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# COMPARISON OF SUBSURFACE AND SURFACE RUNOFF PHOSPHORUS TRANSPORT CAPACITIES IN ALLUVIAL FLOODPLAINS

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## ABSTRACT

There have been numerous studies on phosphorus (P) contributions from surface runoff, but studies comparing the contribution of surface versus subsurface P are limited, as subsurface transport is often considered negligible. Previous work has shown that the transport of P in the gravelly subsurface at two sites in northeast Oklahoma can be significant, especially in preferential flow paths (PFPs), hypothesized to be buried gravel bars. The objective of this project was to quantify subsurface P losses based on field data, and compare with surface runoff P losses derived from Pasture Phosphorus Management Calculator (PPM Plus) simulations. Ozark ecoregion study sites adjacent to the Barren Fork Creek and Honey Creek, neither of which have received litter applications or extensive cattle production in the past decade, were instrumented with observation wells. Groundwater levels and P concentrations were monitored for several months. Using a P transport capacity equation and Monte Carlo simulations based on appropriate statistical distributions derived from these data, the mean subsurface P load traveling along with the groundwater through the non-PFP flow domain and a single PFP was estimated to be 0.12 kg $yr^{-1}$ and 0.02 kg $yr^{-1}$ for the Barren Fork Creek and Honey Creek field sites, respectively. Monte Carlo simulations for surface loads were performed using PPM Plus based on current site conditions (i.e., no fertilization or cattle grazing), resulting in average total P surface runoff loads of 0.46 kg $yr^{-1}$ for the Barren Fork Creek site and 0.67 kg $yr^{-1}$ for the Honey Creek site. Simulations were also performed based on typical intensive pasture management for the region with poultry litter application and cattle grazing. These simulations resulted in average total P surface runoff loads of 14.0 kg $yr^{-1}$ at the Barren Fork Creek site and 9.8 kg $yr^{-1}$ at the Honey Creek site, two orders of magnitude greater than the estimated subsurface P transport capacities on low intensity agricultural fields. Subsurface P contributions with a single PFP was significant compared to surface runoff loads for the low intensity agricultural fields. These results indicated that the subsurface P capacity of alluvial floodplains in the Ozark ecoregion was at least 0.01 to 0.10 kg $yr^{-1}$, although the capacity may be higher in cases with greater numbers of PFPs and where the subsurface is connected to a larger P source. Further work on subsurface P transport should address sites with P application and the factors that influence P leaching through the topsoil.

**KEYWORDS**. alluvial floodplains; hydrologic modeling; phosphorus management; preferential flow; subsurface transport

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## INTRODUCTION

Phosphorus (P) is a necessary nutrient for terrestrial and aquatic plants, yet over-application of organic and/or inorganic fertilizers to agricultural fields can result in elevated Soil Test Phosphorus (STP) levels and can lead to eutrophication in receiving streams and reservoirs (NRCS, 1994). One such area of concern is eastern Oklahoma and western Arkansas where poultry litter is often applied based on nitrogen requirements, resulting in excessive P application (White, 2007). Sharpley at al. (2003) noted that feed imported to support concentrated poultry production has resulted in a net increase of nutrients in the region. After export of poultry products, what remains in the region is nutrient rich poultry litter, which is bulky and expensive to export. Therefore, the poultry litter is applied to nearby pastures as an inexpensive fertilizer, and over time results in elevated STP with an increasing risk of P loss to streams and reservoirs.

Nonpoint source P pollution became a major focus in the 1970's and 1980's after it was discovered that reducing point source pollution did not significantly improve water quality in many watersheds (Crowder and Young, 1988). Compared to point source load reduction, nonpoint source load reduction is much more difficult and complex (Sims and Sharpley, 2005). The design and implementation of agricultural conservation practices to reduce P in runoff, such as buffer strips, riparian zones, terracing, and cover crops, are site specific and may be difficult to implement as economic, social, and political considerations affect farmers' willingness to adopt and maintain these practices (Sharpley et al., 2003; Sims and Sharpley, 2005).

