intervals typical of the stream. The percentage of DO added per mix-interval was calculated by using the standard reaeration curve of Velz (11).

The tabular solution of the Velz method provided a percentage of saturation at each station for the flow and temperature combination on that date. This was adjusted to DO content at the observed temperature for the measurement and plotted as the net DO added by reaeration (after BOD demand was satisfied). Observed DO levels were then plotted with values below the net reaeration line representing respiration and values above the line attributed to productivity. Total daily productivity per station was calculated from the rate of change multiplied by the duration of change. The resulting rate of production or respiration at each station was assumed to be representative of conditions one-half the distances to the next upstream and downstream stations. The distance and mean stream width of these segments was then used to calculate net production on an areal basis.

Conductivity and pH were measured with the Hydrolab water quality instrument, while sodium, calcium, and magnesium were determined by using atomic absorption spectroscopy. Turbidity was measured with a Monitek (Redwood City, CA) nephelometer and total phosphorus was determined according, to the techniques in Standard Methods (8).

RESULTS AND DISCUSSION

Physicochemical conditions

Mean physicochemical conditions for Cow Creek are presented in Table 1. Physicochemical conditions varied in response to waste sources proximity. Cow Creek above its confluence with Claridy Creek (Site 2) represented an unpolluted reach of the stream with no point sources of pollution. The physicochemical data for this reach contrast sharply with those for the polluted downstream reaches below the confluence with Claridy Creek. The mean DO concentration was 8.2 mg/L with a mean saturation of 86%. Total phosphorus concentrations ranged from 0.06 to 0.52 mg/L, with a mean of 0.23 mg/L. Mean conductivity was 554 μmho/cm and mean sodium concentration was 22.4 mg/L.

Cow Creek below the confluence of Claridy Creek, downstream to the town of Comanche (sites 3 and 4), showed the effects of effluents from Duncan and the refinery. Mean DO

TABLE 1. Mean physiochemical conditions in Cow Creek, OK, from April through September[a], 1982

	Station						
Parameter	1	2	3	4	5	6	7
Temperature (°C)	21.4	20.5	21.1	21.2	21.5	21.8	21.3
DO (mg/L)	0.9	8.2	4.5	4.7	6.0	5.2	4.2
DO (% saturation)	10	86	50	51	67	58	47
pH (SU)	7.5	8.0	7.6	7.8	7.9	7.8	7.7
Conduct. (μmho/cm)	1112	554	1123	1345	1519	1603	1607
Tot. Phos. (mg/L)	6.70	0.23	3.10	4.30	3.30	2.50	2.90
Turbidity (NTU)	33	92	52	49	52	45	137

[a]Data for May were excluded because the creek was in flood stage.

dropped to less than 5.0 mg/L in this reach and mean saturation was about 50%. Average total phosphorus concentrations were over 15 times those in the unpolluted reach and mean conductivity exceeded 1100 μmho/cm. Sodium averaged 262.1 mg/L. Mean DO increased to 6.0 mg/L a few kilometers below sewage effluent discharge by Comanche, and then decreased progressively downstream, most likely in response to sewage from Addington. Both total phosphorus and sodium concentration remained high. Conductivity continued to increase in this section, reaching a miximum of 1607 μmho/cm.

Community Metabolism

Values for community metabolism are shown in Table 2. Measurements of oxygen production and respiration are indicative of energy relationships of the community because approximately 1 g of carbohydrate material is synthesized or respired for each gram of oxygen produced or used (12).

Photosynthetic productivity ranged from 1.9 g $O_2/m^2 \bullet$ day in reach 6 to 37.0 g $O_2/m^2 \bullet$ day in reach 4. Photosynthetic productivity declined downstream from each waste source (Fig. 2). The relatively high primary productivity values in the upper three reaches appear to be produced by large populations of benthic producers growing in the stream, primarily *Spirogyra*, *Cladophora*, and *Rhizoclonium.* The sharp depression of productivity in the lower reaches of the creek was caused by a marked reduction of these benthic producers which appears to be unrelated to organic pollution. The initial decline in production from the first (Duncan) pollution input was relatively minor and followed by a recovery within a few kilometers. In spite of the fact that the Duncan input was by far the major perturbation to the system, the Comanche and Addington outfalls appear to cause the largest decrease in productivity. Furthermore, no recovery followed these inputs and the decline in productivity must be attributed to some other factor. The most likely cause was elevated or altered ionic constituents as indicated by increases in conductivity, sodium, calcium, and magnesium. Conductivity increased from 551 in the unpolluted reach to a maximum of 1607 μmho/cm at the lowermost station. The threshold tolerance limit of the producers for conductivity appears to be about 1300 μmho/cm. The increase in sodium was nearly tenfold between the zone of high productivity and that of low production.

