SECTION 5

DISCUSSION

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Algal biomass measurements and areal productivity estimates obtained from diel dissolved oxygen data support characterization of Heaths Creek and Little Drywood Creek as mesotrophic waters. Elevated productivity and algal biomass values indicate that Cedar Creek experienced eutrophy during summer low-flow conditions of 2006. Runoff dominated streamflows destabilized stream metabolism to the detriment of DO concentrations at most sites. However, gradual increases in streamflow observed at Cedar Creek increased DO concentrations. Existing DO source and sinks within studied reaches likely prevent attainment of the 5.0 mg/L instantaneous criterion at steady-state streamflows less than approximately 2 cfs in summer conditions. Mean hydraulic depth and stream temperatures are the best statistical and significant predictors of daily minimum DO concentrations in the 2006 dataset. Only one landscape variable (watershed area) was significantly correlated ($r=-0.78$, $p=0.008$) with a DO variable (minimum percent saturation). Osage Plains data mined from state databases identify DO concentrations below 5.0 mg/L at 184 sites not obviously impacted by point-source discharges.

5.1 Prevalence of Dissolved Oxygen Below Water Quality Criteria in the Osage Plains

Excluding data collected as part of the AERDOR effort, a total of 7,135 DO concentration measurements have been collected within the Osage Plains since 1962. Approximately 40% (2,908 out of 7,135) of all Osage Plains DO records are below 5 mg/L (Table 11) while approximately 42 % (2,383 out of 5,715) of records collected from sites likely unaffected by point sources were below 5 mg/L. Existing Osage Plains datasets support that DO concentrations below 5 mg/L are a relatively widespread occurrence in lotic waters from late spring through early fall.

TABLE 12. Selected Characteristics of the Existing Osage Plains Dissolved Oxygen Dataset.

Data Description	Discrete Grab	Continuous Instrumentation
Total Monitoring Sites	271	5
*Unimpacted Sites	180	4
Total D.O .Records	5,562	1,573
*Unimpacted D.O. Records	4,433	1,282
*Unimpacted Records <5 mg/L	1,277	1,106

*Monitoring locations or data not obviously impacted by a point source as determined through a desktop GIS analysis.

The AERDOR 2006 study period added ~17,400 dissolved oxygen measurements at seven sites to the Osage Plains dataset, predominately within biocriteria reaches of Little Drywood Creek and during low-flow critical conditions. Dissolved oxygen data below 5 mg/L comprised 76% (LDC3) to 100% (LDC5, LDC6, LDC7) of data collected in 2006.

Identification of sites likely unaffected by known point sources is described below. Water quality databases maintained by the Missouri Department of Natural Resources were mined in June 2007 for dissolved oxygen data collected within the Osage Plains ecoregion (Figure 21). Monitoring sites were retained and plotted in Figure 21 if impacts by known point-source discharges were not obvious or readily distinguishable by desktop GIS analysis. Characteristics of retained sites include but are not limited to:

- Located greater than six miles downstream of a known continuous point source discharge that likely contains readily oxidizable (BOD) materials;
- Located upstream of known point source discharge; or
- Located within six miles of a known point source but source is either runoff dependent or not likely to contain oxidizable (BOD) materials.