As in the 1970's and 1980's when the focus was on the easily measurable and reducible point sources, implementation of riparian buffer zones and other conservation practices currently focus on the more easily understood and observable surface runoff mechanism (Lacas et al., 2005; Popov et al., 2005; Reichenberger et al., 2007; Poletika et al., 2009; Sabbagh et al., 2009). Although conservation practices can reduce P loss in surface runoff, the movement of subsurface P and its contribution to the receiving stream system may need to be considered. Studies have shown that subsurface nutrient transport can be significant in soils with spatially variable hydraulic conductivity (Carlyle and Hill, 2001), preferential flow pathways (McCarty and Angier, 2001; Polyakov et al., 2005; Fuchs et al., 2009; Heeren, et al., 2010a), and limited soil sorption capacity (Cooper et al., 1995; Carlyle and Hill, 2001; Polyakov et al., 2005). For example, Storm et al. (2009) used Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) to model the Illinois River basin in eastern Oklahoma and western Arkansas. They estimated 7% of nonpoint source P contributions were derived from baseflow compared to 22% due to surface runoff from application of poultry litter.

The objective of this project was to compare subsurface P flux from two field sites in northeastern Oklahoma (Barren Fork Creek and Honey Creek) to the surface runoff P loads based on simulations of the Pasture Phosphorus Management Calculator (PPM Plus) (White, 2007; White et al., 2009; White et al., 2010). Using long term monitoring of water elevation and P concentrations at the two field sites, the subsurface P capacity was quantified and compared to the total P surface runoff loads predicted by PPM Plus.

## MATERIALS AND METHODS

### *Barren Fork Creek and Honey Creek Floodplain Sites*

The two floodplain sites were located in the Ozark ecoregion of northeastern OK. The Barren Fork Creek (Figure 1a, latitude: 35.90°, longitude: -94.85°) and Honey Creek sites (Figure 1b, latitude: 36.54°, longitude: -94.70°) were immediately downstream of U.S. Geological Survey (USGS) gage stations 07197000 and 07189542, respectively. With a watershed size of 845 $km^2$, the Barren Fork Creek site had a median daily flow of 3.6 $m^3$ $s^{-1}$ and was a fourth order stream. Honey Creek, a third order stream, had a 0.54 $m^3$ $s^{-1}$ median daily flow and a 150 $km^2$ watershed. Both floodplain sites consisted of alluvial gravel deposits underlying a mantle of topsoil (Razort gravelly loam). The Barren Fork site's topsoil thickness ranged from 0.5 to 1.0 m with a STP of 30 mg/kg. The alluvial floodplain consisted of a hay field with no fertilizer applied in recent years

