SPATIAL AND TEMPORAL VARIATIONS IN DISSOLVED P STREAM CONCENTRATIONS FOR WET AND DRY YEARS

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Abstract. Dissolved phosphorus (P) has often been identified as the nutrient of concern in lakes, reservoirs, and streams especially where there is evidence of eutrophication. We analyzed contiguous-spatial and temporal variability of dissolved P [soluble reactive P (SRP)] stream concentrations during times with drought and during times with a series of severe storms (2005 through 2009) in the Fort Cobb Reservoir watershed located in southwestern OK. The streams were sampled every two weeks (212 sampling dates) for SRP. Horizontal, longitudinal, and vertical biogeophysical metrics were compiled for each contributing area, within each stream reach, and from climate and precipitation data, respectively, and were related to SRP concentrations for spatially autocorrelated data and not spatially autocorrelated data. After a series of extreme rainfall events (drought to heavy rainfall) the proportion of spatial autocorrelation of stream SRP increased significantly ($p < 0.05$) as did the corresponding mean stream concentration of SRP.

INTRODUCTION

Dissolved phosphorus [soluble reactive P (SRP)] has often been identified as the nutrient of concern in lakes, reservoirs, and streams especially where there is evidence of eutrophication. Furthermore, landuse has often been shown to influence stream nutrient concentrations (Fisher et al., 2000). While the link is clear, researchers have experienced varied success in applying empirical associations to land use and stream nutrient concentrations or in identifying pathways of influence (Allan, 2004). Because nutrient retention, transformations, and dilutions can vary greatly depending on stream morphology (Gücker and Boëchatand, 2004), the extent to which a given land use or management influences stream P concentrations varies with landscape metric. More information is needed on the extent to which “inherent” variables such as landscape (spatial) and time or seasonal (temporal) metrics influence stream P concentrations for a plethora of landscapes and ecoregions. Additionally, Lytle and Poff (2004) indicated that the pathway, quantity, and quality of water vary under drought and flood flow regimes for a given stream and that organisms living in running waters must adapt to different flow regimes. This then further suggests that to develop successful nutrient management practices we must also have more understanding of dissolved P concentrations in streams under both drought and wet conditions for diverse landscapes with associations to influential landscape metrics.

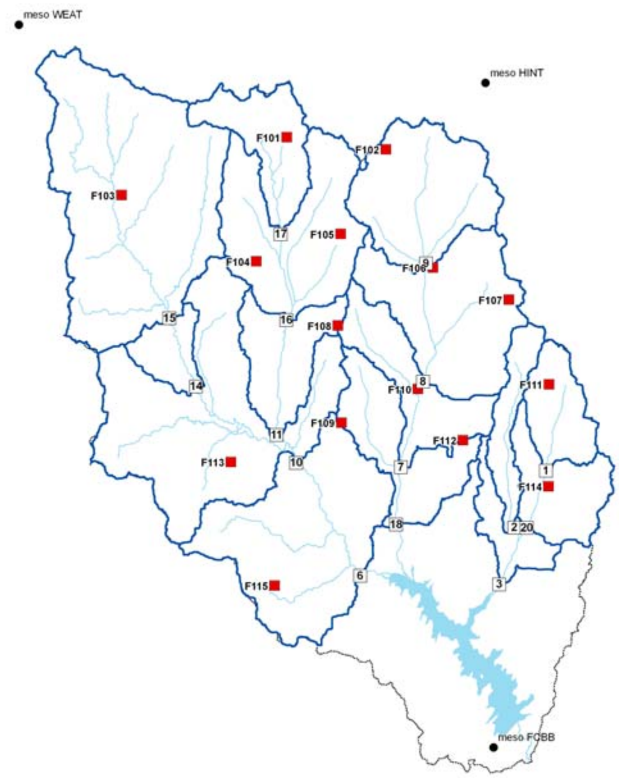

Figure 1. Fort Cobb Reservoir Watershed in southwestern Oklahoma, USA. Red squares identify precipitation and number squares identify sampling sites.