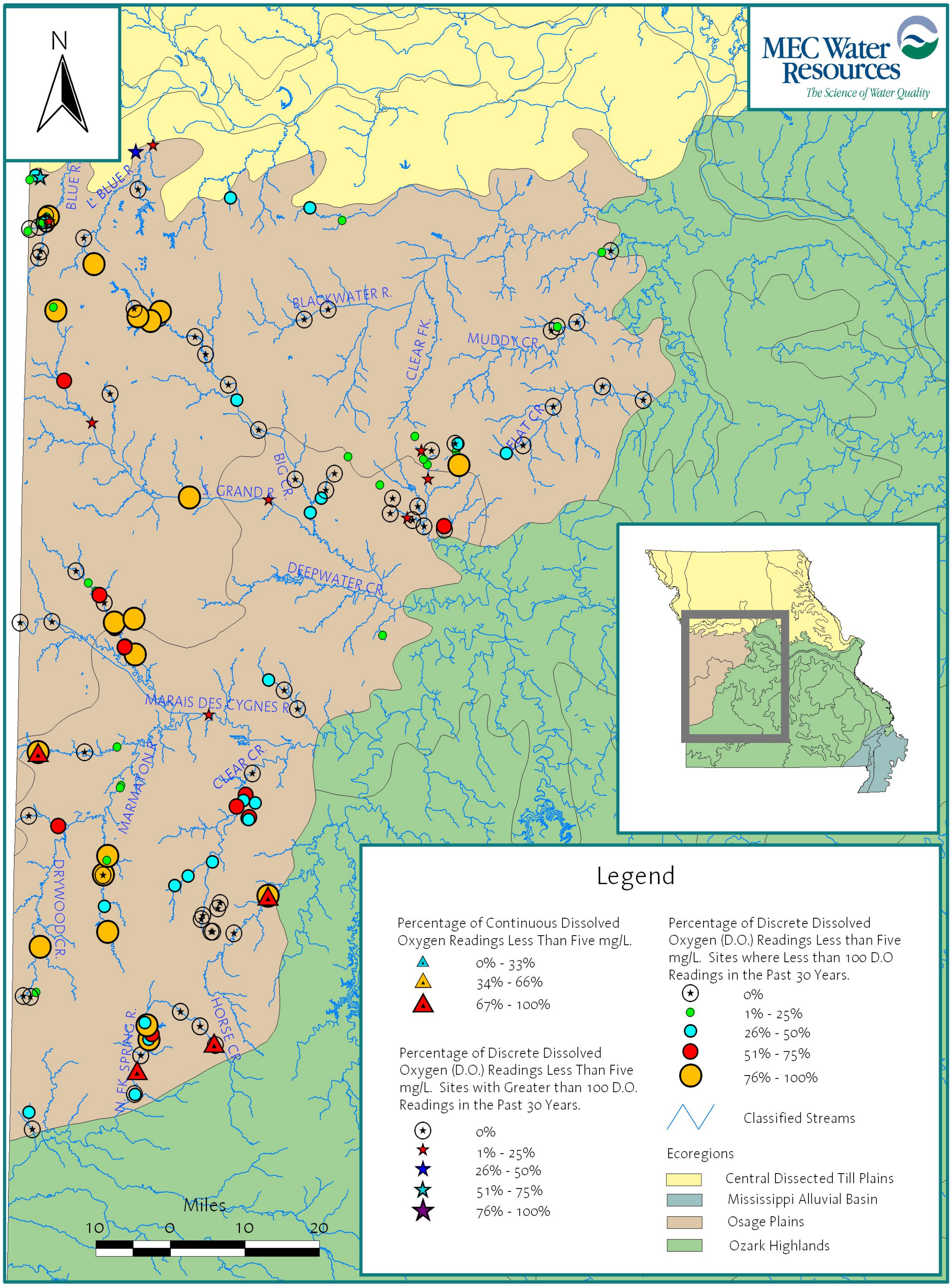

FIGURE 26. Osage Plains Discrete and Continuous Dissolved Oxygen Monitoring Sites Not Significantly Impaced by Continuous Point Source Discharges. Data Queried in 2007 from Databases Maintained by the Missouri Department of Natural Resources.

5.2 Trophic State

Summer chlorophyll-a and phosphorus medians place Cedar Creek site CC1 within the 'eutrophic' category (Table 12) according to EPA Guidance (USEPA 2000a). Nitrogen and algae values at LDC2 and HC2 yield 'mesotrophic' classifications (Table 12). Note that calculated areal production rates for AERDOR sites may be considered 'moderate' by some classifications (see Section 4.5.1).

TABLE 13. Trophic State According to Classification Scheme Included Within National Nutrient Criteria Guidance (US EPA 2000a). Based on n=9 samples between 07/13/2006- 09/14/2006.

Variable	Trophic State (see USEPA 2000a, Page 27)		
	Site LDC2	Site HC2	Site CC1
Mean Benthic Chlorophyll-a	Mesotrophic	Mesotrophic	Eutrophic
Suspended Chlorophyll-a	Mesotrophic	Mesotrophic	Eutrophic
Total Nitrogen	Mesotrophic	Mesotrophic	Mesotrophic
Total Phosphorus	Eutrophic	Eutrophic	Eutrophic

Median total nitrogen to total phosphorus ratios were 14, 8, and 9 for sites LDC2,HC2, and CC1 respectively. Calibrated algal growth rates (see Section 5.4, Appendix I) are generally more limited by incident light intensity than by nutrients or supply (N:P) ratios.

5.3 Streamflow Influences

Rapidly increasing streamflows during runoff events at LDC2 (0.65 ft rise) and HC2 (5.5 ft. rise) disrupted community metabolism and generally yielded lower dissolved oxygen concentrations (Figure 27). A less pronounced increase in flow and level at CC1 (0.2 ft rise) increased dissolved oxygen concentrations (Figure 27). Conditions during runoff spates often reduce photosynthesis through algal scouring, flushing, and light limitation. Reduced SOD effect from increased depths can offset respiration increases from BOD and detritus loading during runoff events. Reaeration during increased flow conditions may increase or decrease depending on reach specific hydrogeometry. Stream metabolism did not return or recover to stable behavior at LDC2 or HC2 during the study period following late August runoff events. Further investigation is needed to sufficiently quantify DO mechanics during runoff events.