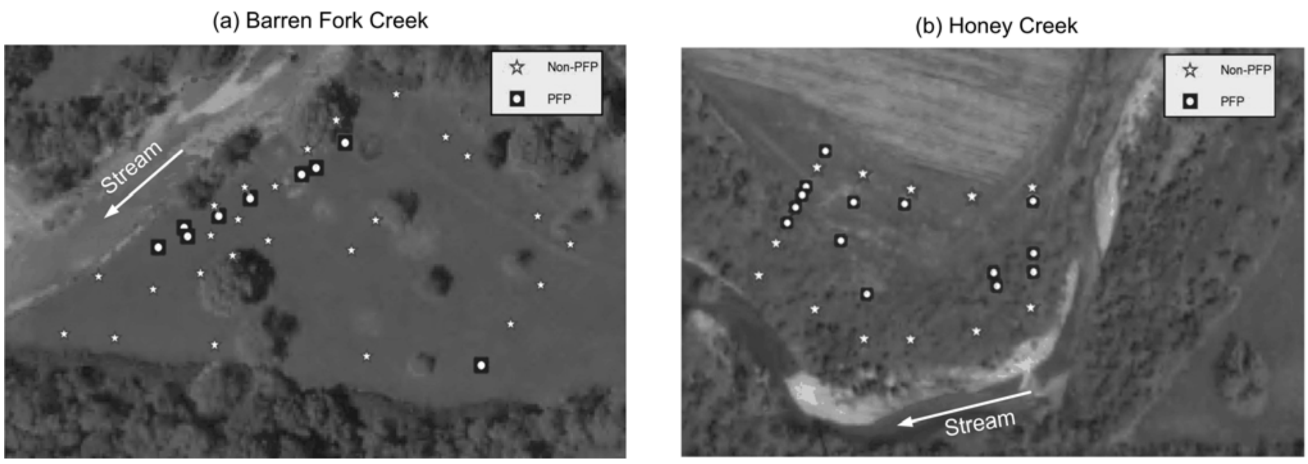


**Figure 1. Observation well locations for (a) Barren Fork Creek site, located near Tahlequah, Oklahoma, and (b) Honey Creek site, located near Grove, Oklahoma. Arrows indicate stream flow direction.**

and had an area of 2.7 ha with a 0.004% slope. The Honey Creek site had a topsoil thickness ranging from 0.1 to 0.5 m and a higher STP level of 53 mg/kg due to historical poultry litter application. The site had a 0.01% slope and a total area of 3.2 ha, of which 1.5 ha was forest along the stream and the remainder was a hay field.

***Subsurface P Sampling***

Based on previous work by Miller et al. (2010), 24 observation wells were located and installed at each site. Assuming a positive correlation between electrical resistivity and saturated hydraulic conductivity ($K$), well locations were selected in both high conductivity (PFP) and low conductivity (non-PFP) subsoils (Miller et al., 2010). Using a peristaltic pump, groundwater samples were collected during high flow events, preserved on ice, transported back to the laboratory, and digested based on the sulfuric acid-nitric acid method (Pote et al., 2009). Total P concentrations were then determined colorimetrically (Murphy and Riley, 1962; EPA Method 365.2) with a spectrophotometer (Spectronic 21D, Milton Roy, Ivyland, PA).

***Subsurface Phosphorus Transport Capacity***

The subsurface P transport capacity was defined as the average subsurface load crossing the down-gradient boundary of the observation well field at each field site (i.e., the south boundary at the Barren Fork Creek site and the northwest boundary at the Honey Creek site). Subsurface P load was calculated by first determining the average groundwater flow based on Darcy's Law:

$$Q = qA = \left(-K\frac{\partial h}{\partial x}\right)wd = (Ki)wd \tag{1}$$

where $Q$ is the groundwater discharge ($L^3/T$), $q$ is the Darcy velocity (L/T), $h$ is the groundwater head (L), $x$ is the distance along the direction of flow (L), $A$ is the cross-sectional area ($L^2$), $w$ is the width of the monitored boundary or groundwater flow domain (L), $d$ is the depth of the aquifer (L), and $i$ is the average groundwater gradient (L/L). Note that this equation was applied separately to PFP and non-PFP groundwater domains crossing the selected boundary at each field site with their site specific width ($w$) and depth ($d$) of the aquifer domain. The P transport capacity, $m_p$, (M/T) was then calculated using the following equation:

$$m_P = Q \times TP \times n_d \tag{2}$$

where $TP$ is the total P concentration ($M/L^3$) measured from observation wells in the PFP and non-PFP domains, and $n_d$ is the number of days per year in which each groundwater flow domain was activated.

A Monte Carlo simulation was performed using 10,000 realizations of subsurface transport capacity due to uncertainty in several variables; six variables were selected with the distributions and statistics shown in Table 1. A normal distribution after a Box Cox transformation was used

**Table 1. Distributions and their statistics for input parameters used in the Monte Carlo simulations at both the Barren Fork Creek (BFC) and Honey Creek (HC) field sites. Note that unique distributions were used for the preferential flow (PFP) and non-preferential flow (non-PFP) domains.**

