# PHOSPHORUS SOURCES IN AN OZARK CATCHMENT, USA: HAVE WE FORGOTTEN PHOSPHORUS FROM DISCRETE SOURCES?

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## ABSTRACT:

In the Ozark Plateaus, the focus of watershed mangers is often on diffuse sources of phosphorus (P), especially agricultural runoff and land application of animal manure. However, it has become apparent in the Ozarks that this shift in focus may be premature and neglect P from discrete sources, e.g. wastewater treatment plants (WWTPs). We sampled the water column at 30 sites in the Illinois River Basin [Ozark Plateaus, USA]; this catchment receives effluent from four municipal WWTPs. The average annual P load was approximately 208,000 kg from 1997 through 2001, and municipal WWTPs represented almost 45% of the average annual load. Water column P concentrations were significantly greater during surface runoff conditions compared to base flow conditions. Phosphorus concentrations and stream flow displayed distinct relations during base flow and surface runoff conditions. Water column P concentrations were increased by WWTP effluents during base flow conditions and the increase in P concentrations may be traced upstream to one WWTP. The sediments at these systems may represent a transient storage pool of P, lengthening the time required to see improvements in water-quality after WWTP inputs are reduced. Thus, watershed managers in the Ozark Plateaus must address discrete sources of P and sediment-bound P to facilitate a reduction in stream P concentrations.

**KEY WORDS:** ***Phosphorus Sources, WWTPs, Diffuse Pollution, Sediments.***

## INTRODUCTION

In the Ozark Plateaus, USA, import of phosphorus (P) in animal feeds has resulted in substantial accumulation of this element within watersheds with high densities of confined animal feeding operations. Often, the focus of watershed mangers is on diffuse sources of P, especially agricultural runoff and land application of animal manure. However, it has become apparent in the Ozarks that this shift in focus may be premature and neglect P from discrete sources, e.g. wastewater treatment plants (WWTPs). Several studies in this region have shown the significant impact of municipal WWTPs have on stream P concentrations and retention (Haggard et al., 2001; Haggard et al., 2003). The impacts of WWTPs may persist several km downstream, and often the stream sediments become a P source when WWTP effluent P concentrations are reduced.

The focus of this study is the Illinois River Basin in the southwestern portion of the Ozark Plateaus of northwestern Arkansas and northeastern Oklahoma. The Illinois River Drainage Area (IRDA) in northwestern Arkansas is predominately an agricultural catchment with 58, 36, and 6% in pasture, forest and urban land use (White et al., 2002). Water column P concentrations and loads in the Illinois River have been under constant scrutiny by Oklahoma environmental agencies over the last decade. In 1992, the U.S. Supreme Court rendered a decision that the U.S. Environmental Protection Agency may require upstream states to meet downstream states water-quality standards. Thus, the 2002 adopted water-quality standard (0.037 mg $L^{-1}$ total P criterion, Oklahoma Water Resources Board, 2002) in Oklahoma's scenic rivers has brought the sources of P in the Illinois River under even closer scrutiny. The Illinois River is one of four Oklahoma scenic rivers which have upstream drainage basins in Arkansas.

The objectives of this study were to 1) estimate the average annual P load at the Illinois River near the Arkansas and Oklahoma border, 2) separate the P load into contributions from point sources and diffuse pollution, and 3) collect water-quality samples spatially distributed throughout the IRDA during base flow conditions to identify substantial P sources.

## METHODS

The distribution of P concentrations with respect to base flow and surface runoff conditions was evaluated at the Illinois River at Highway 59, using water-quality data (http://waterdata.usgs.gov/ar/nwis/qw/) collected using equal width increment sampling techniques. Water-quality data from 1997 through 2001 was separated into base flow and surface runoff samples using the automated hydrograph separation software program Base Flow Index (Wahl and Wahl, 1997); base flow samples were collected when base flow was greater than or equal to 70% of total stream flow, and surface runoff samples were collected when base flow was less than 70%. The U.S. Geological Survey ESTIMATOR software was used to estimate annual P loads at this site. The relation between the natural logarithm of concentration (C, mg $L^{-1}$) or load (L, kg $d^{-1}$) and daily discharge ($Q_d$, $m^3$ $s^{-1}$) was used to estimate daily P loads which were summed to give annual P loads:

$_0$ and $â_1$are the model coefficients. In this model, if a relation between L and $Q_d$ exists, then the $â_1$ coefficient will be significantly different than zero. A minimum variance unbiased estimator (Cohn et al., 1989) was used to transform logarithm results to linear results.