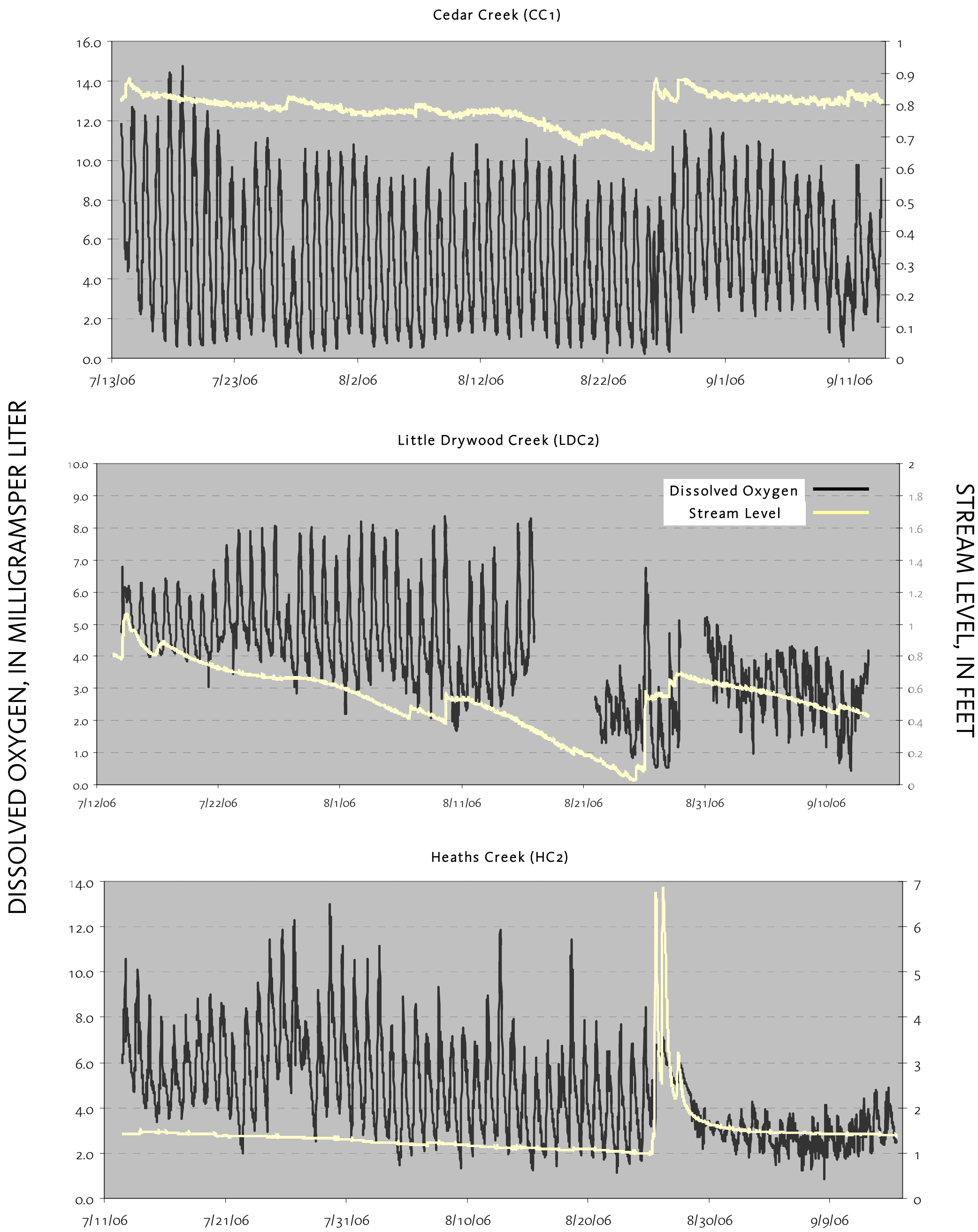

FIGURE 27. Continuous Level and Dissolved Oxygen Concentration Timeseries in AERDOR Reference Streams for the Period of 7/12/2006 to 9/14/2006.

5.4. Statistical Dissolved Oxygen Correlations

5.4.1 Stream Variables

Potential relationships between DO and the various measures of water quality and hydrogeometry collected during the study were evaluated with correlation techniques to identify equations to predict DO concentrations within AERDOR streams (Table 13). Of the 29 variables (10 water chemistry variables) measured during Summer 2006, few significant ($p < 0.05$) or statistically powerful relationships were identified.

TABLE 14. Evaluated Cause and Response Regression Variables from the 2006 AERDOR Continuous Record Dataset.

Response Variables	Causal Variables	
Mean Daily D.O. Concentration	Mean Daily Water Temp.	Mean Daily Depth
Minimum Daily D.O. Concentration	Maximum Daily Water Temp.	Mean Daily Air Temp.
Daily D.O. Concentration Range	Total Daily Light Intensity	Maximum Daily Air Temp.
Mean D.O. Deficit	Mean Daily Photoperiod Intensity	Mean Daily Air Pressure
Maximum D.O. Deficit	Mean Daily Streamflow	Mean Daily Conductivity
Mean Percent Saturation	Watershed Area	Mean Chemistry Data
Minimum Percent Saturation	Stream Metabolism Parameters	

Simple correlations between minimum daily DO and other measured parameters were investigated using the Pearson product moment correlation coefficient (r). In order to assess the relationships of DO with hydrology, water chemistry, and other environmental conditions only those sites (LDC2, HC2, and CC1) on each stream at which hydrogeometry, water chemistry, and continuous data were collected were included in this analysis.

5.4.1.1 Minimum Dissolved Oxygen Correlations with Hydrologic Variables

Correlations between observed daily minimum DO concentrations and measured hydrologic variables were investigated to assess the impacts of physical stream characteristics. Significant (two-sided $p<0.05$) correlation coefficients of 0.52, 0.33, and 0.56 exist between mean hydraulic depth and daily minimum D.O. at sites LDC2, HC2, and CC1, respectively (see also Mullholand *et al.* 2005). In addition, significant correlations between minimum DO and daily average flow exist at sites LDC2 ($r=0.53$) and CC1 ($r=0.63$). No individual hydrologic variable explained greater than 50% of the variation ($r^2>0.5$) in observed daily minimum dissolved oxygen at any site.