Partitioning of biochemical and physiochemical characteristics referenced with time, landscape metrics and for wet and for dry stream flow regimes may give us further understanding and the ability to design land management practices and in some cases water allocations to reduce ecological and sanitary problems for these extreme weather conditions. Spatial autocorrelation measures presence or absence of spatial influence and has been used to identify influence of landscape metrics (Jones et al., 2001, Franklin et al., 2002, and Allan, 2004). Recursive partitioning, like other classification and regression trees (CART), has been shown to be a robust and flexible analytical tool to discern relationships between complex ecological data (Young, 1992; Bücker et al., 2008) and has been used to identify *a-priori* most important variables (metrics) for prediction of dependent variables in climate studies (Cannon and Whitfield, 2002). The Fort Cobb Watershed in Oklahoma (USA) has diverse biophysical settings (Steiner et al., 2008) and as such provides an opportunity to explore a diverse group of landscape matrices and water quality. This manuscript was developed to evaluate background spatial and temporal variations of water quality observed over a five-year period (2005 through 2009) with a distinct shift in precipitation. The objective of this work is to identify spatial and temporal patterns in SRP and biogeophysical metrics associated with the spatial and temporal patterns.

MATERIALS AND METHODS

The Fort Cobb Reservoir Watershed (FCRW) is made up of first-through fourth-order tributaries dissecting diverse geologic formations (iron rich sandstones to gypsum escarpments) in southwestern, Oklahoma, USA. The four main drainage basins: Cobb Creek, Five Mile Creek, Lake Creek, and Willow Creek are set in a subhumid climate with normal annual precipitation of 800 mm. During the water sampling period, water samples were collected bi-weekly from 15 sites on the FCRW from Jan, 2005 through Dec, 2009, when annual precipitation ranged from 560 mm to 1120 mm. Time series plots of mean precipitation for two-week sampling periods and variability were analyzed. A shift in precipitation was identified (Figure 2) between Dry Years (2005 and 2006) and the Wet Years (2007, 2008, and 2009).

Collected water samples were filtered (0.45 µm) and filtrate analyzed for SRP by the molybdate-blue method (Murphy and Riley, 1962). Soluble reactive P stream concentrations were analyzed for contiguous-spatial dependence and modeled using recursive partitioning to identify best predictive variables using the Horizontal, Longitudinal, and Vertical biogeophysical metrics.

System-wide spatial dependence (SAC) was determined in bi-weekly SRP stream concentrations by Moran's Coefficient (Griffith, 1993, Franklin et al., 2002) using first-nearest neighbor connectivity matrices in SAS (SAS Institute Inc., 2008; Griffith, 1993). Values for SAC can range from -1 to +1. All negative spatial autocorrelations were found to be insignificant ($p > 0.05$). Criteria for moderate spatial dependence (SAC = Yes) was set as SAC > 0.20 and $p < 0.05$ and criteria for no spatial dependence (SAC = No) was set as SAC < 0.19. Results for moderate spatial dependence were plotted on polar plots using SigmaPlot by year.

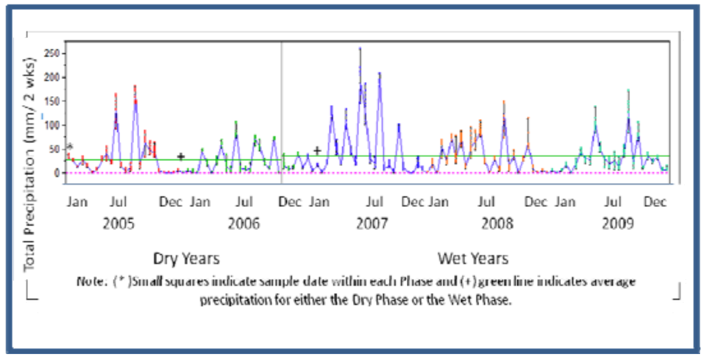

Figure 2. Mean precipitation for 2 week sampling period for the Fort Cobb Reservoir Watershed, years 2005 through 2009.