Additional water-quality samples were collected from 30 sites in the IRDA, from the Illinois River, South of Siloam Springs, Arkansas, at Highway 59 (U.S. Geological Survey Station No. 07195430) upstream into Osage, Spring, Moores and Mud Creeks (Figure 1) during spring 2002. Sites were selected upstream and downstream from WWTP discharges of the cities of Rogers, Springdale and Fayetteville at Osage, Spring and Mud Creeks.

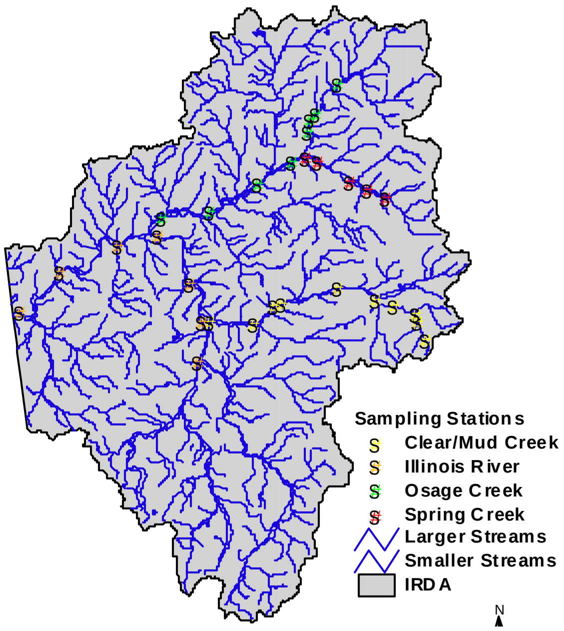


*Figure 1. Water-quality sampling sites at the Illinois River Drainage Area (IRDA).*

Water-quality samples were collected in triplicate at each site with one sample from the middle of the stream, and one from the left and right center of the stream. Water samples were collected using HDPE syringes, immediately filtered through a 0.45 ìm membrane, acidified with concentrated HCl to about pH 2 and stored on ice until return to the laboratory. Water-quality samples were analyzed for soluble reactive P (SRP) using the ascorbic acid reduction method (APHA, 1998). Distance between sites was estimated using the GPS coordinates, digital stream hydrography, and ESRI ArcView software.

## RESULTS AND DISCUSSIONS

Total P (TP) concentration reported by the U.S. Geological Survey from 1997 through 2001 at the Illinois River at Highway 59 near the Arkansas and Oklahoma border are much greater than the proposed 0.037 mg $L^{-1}$ Oklahoma TP criterion (Figure 2). Median and average TP concentrations at this site were almost 7 and 9 times greater than the proposed criterion; no water samples had TP concentrations less than the proposed criterion. When hydrograph separation techniques were used to distinguish base flow and surface runoff samples, TP concentrations in the water column were significantly greater during surface runoff conditions as compared to concentrations during base flow conditions (Wilcoxon Signed Rank Test, P<0.001). Median and average TP concentrations during base flow conditions were 5 and 6 times greater than the proposed criterion whereas median and average TP concentrations during surface runoff conditions were 11 and 12 times greater. Total P during base flow conditions was almost all in the soluble reactive form whereas the particulate form dominated during surface runoff conditions.