5.4.1.2 Minimum Dissolved Oxygen Correlations with Light Measurements

Relationships between daily minimum D.O. concentrations and light intensity were significant in some cases, but not particularly powerful. In general, 24-hour mean intensity was the most correlated light variable with minimum D.O. values. Mean light intensity correlations were 0.58, 0.35, and -0.34 at sites LDC2, HC2, and CC1, respectively. Negative correlation between incident light intensity and minimum dissolved oxygen concentration at CC1 could indicate photoinhibition of primary production in Cedar Creek reference reaches.

5.4.1.3 Minimum Dissolved Oxygen Correlations with Water Chemistry and Stream Metabolism Variables

Correlations between daily minimum D.O. concentrations and discrete water chemistry variables were insignificant at most sites. However, nutrients (total nitrogen and phosphorus) were significant and inversely correlated at site CC1 (TN 'r'=-0.74, TP 'r'=-0.68).

Daily maximum temperature was significantly correlated with minimum D.O. at all sites. At sites LDC2 (r= 0.59) and HC2 (r= 0.43), the relationship was positive while at site CC1 negative (r=-0.46). Light intensity relationships displayed a similar pattern in that DO at sites HC2 and LDC2 increased with light intensity but decreased at site CC1. Light intensity is a measure of radiant power. Stream reaches receiving higher incident light intensity would be expected to yield higher temperatures and higher base photosynthetic rates. Deployment period temperature and photosynthetic rates at CC1 were higher than LDC2 or HC2. There are several mechanisms that could explain light, temperature, and dissolved oxygen relationships at CC1. In keeping with Ockham's razor, best-fit reaeration rates (at 20°C) increased during the study period while light intensity decreased. Higher observed DO concentrations during periods of lower light intensity and lower temperatures may simply be a function of coincidental reaeration time trends (Figure 28).

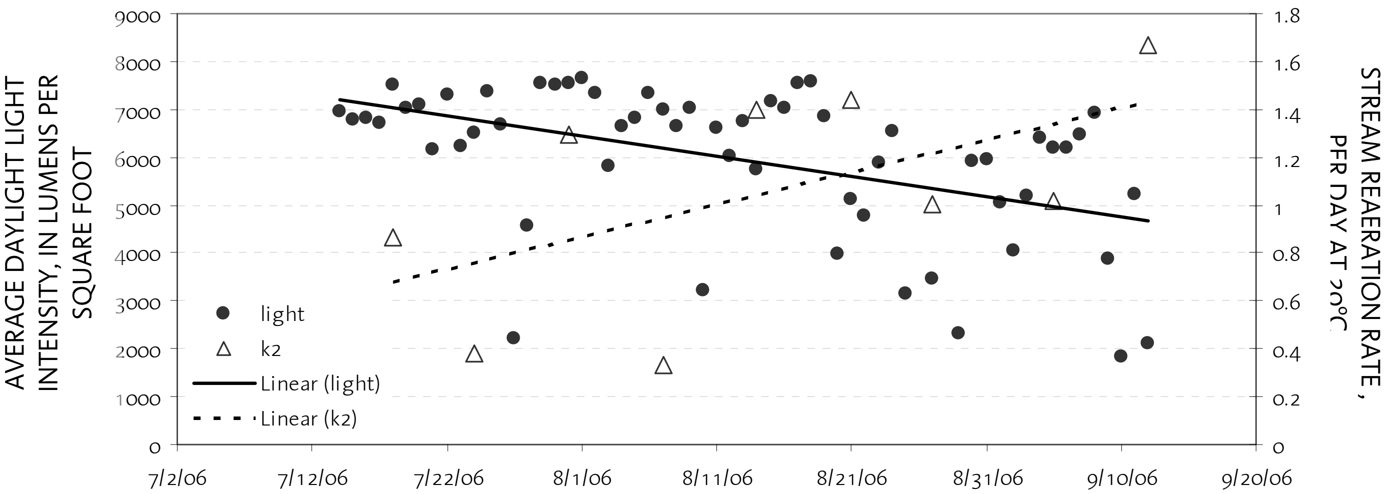

FIGURE 28. Timeseries of Best-Fit Reaeration Rates (at 20°C) and Average Daylight Light Intensity at Cedar Creek Site CC1 During the 2006 Study Period.

Deployment period mean dissolved oxygen concentrations for sites LDC2 (4.0 mg/L), HC2 (4.6 mg/L), and CC1 (5.2 mg/L) correspond to observed median production rates of 1.6 gO m^{-2} day^{-1}, 2.1 gO m^{-2} day^{-1}, and 4.1 gO m^{-2} day^{-1}, respectively (r=0.93, p=0.13). Deployment period respiration rates of 3.1 gO m^{-2} day^{-1}, 3.5 gO m^{-2} day^{-1}, and 5.9 gO m^{-2} day^{-1} at sites LDC2, HC2, and CC1 yield deployment period minimum DO concentrations of 2.5 mg/L, 2.6 mg/L, and 1.25 mg/L respectively (r=-0.98, p=0.13). Other researchers have noted positive relationships between daily average DO and photosynthesis and inverse relationships between daily minimum DO and respiration (Mullholand et al 2005).

