Chlorophyll *a* and Inorganic Suspended Solids in Backwaters of the Upper Mississippi River System: Backwater Lake Effects and Their Associations With Selected Environmental Predictors

By James T. Rogala and Brian R. Gray

The Long Term Resource Monitoring Program (LTRMP) uses a stratified random sampling design to obtain water quality statistics within selected study reaches of the Upper Mississippi River System (UMRS). LTRMP sampling strata are based on aquatic area types generally found in large rivers (e.g., main channel, side channel, backwater, and impounded areas). For hydrologically well-mixed strata (i.e., main channel), variance associated with spatial scales smaller than the strata scale is a relatively minor issue for many water quality parameters. However, analysis of LTRMP water quality data has shown that within-strata variability at the strata scale is high in off-channel areas (i.e., backwaters). A portion of that variability may be associated with differences among individual backwater lakes (i.e., small and large backwater regions separated by channels) that cumulatively make up the backwater stratum. The objective of the statistical modeling presented here is to determine if differences among backwater lakes account for a large portion of the variance observed in the backwater stratum for selected parameters. If variance associated with backwater lakes is high, then inclusion of backwater lake effects within statistical models is warranted. Further, lakes themselves may represent natural experimental units where associations of interest to management may be estimated.

Patterns of chlorophyll *a* and inorganic suspended solids concentrations are an integral part of our understanding of the water quality of the UMRS. For this reason, predictive models for these parameters are the initial focus of a multiyear effort to model the LTRMP water quality data. However, the high variability in both of these parameters within the backwater stratum suggests that we should consider backwater lake effects in these models. This is justified in that differences in means, variance, and relations with predictors all potentially vary among backwater lakes. This is significant because managers typically plan projects at the backwater lake scale (e.g., alter flows within a selected lake) more frequently than at the across-strata scale (e.g., water level drawdown). Correspondingly, models that incorporate backwater lake effects on water quality parameters should assist backwater restoration planning through an enhanced understanding of how the Mississippi River functions.

We began investigations into substrata level effects by determining whether a substantial portion of the observed variance was explainable by differences among backwater lakes. We did this using hierarchical linear mixed statistical models. These models allow variance terms associated with different spatial scales to be estimated using a single model. The Akaike Information Criteria (AIC) statistic (Akaike 1973), a measure of the fit of a model to a dataset, was used to compare models with backwater lake effects to models without. Models with smaller AIC values are considered better estimating models. All models allowed for year effects. Summer data from sampling years 1993–2002 were modeled for each of Pools 4, 8, and 13.

Chlorophyll *a* was measured fluorometrically. Inorganic suspended solids concentration was calculated as the difference between measured total suspended solids and organic suspended solids. Backwater lakes were identified in a geographical information system (GIS) by using channel types to determine isolated regions within the backwater stratum. These lakes include very small and highly connected (e.g., submerged islands) portions of the backwater stratum. Selected morphometric characteristics used as predictors of the backwater effects were measured in a GIS.

Models that included backwater lake effects were observed to fit the data substantially better for both chlorophyll *a* and inorganic suspended solids (compare models C1 with C2 and I1 with I2, respectively, in Table). The variance estimates from models C2 and I2, expressed as percentages of the sum of the variance estimates, illustrate that a large portion (20–50%) of the variance in these data were associated with backwater lakes, either across all years or differing effects among years

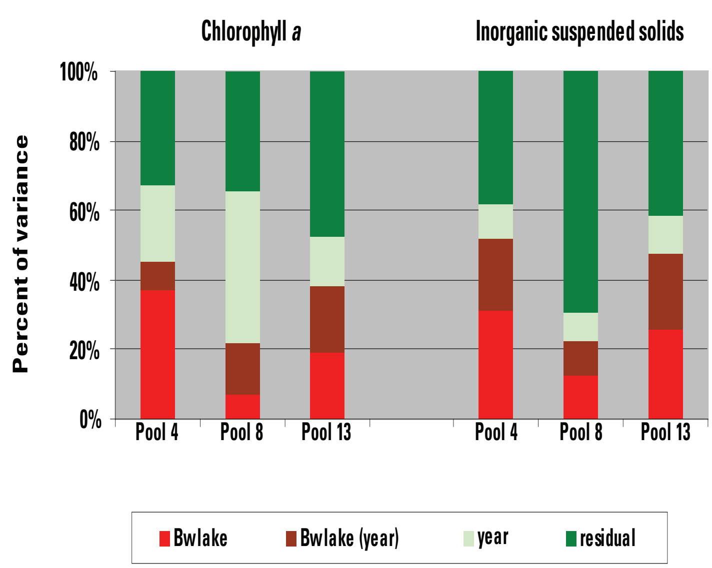

Figure. Percent of variance associated with selected variance components in models for backwater chlorophyll *a* and inorganic suspended solids for summer data 1993–2002 in Pools 4, 8, and 13.