| Parameter | Site | Flow Domain | Input Distributions for Monte Carlo |
|---|---|---|---|
| Saturated Hydraulic Conductivity (m/d) | BF | Non-PFP | Normal after power function ($\lambda^a$ =-0.62); $\mu_x{}^b$=0.13; $\sigma_x{}^b$=0.04 |
| | | PFP | Normal after power function ($\lambda$=-0.62); $\mu_x$=0.13; $\sigma_x$=0.04 |
| | HC | Non-PFP | Normal after power function ($\lambda$=0.23); $\mu_x$=2.3; $\sigma_x$=0.17 |
| | | PFP | Normal after power function ($\lambda$=0.23); $\mu_x$=2.3; $\sigma_x$=0.17 |
| Groundwater Gradient(m/m) | BFC | Non-PFP | Uniform; Min=0.0005; Max=0.0015 |
| | | PFP | Uniform; Min=0.0015; Max=0.0025 |
| | HC | Non-PFP | Uniform; Min=0.0005; Max=0.0015 |
| | | PFP | Uniform; Min=0.0015; Max=0.0025 |
| Aquifer Depth (m) | BFC | Non-PFP | Uniform; Min=2.0; Max=3.0 |
| | | PFP | Uniform; Min=1.5; Max=2.5 |
| | HC | Non-PFP | Uniform; Min=0.25; Max=1.0 |
| | | PFP | Uniform; Min=0.5; Max=1.5 |
| Domain Width (m) | BFC | Non-PFP | Fixed; 150 |
| | | PFP | Uniform; Min=5.0; Max=10 |
| | HC | Non-PFP | Fixed; 65 |
| | | PFP | Uniform; Min=2.0; Max=4.0 |
| Total Phosphorus Concentration(mg/L) | BFC | Non-PFP | Uniform; Min=2.0; Max=3.0 |
| | | PFP | Uniform; Min=1.5; Max=2.5 |
| | HC | Non-PFP | Uniform; Min=0.25; Max=1.0 |
| | | PFP | Uniform; Min=0.5; Max=1.5 |
| Activity (d) | BFC | Non-PFP | Fixed; 365 |
| | | PFP | Lognormal; $\mu_x$=2.19; $\sigma_x$=1.02 |
| | HC | Non-PFP | Fixed; 365 |
| | | PFP | Lognormal; $\mu_x$=1.34; $\sigma_x$=1.17 |

[a] $\lambda$= exponent for the power transformation of the original distribution.
[b] $\mu_x$ , $\sigma_x$ = mean and standard deviation for the normal and lognormal distributions.

to quantify $K$ using electrical resistivity measurements correlated to point measurements of $K$ as reported in Miller et al. (2010). The aquifer width, $w$, was held constant for each field site for the non-PFP domain, but varied for the PFP domain assuming a uniform distribution. The $w$ of the PFP was stochastic since electrical resistivity data were not available for the entire floodplain site. The distribution for $d$ was assumed uniform for both PFP and non-PFP domains. Differences in $d$ between the PFPs and non-PFPs were identified based on electrical resistivity mapping of high $K$ zones at each field site as reported in Miller et al. (2010). The non-PFP domain was assumed active for 365 days; therefore, a fixed value was used for these calculations. The PFP activity was quantified based on the minimum stream stage that resulted in PFP activation during the study period (Heeren et al., 2010b). This parameter distribution was derived from 60 yr and 11 yr of daily mean streamflow measurements by the USGS at the Barren Fork Creek and Honey Creek sites, respectively. For the Barren Fork Creek and Honey Creek field sites, the activation stage corresponded to flows of 43.0 and 5.7 $m^3 s^{-1}$, respectively. A lognormal distribution was used for $n_d$ for PFP activation. The P transport capacity or P load was therefore highly dependent on $n_d$. Uniform distributions were used for $i$ and TP with unique $i$ and TP for the PFPs and non-PFPs. The $i$ and TP distributions were derived from groundwater level and P concentrations measured in the observation well fields with higher $i$ and TP for the PFP domains due to their activation during storm events (Heeren et al., 2010b).

***Surface Runoff Phosphorus Loads***

PPM Plus is a software tool which predicts the amount of P and sediment in runoff from an agricultural field in Oklahoma (White, 2007; White et al., 2009; White et al., 2010). It predicts the average annual P and sediment load delivered to the nearest stream from a single agricultural field using a region-specific, 15-yr weather period. PPM Plus can be used to simulate a myriad of management options by accounting for detailed field characteristics and land management. PPM Plus is based on the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998); a product of more than 30 years of model development by the U.S. Department of Agriculture, Agricultural Research Service. Models like SWAT are primarily used by highly trained specialists and are too complex for use by most conservation and nutrient management planners. PPM Plus simplifies the operation of SWAT to put the predictive power of a proven water quality model into the hands of people who make daily decisions that affect water quality.