5.4.2. Landscape Variables

Landuse classifications and watershed area were evaluated against summer deployment period mean and minimum D.O. statistics at all monitoring sites (n=10). Four Pearson 'r' correlation statistics were significantly different than zero (two-sided) at the $p \leq 0.1$ level but only one at the $p \leq 0.05$ level:

- Percent Row-Crop vs. Daily Minimum Percent Saturation (r=0.55, p=0.096)
- Percent Grassland vs. Daily Minimum Percent Saturation (r=-0.59, p=0.071)
- Watershed Area vs. Daily Minimum Concentration (r=-0.57, p=0.085)
- Watershed Area vs. Daily Minimum Percent Saturation (r=-0.78, p=0.008)

The negative correlation between daily minimum percent saturation and watershed area is the lone landscape relationship that yields an r^2 value that explains greater than 50% of the variance in an observed D.O. response variable and is highly significant. Low D.O. data collected at site LDC5 exerts relatively high leverage on the watershed area vs. Minimum Percent Saturation relationship. Landscape and D.O. response relationships will be reevaluated following the 2007 data collection season.

5.5 Dissolved Oxygen Sources and Sinks

Least-squares optimization was used to calibrate a simple mechanistic desktop model (Figure 27) of D.O. production and consumption at sites LDC2, CC1, and HC2. Observed photosynthesis and respiration rates obtained from stream metabolism calculations (See Section 4.5) were used as calibration targets. Model predictions of photosynthesis and respiration are derived from observed chemistry and chlorophyll-a data. Kinetic and mass-transfer processes in the model were forced within the boundary of reasonable literature values.

Sinks in the model include CBOD, NBOD, Sediment Oxygen Demand (SOD), and respiration from benthic and sestonic algae. Sources include photosynthesis from benthic and sestonic algae. As reaeration acts on DO deficits, reaeration is a 'sink' during periods of supersaturation and a 'source' when the water column is undersaturated.

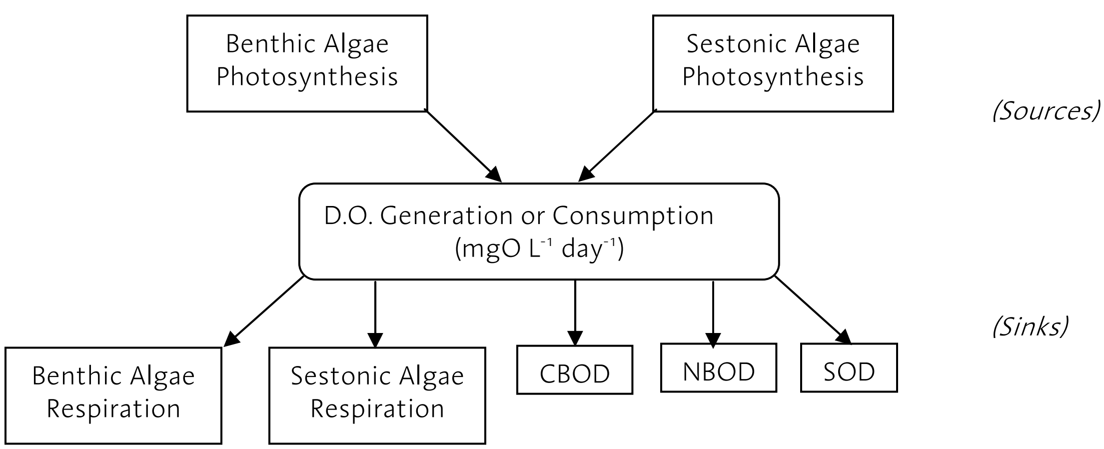

FIGURE 29. Conceptual Model of Dissolved Oxygen Sources and Sinks in AERDOR Study Streams.

Model calibration performance plots and source/sink partitioning are discussed by site. Model rates are included in Appendix I. Prediction error may generally be attributed to either data uncertainty (insufficient quantity or analyte selection) or inadequate representation of stream processes by the model. In general, similar model fits were obtained through minor to moderate adjustments in rate parameters. Based on non-uniqueness of model fits, sources and sinks, expressed as mgO L^{-1} day^{-1}, should be considered accurate to $\pm 30\%$ of the estimated value.

5.5.1. Little Drywood Creek (LDC2)

A sediment oxygen demand level of 1.8 mgO m^{-2} day^{-1} at 20°C covering approximately 90% of the wetted perimeter accounts for approximately 86% of observed community respiration at LDC2 (Figure 28a,b). Sestonic algae dominated production during evaluated days. Calculated respiration rates at LDC2 were not significantly different that HC2 (p=0.15) but were significantly lower than CC1 (p=0.000).