Community respiration showed less longitudinal variation than primary productivity, but also exhibited a large decrease when conductivity values reached approximately 1300 μmho/cm. Respiration varied from 26.2 g $O_2/m^2 \bullet$ day in reach 5 to 50.0 g $O_2/m^2 \bullet$ day in reach 4. Only in reach 2 did productivity exceed respiration, and apparently the input of allochthonous material from the point sources

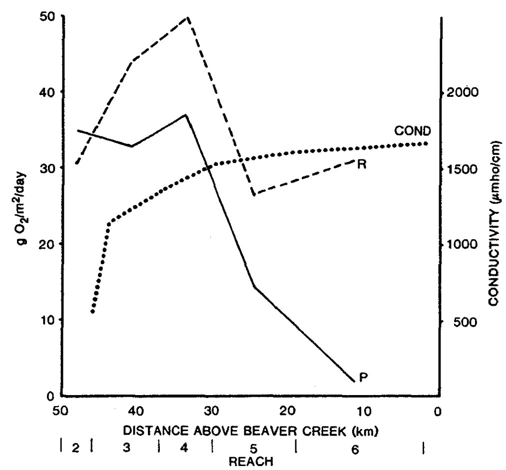

Figure 2. Productivity (P), respiration (R), and conductivity at Cow Creek, Oklahoma.

TABLE 2. Community metabolism of Cow Creek, OK.

Reach	Oxygen Productivity (g m^{-2} day^{-1})	Oxygen Respiration (g m^{-2} day^{-1})	P/R
2	34.9	30.6	1.14
3	32.9	44.2	0.74
4	14.4	50.0	0.74
5	37.0	26.2	0.55
6	1.9	31.0	0.06

influenced respiration to a greater extent than production. An alternative explanation would be that sediment oxygen demand was not negligible as had been assumed. Respiration was highest in reaches which had large populations of benthic producers. Respiration exhibited a pattern similar to production, declining precipitously in reach 5. This was attributed to the previously discussed changes in ionic composition.

The Production to Respiration (P/R) ratio has been advanced as a functional index of the relative maturity of the system (13). As P/R approaches unity, the system reaches a steady state, with longitudinal stream succession tending toward this steady state condition downstream (14). However, the P/R ratios shown in Table 2 decreased downstream, with the smallest in the lowermost reach. This indicates these reaches remained in a developmental stage. This is most likely caused by movement of the critical threshold point for conductivity in response to changing flows. At low flow this point would move upstream, while at high flows it would be located downstream or be nonexistent. This zone of flux would prevent establishment of producers tolerant of either extreme and would be manifested in both decreased production and respiration.

Decreased productivity might have been influenced by sodium chloride. Conductivity values of 1600 μmho/cm correspond approximately to sodium chloride concentrations of 800 mg/L. An inhibition of photosynthesis in algae exposed to elevated salinity has been demonstrated (15,16). Sodium chloride concentrations of 1000 mg/L partially inhibited photosynthesis in some algae and completely inhibited it in others in a study conducted by Dickman and Gochnauer (17). The same study found that certain filamentous and budding bacteria were stimulated by the 1000 mg/L sodium chloride. Such a mechanism would explain the less severe drop in respiration as compared to production in those portions of Cow Creek with elevated sodium chloride.

Unpolluted streams in Oklahoma had productivity rates ranging from 1.03 to 21.4 g $O_2/m^2 \bullet$ day (14,18,19,20). Baumgardner (21) studied the oxygen balance in Skeleton Creek, near Enid, which receives domestic and oil refinery effluents. He reported primary productivity rates ranging from 2.8 to 29.4 g $O_2/m^2 \bullet$ day and respiration from 11.5 to 57.1 g $O_2/m^2 \bullet$ day. The use of the Velz Oxygen Model appears to be an acceptable method for estimating community metabolism in streams when compared with estimates in other studies that used the methods described by Odum (22) or Odum and Hoskins (12).

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