Due to its ease of use and applicability, PPM Plus was selected to estimate the average annual P loss from the two field sites. PPM Plus was parameterized for the Barren Fork Creek and Honey Creek field sites for two scenarios (Table 2). The first scenario represented low intensity

**Table 2. High and low intensity agricultural production scenario PPM Plus inputs for the Barren Fork Creek and Honey Creek field sites.**

| **Input Parameter** | **Barren Fork Creek** | **Honey Creek** |
|---|---|---|
| *Common Inputs* | | |
| Land Use | Pasture | Pasture |
| Field Area (ha) | 2.7 | 1.7 |
| Riparian Buffer Area (ha) | 0 | 1.5 |
| Riparian Buffer Width (m) | 0 | 53 |
| Field Slope Length (m) | 120 | 120 |
| Distance to Stream (m) | 0 | 0 |
| Bank Full Width (m) | 34 | 24 |
| Soil Type | Razort Gravelly Loam | Razort Gravelly Loam |
| Forage Type | Mixed Warm and Cool Season Grasses | Mixed Warm and Cool Season Grasses |
| *Low Intensity Agricultural Production Scenario* | | |
| Grazing Density (AU/acre) | 0 | 0 |
| Management Operation | Hay - August | Hay - August |
| *High Intensity Agricultural Production Scenario* | | |
| Grazing Density (AU/ha) | 1.2 | 1.2 |
| Grazing Duration | 365 Days with Supplemental Feed | 365 Days with Supplemental Feed |
| Forage Management | Optimally Managed | Optimally Managed |
| Fertilization | 6 Mg/ha Poultry Litter March 1 | 6 Mg/ha Poultry Litter March 1 |

agricultural production for pasture without any cattle grazing, which was the current land use. The only agricultural activity was hay removal scheduled for August. The second scenario represented high-intensity agricultural production for pasture with a high stocking rate of 1.2 animal units (AU) per ha and a 6 Mg/ha poultry litter application rate in March to meet the nitrogen requirements for a 9000 kg $ha^{-1}$ forage yield goal (Zhang et al., 2009). Due to uncertainty in several variables, a Monte Carlo simulation was performed with 10,000 computations on six variables, which were selected due to their uncertainty and sensitivity. Table 3 shows the six input

**Table 3. Distributions and their statistics for input parameters used in the Monte Carlo simulations at both the Barren Fork Creek (BFC) and Honey Creek (HC) field sites. Results were entered into the PPM Plus Phosphorus Tool.**

| Site | Input Parameter | Input Distribution for Monte Carlo |
|---|---|---|
| Barren Fork Creek | Soil Test Phosphorus (mg/kg) | Triangular; Min=57.0; Mode=59.0; Max=61.0 |
| | Curve Number | Uniform; Min=55.0; Max=67.0 |
| | Slope (m/m) | Uniform; Min=0.0036; Max=0.0044 |
| | Phosphorus Percolation Coefficient | Uniform; Min=10.0; Max=17.0 |
| | Phosphorus Soil Partitioning Coefficient | Uniform; Min=100; Max=300 |
| | Phosphorus Sorption Coefficient | Uniform; Min=0.20; Max=0.60 |
| Honey Creek | Soil Test Phosphorus (mg/kg) | Triangular; Min=103.0; Mode=106.0; Max=110.0 |
| | Curve Number | Uniform; Min=55.0; Max=67.0 |
| | Slope (m/m) | Uniform; Min=0.009; Max=0.011 |
| | Phosphorus Percolation Coefficient | Uniform; Min=10.0; Max=17.5 |
| | Phosphorus Soil Partitioning Coefficient | Uniform; Min=100; Max=300 |
| | Phosphorus Sorption Coefficient | Uniform; Min=0.20; Max=0.60 |