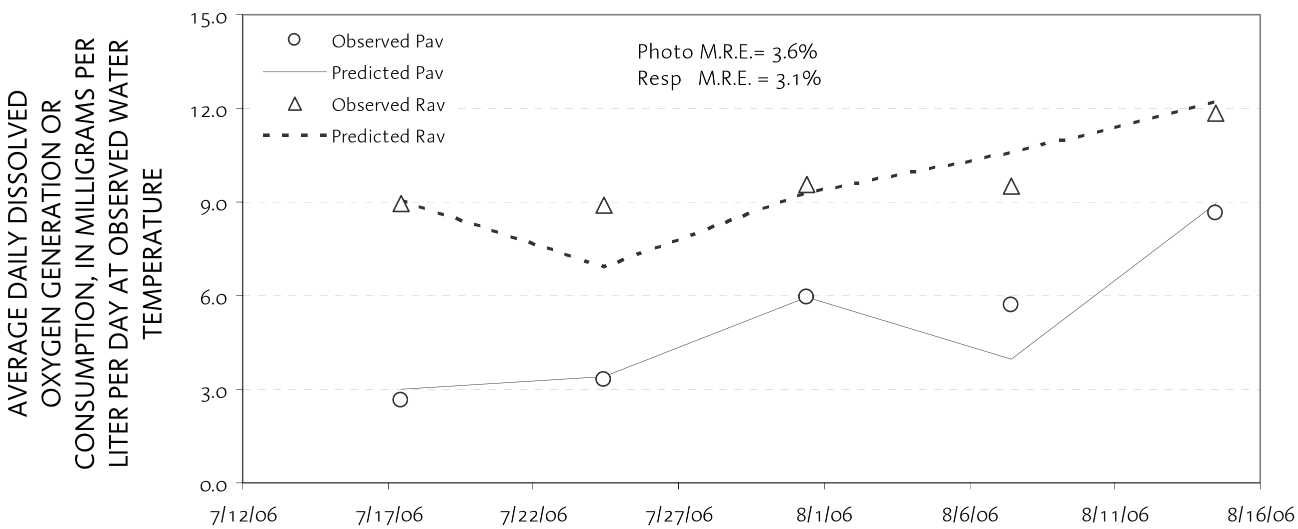

FIGURE 30a. Predicted vs. Observed Average Daily Photosynthesis and Respiration for Selected Days at Little Drywood Creek Site LDC2.

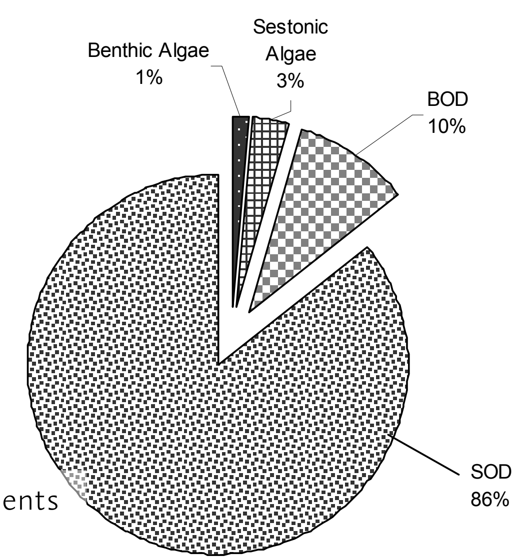

FIGURE 30b. Calibrated Respiration Components for Little Drywood Creek Site LDC2.

5.5.2. Cedar Creek (CC1)

Respiration from benthic algae (20% bottom coverage) consumed the majority (64%, median =12.5 mgO L^{-1} day^{-1}) of D.O. at Site CC1(Figure 29a,b). Calibrated background SOD values (0.5 mgO m^{-2} day^{-1} at 20°C) appear to be the least significant D.O. sink during the 2006 study period at CC1. Cedar Creek respiration rates were significantly higher (p=0.000) than LDC2 and HC2.

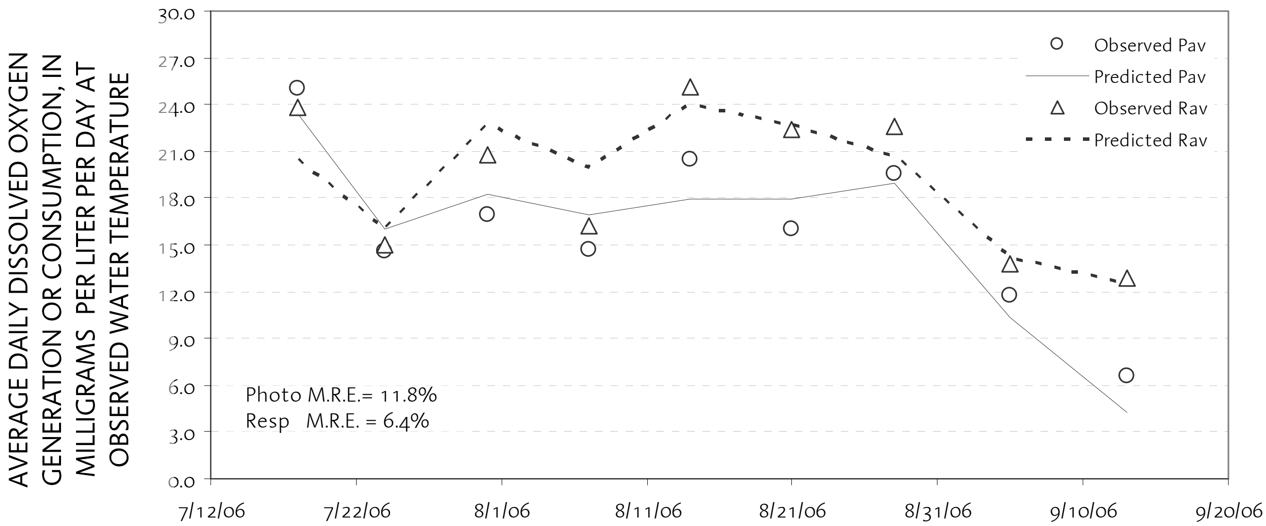

FIGURE 31a. Predicted vs. Observed Average Daily Photosynthesis and Respiration for Selected Days at Cedar Creek Site CC1.