The relation between discharge and TP concentrations during base flow and surface runoff conditions was distinct in each flow regime at the IRDA (Figure 2). Total P concentrations in base flow samples decreased with increasing instantaneous discharge ($\ln(C) = -0.61 \ln(Q_i) - 0.44$, $R^2 = 0.46$, $P<0.001$) whereas concentrations during surface runoff conditions increased with increasing instantaneous discharge ($\ln(C) = 0.32 \ln(Q_i) - 2.36$, $R^2 = 0.30$, $P<0.01$). Annual P loads were estimated when base flow was greater than or equal to 70% (base flow load) and when base flow was less than 70% (surface runoff load). The average annual P loads during base flow and surface runoff conditions were approximately

34,000 and 174,000 kg from 1997 through 2001. Thus, 16 and 84% of the average total load (208,000 kg) was transported during base flow and surface runoff conditions. Of the average total load from 1997 through 2001, almost 45% was likely from municipal WWTPs in the IRDA; municipal WWTPs accounted for approximately 93,400 kg $yr^{-1}$ from 1997 through 2001 (data from White et al., 2002). The partitioning of this average P load showed that the Springdale WWTP contributed almost 83% of the total average annual P load from discrete sources. Only 55% of the annual average P load was estimated to be from diffuse sources, less than 4% of the P input into the basin from animal manure and fertilizers (White et al., 2002). The transport of P during surface runoff conditions at the Illinois River included a large fraction (at least 35%) of P resuspended from the stream benthos in this system. Other studies have suggested that 50% of P transported during storms may be from in-stream sources (Svendsen et al., 1995).

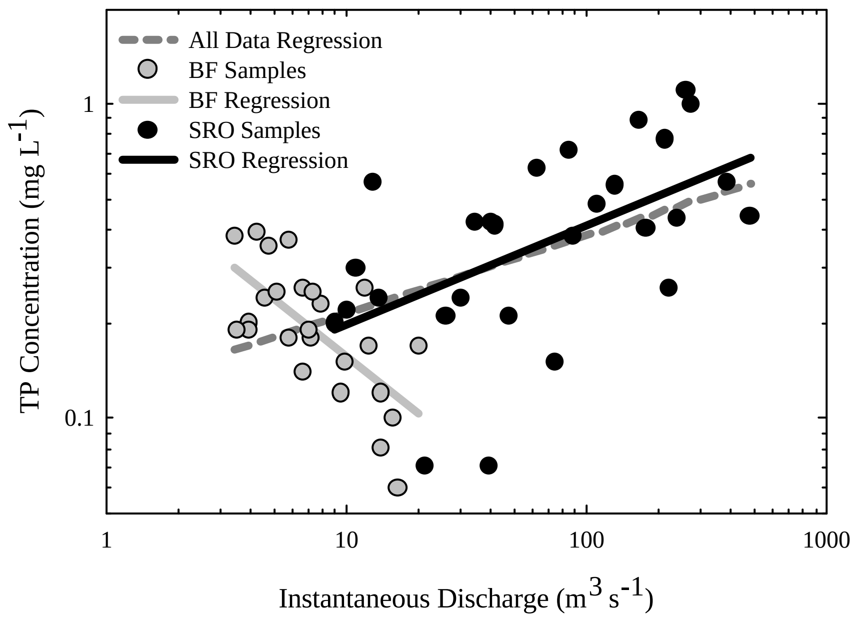


*Figure 2. Total phosphorus (TP) concentrations as a function of instantaneous discharge ($Q_i$) during base flow (BF) and surface runoff (SRO) conditions.*

Base flow conditions were specifically targeted during spring 2002 water-quality sampling in order to identify discrete sources contributing to elevated P concentrations at the Illinois River at Highway 59. During spring 2002, the average SRP concentration at the Illinois River at Highway 59 was about 0.18 mg $L^{-1}$ and similar to the long-term average of 0.21 mg $L^{-1}$ measured from 1997 through 2001. Osage Creek, by far, had the greatest effect on SRP concentration in the Illinois River, increasing concentrations almost 9 times that measured upstream of the Osage Creek and Illinois River confluence (Figure 3). Further upstream at the Illinois River concentrations were fairly stable and generally equal to or less than the proposed Oklahoma 0.037 mg $L^{-1}$ P criterion.