Table. Akaike Information Criteria (AIC) values for chlorophyll *a* and inorganic suspended solids models with and without backwater lake effects for data from Pools 4, 8 and 13. Decreases in AIC values of ≥2 units or more indicate a better approximating model.

		AIC values		
Model	**Chlorophyll *a* (Chl)**	**Pool 4**	**Pool 8**	**Pool 13**
C1 (naïve)	Chl = year effects	1,195.4	1,107.2	1,369.0
C2	Chl = year effects + backwater lake + backwater lake by year	992.0	1,057.9	1,191.2
	Inorganic Suspended Solids (ISS)			
I1 (naïve)	ISS = year effects	1,420.1	1,460.4	1,655.9
I2	ISS = year effects + backwater lake + backwater lake by year	1,168.0	1,394.1	1,416.0

(Figure). Of the variance associated with backwaters themselves, a majority was associated with effects that did not vary across years (excepting the chlorophyll *a* model for Pool 8). This result suggests that differences in chlorophyll *a* and inorganic suspended solids among backwater lakes are partially driven by processes that are consistent across at least the 10 years modeled.

The above estimates were not corrected for spatial correlation among backwater lake effects. Such correlation appears important and, if so, adjusting for it will lead to revising upward the proportion of variance in chlorophyll *a* and inorganic suspended solids levels associated with backwaters (i.e., the study's backwater variance estimates provided are expected to be conservative). This issue was not conclusively addressed because spatial correlation among backwater lakes is indistinguishable from spatial correlation among observations when the number of samples in a lake in a given year is only one. The models we present did, however, address spatial correlation *within* lakes.

We next examined whether lake effects on chlorophyll *a* and inorganic suspended solids levels might be explained by morphometric predictors that themselves vary at the backwater scale. These predictors included backwater area, amount of connection to adjacent channels (a surrogate for water retention time), shoreline development index (a surrogate for water retention time) and backwater mean depth. All backwater metrics were assumed constant over the study years and based on conditions present in 1989.

None of these morphometric predictors explained more than trivial proportions (<5%) of among lake variability in chlorophyll *a* or inorganic suspended solids levels. The hope that the selected backwater metrics would explain variability in water quality parameters derived from some success in earlier modeling of water quality-based habitat using backwater metrics. In those models, backwater metrics were found to explain habitat suitability when considering thresholds, as opposed to linear correlation, for several selected backwater metrics. It could be that similar correlations with these backwater metrics are present in the chlorophyll *a* and inorganic suspended solids data investigated in this study, but need to be determined using nonlinear assumptions.

Although the emphasis in these initial models was to examine backwater lake effects, we also considered whether variation in chlorophyll *a* at the sampling scale might be associated with variation in inorganic suspended solids at the same scale. The resulting models, which included backwater lake effects, suggested that 10–30% of the variation in chlorophyll *a* at the sampling scale was associated with inorganic suspended solids (a positive correlation between chlorophyll *a* and inorganic suspended solids). In some of the models, up to 30% of the variance associated with backwater lakes was associated with inorganic suspended solids, a result that is not surprising given that we found substantial backwater lake effects when modeling inorganic suspended solids data. These associations between chlorophyll *a* and inorganic suspended solids likely reflect, in part, common effects, such as water exchange rates that influence both chlorophyll *a* and inorganic suspended solids. We also considered vegetation cover index (four categories of cover in proximity to sample site) effects on chlorophyll *a*, but found little (<5%) variance in chlorophyll *a* to be associated with the vegetation index.

These results demonstrate substantial variation among backwater lakes for at least two water quality variables. These findings suggest that contiguous backwater lakes exhibit unique characteristics and act partially independently, and that these features may be used to clarify relationships among physical and biotic variables of interest to managers and scientists.

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This report is a product of the Long Term Resource Monitoring Program.

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