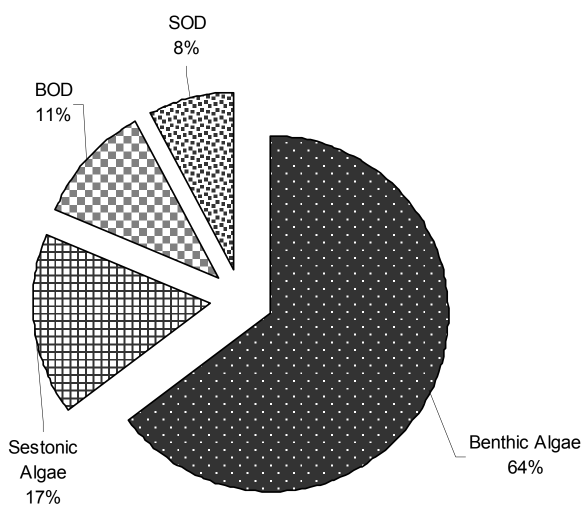

FIGURE 31b. Calibrated Respiration Components for Cedar Creek Site CC1.

5.5.3. Heaths Creek (HC2)

Total BOD comprised the majority (Figure 30a,b) of respiration at HC2 during the 2006 field season. Total BOD was low at all AERDOR sites, with deployment period means of 12 mg/L, 9 mg/L, and 8 mg/L at sites CC1, HC2, and LDC2, respectively (see Section 4.3.9). Total BOD levels between HC2 and CC1 are statistically similar (p=0.323) as are levels between HC2 and LDC2 (p=0.482).

Non-linear increases in respiration and total BOD through time at site HC2 from 7/18/2006 through 8/22/2006 exerted sufficient influence within the model for total

BOD to dominate (62%) respiration components. Sources of labile BOD loads to monitored reaches of Heaths Creek during low-flow periods have not been identified. As with other sites, a substantial reduction (~40%) in respiration would be necessary at HC2 to achieve the 5.0 mg/L DO criterion during low-flow or stagnant conditions during summer temperatures.

Photosynthesis model accuracy at HC2 is reduced by a sestonic chlorophyll-a sample collected in August 8, 2006. As a blind duplicate of this sample is within acceptable error range (20%), this sample may not be representative of the diel mean value for August 8th, 2006.

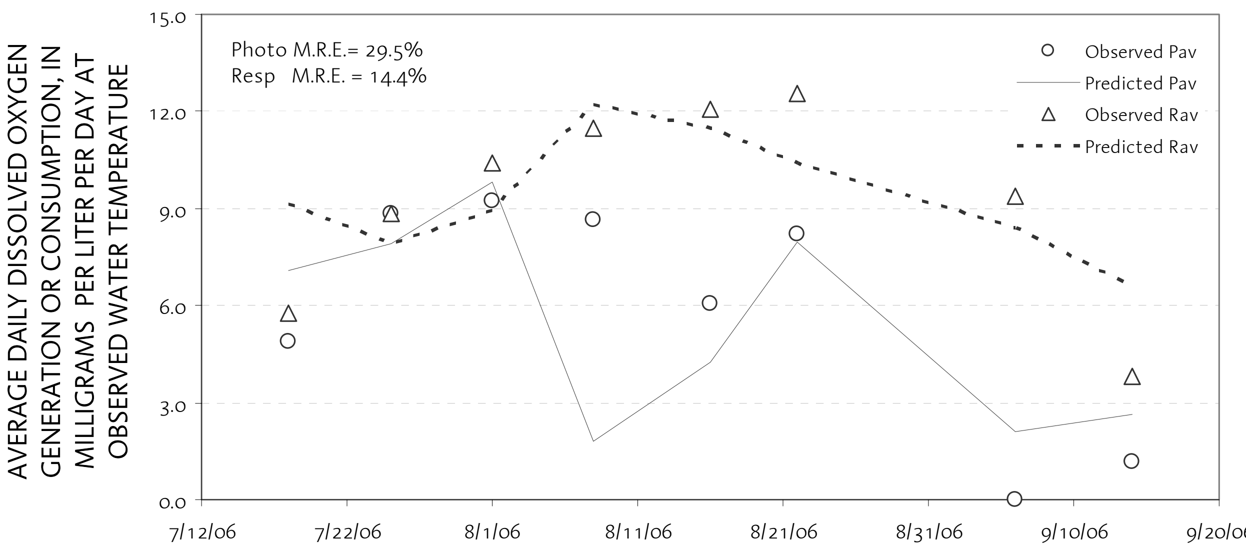

FIGURE 32a. Predicted vs. Observed Average Daily Photosynthesis and Respiration for Selected Days at Heaths Creek Site HC2.

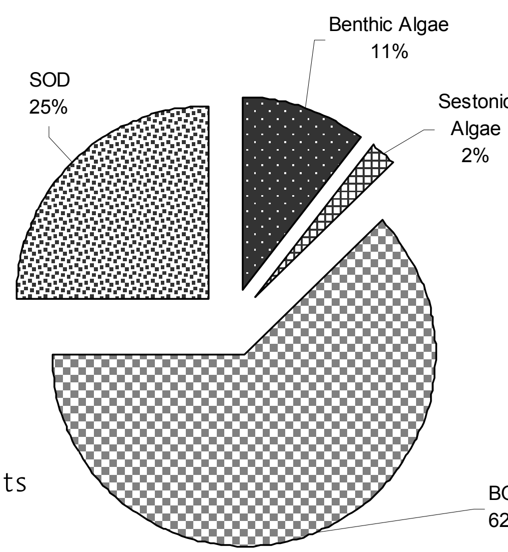

FIGURE 32b. Calibrated Respiration Components for Heaths Creek Site HC2.