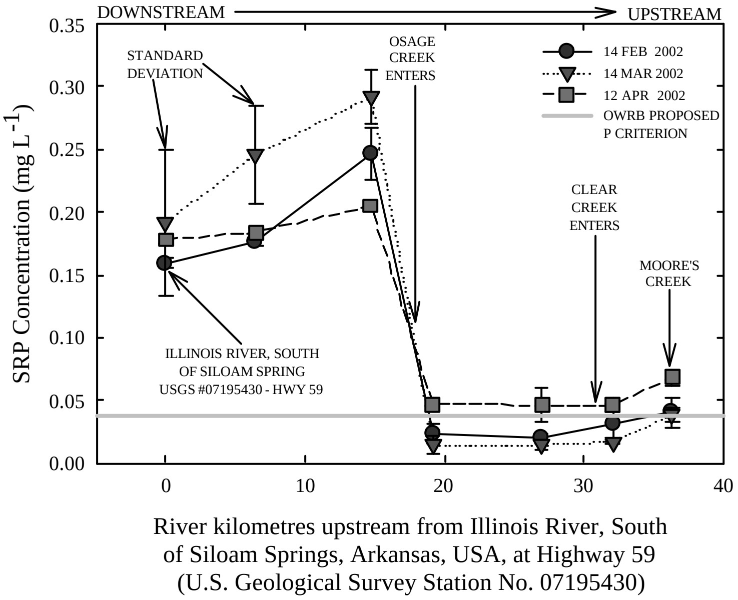


*Figure 3. Soluble reactive P (SRP) concentrations at the Illinois River.*

In Osage Creek, SRP concentrations were substantially increased by inputs from Spring Creek (Figure 4). Spring Creek increased SRP concentrations at Osage Creek over 10 times that observed upstream from Spring Creek. The City of Rogers, Arkansas, WWTP discharge increased SRP concentrations from 0.04 to 0.20 mg $L^{-1}$ further upstream at Osage Creek.

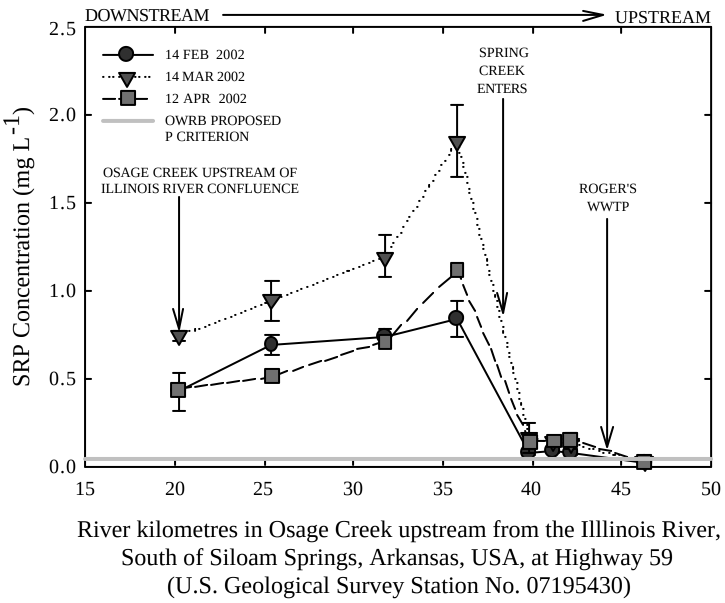


*Figure 4. Soluble reactive P (SRP) concentrations at Osage Creek.*

In Spring Creek, average SRP concentrations were greater than 6 mg $L^{-1}$ downstream from the City of Springdale, Arkansas, WWTP discharge (Figure 5). A maximum SRP concentration of 9.5 mg $L^{-1}$ was observed on 14 March 2002. Concentrations of the same magnitude have been observed in other Ozark streams impacted by discrete sources (Haggard et al., 2003).