parameters and their distributions and statistics. A triangular distribution was used for STP using three random samples at each site; a uniform distribution was chosen for the other five variables. The curve number (CN) distribution varied by +/- 10% and was centered at the CN for a Razort soil (hydrologic soil group B) (Soil Conservation Service, 1972) for pasture in good condition (Haan et al., 1994). The average field slope was estimated from ArcGIS using the 2008 National Agricultural Imagery Program Mosaic (NRCS, 2009). The distribution was then taken as +/- 10% of the calculated value. The distributions for P percolation coefficient (PPERCO), P soil partitioning coefficient (PHOSKD), and the P sorption coefficient (PSP) were based on professional judgment and the SWAT recommended calibration range (Neitsch et al., 2002).

## RESULTS AND DISCUSSION

Based on the Monte Carlo simulation of the subsurface load (Equations 1 and 2), the estimated average total subsurface P load transport capacity (i.e., annual P load) of the non-PFP flow domain at the Barren Fork Creek field site was 0.10 kg $yr^{-1}$. This compared to an average of 0.02 kg $yr^{-1}$ from the single PFP. The average total P load from surface runoff based on the PPM Plus Monte Carlo simulations was 0.58 kg $yr^{-1}$ from the current conditions and 14.0 kg $yr^{-1}$ with litter application and cattle grazing (Figure 2a). For the Honey Creek site, the estimated average subsurface P transport capacity (i.e., annual P load) was 0.02 kg $yr^{-1}$, respectively, in the non-PFP domain and 0.0004 kg $yr^{-1}$ in the single PFP. These results compared to 0.67 kg $yr^{-1}$ of surface P runoff based on current site conditions and 9.8 kg $yr^{-1}$ of surface P runoff with poultry litter application and cattle grazing (Figure 2b).

The Honey Creek site had a smaller subsurface P transport capacity due to a smaller aquifer cross-sectional area (both in terms of $d$ and $w$) and $K$ compared to the Barren Fork Creek site. As stream order increases, $d$ and $K$ increase due to larger gravel deposits. Therefore, the size of the PFP was larger at the Barren Fork Creek site making the P load higher than at Honey Creek, the smaller order stream.

The subsurface P capacity was in the same order of magnitude relative to the surface runoff P load at the current site conditions, yet was small compared to the simulation with poultry litter application and cattle grazing. Though the total P capacity was small in the PFP due to the small area and number of days active, it may provide rapid transport from the ground surface to the