5.5.4 Conditions of Attainment

Steady-state streamflows needed to attain a 5.0 mg/L instantaneous minimum D.O criterion may be estimated using calibrated stream-specific models presented in previous sections. For example, assuming average climatic, constituent loading, SOD, and fixed plant conditions, a steady streamflow value of approximately 2 cfs is likely to yield a diel minimum of 5.0 mg/L (±30%) for Little Drywood Creek Site LDC2 between July and mid-September (Figure 31). Similar estimates for Heaths Creek (HC2) and Cedar Creek (CC1) are 3 cfs and >10 cfs, respectively. High levels of benthic respiration will likely prevent Cedar Creek site CC1 from attaining the statewide criterion during temperatures and steady-state flows expected to occur between July through September. Mechanistic prediction of D.O. mimima based on variable streamflows generally compare within 5% to 35% of observed D.O. data (for a given streamflow). As 2006 data were predominantly collected during stagnant conditions and without knowledge of yearly variation in algal, nutrient, or BOD loading, it is possible that a daily minimum of 5.0 mg/L could be attained at flows less than predicted above.

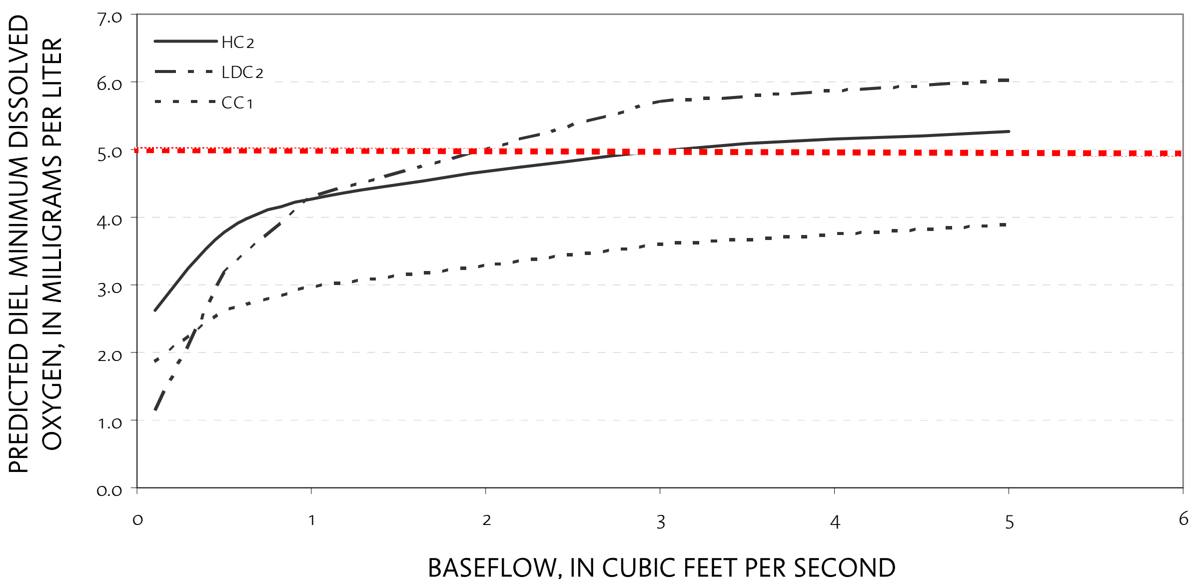

FIGURE 33. Predicted Influence of Increasing Baseflow on Diel Minimum Dissolved Oxygen Concentrations for Selected AERDOR Reference Sites. Based on Summer Mean Temperature, Light, Loading, and Fixed Plant Conditions.

Uncertainty in attainment flow estimates, particularly at flows less than 0.2 cfs, are attributed to the erratic behavior of observed reaeration (main assimilation factor) at low or stagnant conditions. Hydraulic-based equations of Owens *et al.* (1964) and Melching and Flores (1999) performed reasonably well at flows greater than ~0.2 cfs. As local wind patters are sporadic in nature, a combination of hydraulic and *wind driven* reaeration mechanisms may explain low-flow reaeration errata (Chu and Jirhka 2003). Uncertainty not withstanding, model results do elucidate the need for measurable and substantive baseflow to attain existing water quality criteria for dissolved oxygen in sampled reference streams.

Additional data and a more complex modeling framework may be needed to reduce uncertainty and increase accuracy of attainment streamflow values. Data collected during the 2007 study period will be evaluated to refine attainment streamflow estimates.

5.5.5 Recommendations

Model-driven monitoring efforts are needed to further refine quantitative source and sink estimates. Sampling strategies to improved predictive models could include:

- SOD measurement through in-situ or sediment column respirometry;
- Improved representation of hydrogeometry and velocity (time of travel);
- Reaeration measurement using gas tracers and collection of local wind data
- Event sampling to define and evaluate constituent loading regimes during runoff conditions
- Increase sampling frequency and sites to identify diel constituent cycles; and
- Expand sampling suite to include analytes that are more relevant to stream metabolic processes, e.g. soluble reactive phosphorus.

Collection of model-driven data will allow decision-makers to better quantify the highest dissolved oxygen concentrations attainable within reference reaches.