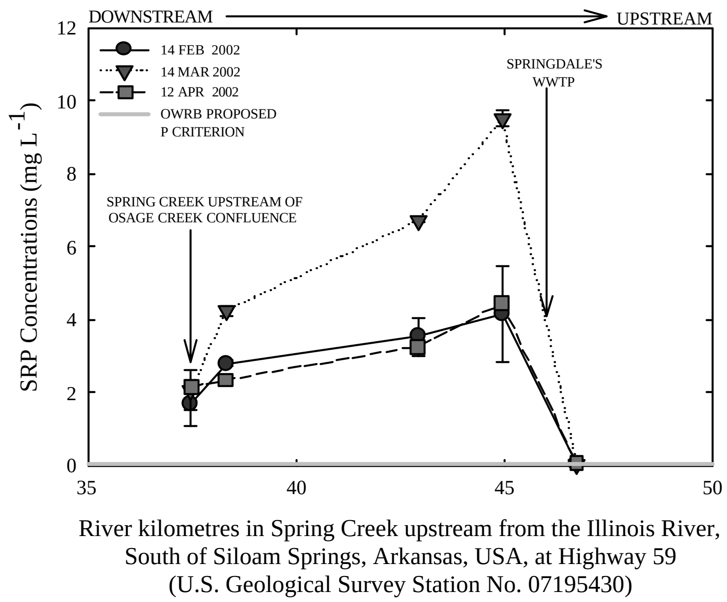


*Figure 5. Soluble reactive P (SRP) concentrations at Spring Creek.*

Average SRP concentrations were much less in Clear and Mud Creeks (Figure 6); Mud Creek receives the City of Fayetteville WWTP discharge. Average concentrations were ~0.07 mg $L^{-1}$ below the discharge during spring 2002. Concentrations decreased downstream and were generally below the proposed criterion in Mud Creek just upstream from Clear Creek.

## CONCLUSIONS

The spatial distribution of these sites clearly identified elevated P concentrations at the Illinois River at Highway 59 were likely from a single WWTP over 46 kilometres upstream. This WWTP was responsible for almost 83% of the average annual P load from discrete sources, and discrete sources were a substantial fraction (45%) of the amount of P transported from the IRDA across the Arkansas and Oklahoma border. Over 35% of the P transported during surface runoff conditions was likely from resuspension of P retained by stream sediments. Thus, these sediments may represent a considerable transient storage pool of P after management strategies are utilized to reduce elevated P concentrations at the Illinois River. Watershed managers in the Ozark Plateaus must address discrete sources of P and sediment-bound P to facilitate a reduction in stream P concentrations.

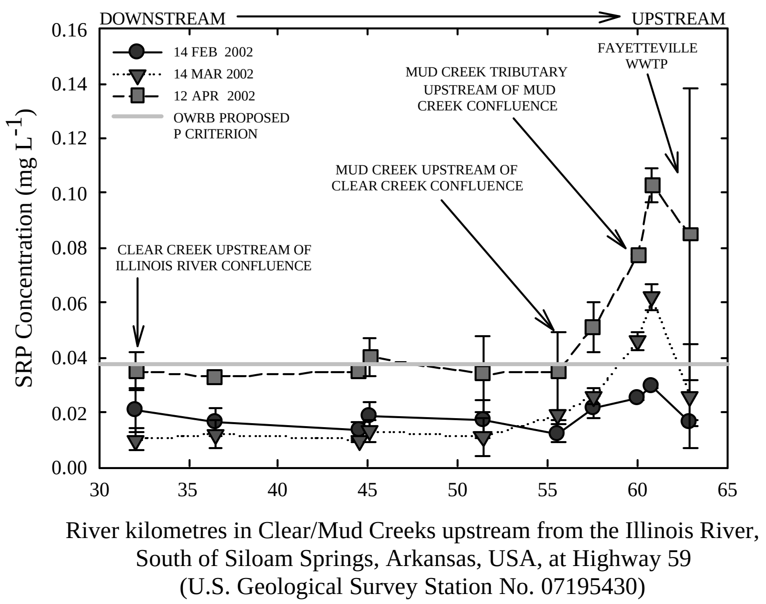


*Figure 6. Soluble reactive P (SRP) concentrations at Clear and Mud Creeks.*

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