Recursive partitioning (RP) (SAS, JMP, 2008) analysis was done on SRP sub-datasets partitioned by Dry Years (2005 and 2006) or Wet Years (2007, 2008, 2009) each split by not spatially autocorrelated (SAC = No) or spatially autocorrelated (SAC = Yes). The method utilizes binary or continuous classification and regression trees to develop structural-tree models (Qian and Anderson 1999; Cannon and Whitfield, 2002) and predictive variables or metrics (Horizontal, Longitudinal and Vertical) to determine which metrics contribute significantly to SRP stream concentration variability. The **Horizontal metrics** were: *Topography* (Area, contributing area; drainage, drainage basin; SD, stream density; SL, stream length; Sl_avg, average slope; and Sl_max, maximum slope), *Soil* (HG_A, Hydrologic Group A; HG_B, Hydrologic Group B; HG_C, Hydrologic Group C; HG_D, Hydrologic Group D; C, clay in surface layer; S, Sand percent in surface layer;and SOC, soil organic carbon in surface layer), *Geology* (G_al, Alluvium; G_cc, Cloud Chief Formation; G_rs, Rush Springs Formation; and G_wg, Weatherford Gypsum Bed) and *Management* (M_cl, Annual crop land; and M_Ir, Irrigable by center pivot) variables. The **Longitudinal metrics** were: : *Stream stage* (Ch_S3, geomorphic stage 3; Ch_S4, geomorphic stage 4; Ch_S5, geomorphic stage 5; Ch_S3-5, sum of RGA stage 3,4, and 5) and *Water chemistry* (ORP, oxidation-reduction potential; pH; TDS, total dissolved solids; and Turb, turbidity) and the **Vertical metrics** were: *Weather* (Q, Quarter; Prec_cum3, cumulative precipitation over 3 sampling intervals (6 weeks); Prec_max, maximum 30-min precipitation in contributing area in sampling interval; and Prec_tot, total precipitation in 2-week sampling interval).

RESULTS AND DISCUSSION

Soluble reactive phosphorus (PO_4-P) stream concentrations for the Fort Cobb watershed ranged from 3 to 967 µg P L^{-1} over the five years (2005, 2006, 2007, 2008, 2009) with a mean of 181 µg P L^{-1} and a median

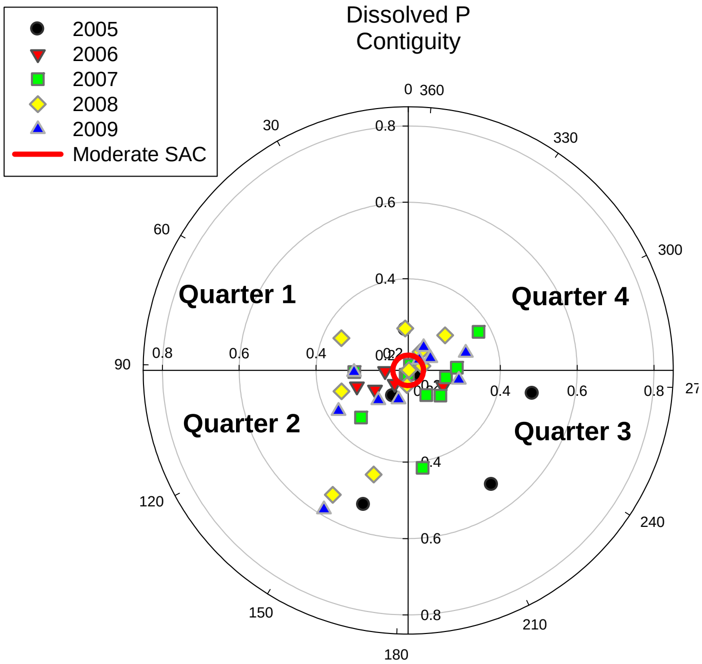

Figure 3. PolarPlot illustrating spatial dependence of soluble reactive P. Red circle marks 0.20 Moran's Coefficient (moderate spatial autocorrelation). Degrees on the polar plot (north pole =0 degrees) represent days of the year (DOY). Zero degrees to 91 represent Jan 1 to Mar 30 or the winter months and quarter 1. Quarters 1, 2, 3, 4 are depicted in the figure as DOY 0 to 91, DOY 91 to 183, DOY 183 to 274, and DOY 274 to 365, respectively.

of 143 µg P L^{-1}. Results from analysis for contiguous-spatial dependence for each of the years tested indicated that spatial autocorrelation was present ($p < 0.05$) for stream SRP concentrations (Figure 3). However, the proportion of dates with spatial dependence on a yearly basis varied depending on year. In addition, the proportion of spatial dependence was significantly more in the Wet Years than in the Dry Years (Figure 3 and Table 1; N=150 compared to N=375). The polar plot also indicates that there may be seasonal differences in SRP associated with spatial dependence. Results for recursive partitioning (RP) indicated that Horizontal metrics (topography, geology, management) were always better predictors for SRP stream concentrations for dates when there was SAC. Soil Hydrologic Group A and Contributing Area were the two most important Horizontal predictor variables chosen by RP for both Wet and Dry Years when there was contiguous-spatial dependence. However, during the Wet Years, the Vertical metric, cumulative precipitation for 3 sampling periods. was the strongest predictor variable when spatial dependence was not identified.

If Horizontal metrics are better predictors of SRP stream concentrations, then those best predictor variables can be focused on when developing management strategies for efficient use of fertilizer P. For example, for RP results (Wet Year, SAC = YES): stream SRP concentrations were almost 1.5 times greater when Hydrologic Group A was > 2.8% (data not shown) of the contributing area. In basins with landscape metrics which were indicative of rapid water movement [such as Hydrologic Group A or highly dissected landscapes (small contributing areas and/ or large stream density)], management strategies might include smaller applications rates applied when most needed in grasslands systems or time-released nutrients in vegetable or turf systems. Also note that Hydrologic Group A was identified as a variable of importance during the Wet Years which suggests that residual SRP was flushed from within the landscape and from within the stream channel. Applying nutrients in smaller amounts on an as-needed basis may also help prevent flushing of residual nutrients during wet periods.

CONCLUSIONS

Analysis of The Fort Cobb Reservoir Watershed indicated that background dissolved P stream concentrations were influenced by spatial (geophysical) and temporal (weather) features. Also, the extent to which a feature influenced dissolved P stream concentrations varied depending on absence or presence of spatial autocorrelation and hydrologic regime. We have demonstrated how varied background dissolved P stream concentrations can be as a result of both geophysical and weather influences. In addition, we have demonstrated that we can discern with some certainty the areas of a watershed that may be more vulnerable to P losses and/ or contaminations due to extreme weather variations.

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Table 1. Results for recursive partitioning for soluble reactive P. First-split metrics are considered best predictive metric. Second-split variables follow in order of largest coefficient of determination.

Phase	**DRY**		**WET**	
SAC	**NO**	**YES**	**NO**	**YES**
N	555	150	630	375
Mean (STD)	75.6 (*78.6*)	82.2 (*61.9*)	219.8 (*148.7*)	235.7 (*96.9*)
First-split metric	Hydrologic Group A	Contributing Area	Cum Precip (mm/6 wks)	Hydrologic Group A
N ratio	518:37	130:20	284:346	75:300
Mean ratio (µg P L-1)	67:196	70:161	129:294	152:257
R2/ split #	.30/6	.51/6	.55/6	.59/6
Sub-split metric	Turbidity Drainage basin Max 30 min precip (mm/2wks) Cum Precip (mm/6 wks) Quarter	Soil Organic Carbon Tot precip (mm 2/wks) Quarter Cum Precip (mm/6 wks) Cloud Chief Formation	Tot precip (mm/2wks) Quarter Turbidity Irrigation Pivots Quarter	Cum precip (mm/6 wks) Total precip (mm/2wks) Stream density Max 30 min precip (mm/2wks) Quarter

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