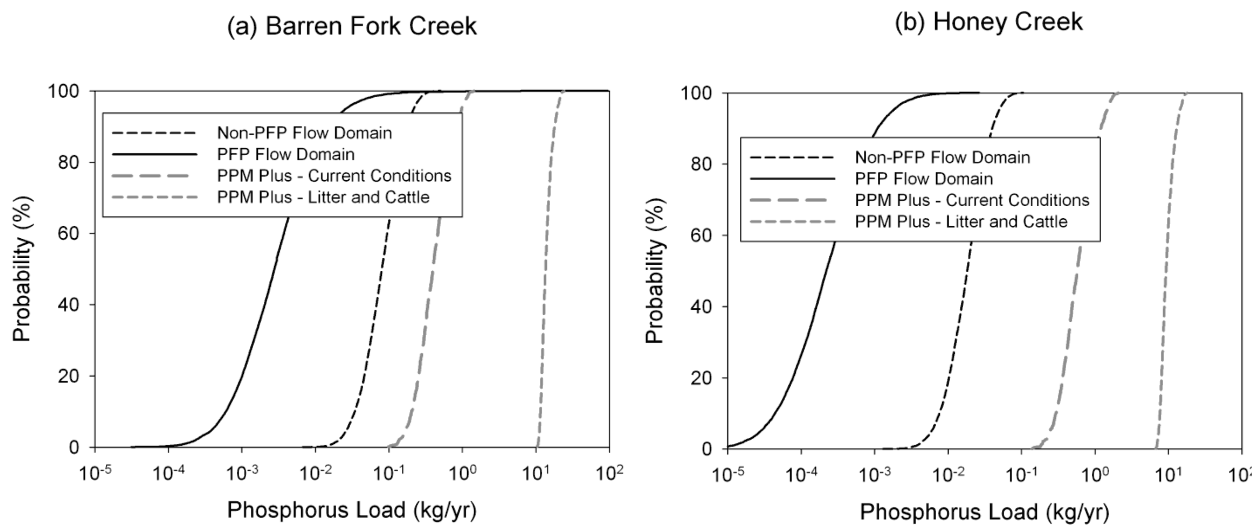


**Figure 2. Total phosphorus load capacity of subsurface based on Equations 1 and 2 and total phosphorus loads of surface runoff based on PPM Plus simulations at the Barren Fork Creek and Honey Creek field sites. PFP = preferential flow pathways; non-PFP = non-preferential flow. All curves were generated with Monte Carlo Analysis**.

aquifer and then from the aquifer to the stream. In areas where there is a larger number of PFPs and/or during years where the PFP remains active for longer periods of time, the PFPs may provide a larger P transport capacity. For example, the P load transport capacity at the 99th percentile of the Monte Carlo simulation was 0.10 kg $yr^{-1}$ in the single PFP at the Barren Fork Creek, or 25% of the median surface runoff P load from the current conditions.

The Illinois River, of which the Barren Fork Creek is a tributary, may have a deeper aquifer, higher *K*, and larger PFPs, resulting in a higher subsurface P capacity. Therefore, as the stream order increases, the significance of subsurface P capacity and PFPs may also increase.

These results suggest that the subsurface P capacity of alluvial floodplains with one PFP in the Ozark ecoregion may be at least 0.01 to 0.10 kg/yr and perhaps even higher in cases where the subsurface is connected to a larger source of P. The field data used in this analysis did not include floodplains with poultry litter application or cattle production. Further work is needed to quantify P leaching through the surface topsoil, potentially resulting in additional subsurface P loads.

## CONCLUSIONS

Research has shown that subsurface P contributions can be significant in soils with spatial variability in hydraulic conductivity, preferential flow pathways, and limited sorption capacity in riparian zone soils. This study estimated subsurface P transport capacity as quantified by annual P load crossing the outflow boundary of two groundwater systems, with uncertainty parameters quantified through Monte Carlo simulation. The subsurface P transport capacity was compared to surface runoff loads based on simulations of PPM Plus. Results suggested that the subsurface P transport capacities were significant compared to surface runoff P loads at low intensity agricultural field sites. Though the subsurface contributions were small compared to the PPM Plus simulations with more intensive land use, floodplains with poultry litter application or cattle grazing may have a corresponding increase in subsurface P transport. The field sites in this study had low agricultural intensity; therefore, the calculated subsurface P transport included a relatively small amount of P leaching from the surface. Future work needs to quantify P leaching through the soil from a surface P source and determine whether this significantly elevates levels of subsurface P transport. It is hypothesized that as the stream order increases, the significance of subsurface P transport capacity and preferential flow pathways increase.

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## REFERENCES

1. Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large area hydrologic model development and assessment part 1: model development. *J. Am. Water Resourc. As.* 34(1): 73-89.
2. Carlyle, G.C., and A.R. Hill. 2001. Groundwater phosphate dynamics in a river riparian zone: Effects of hydrologic flow paths, lithology, and redox chemistry. *J. Hydrol.* 247(3-4): 151-168.
3. Cooper, A.B., C.M. Smith, and M.J. Smith. 1995. Effects of riparian set-aside on soil characteristics in an agricultural landscape: Implications for nutrient transport and retention. *Agric. Ecosyst. Environ.* 55(1): 61-67.
4. Crowder, B., and C.E. Young. 1988. Managing farm nutrients: Tradeoffs for surface and ground water quality. Agric. Econ. Rep. 583. USDA, U. S. Gov. Print. Office, Washington, DC.
5. Fuchs, J.W. G.A. Fox, D.E. Storm, C. Penn, and G.O. Brown. 2009. Subsurface transport of phosphorus in riparian floodplains: Influence of preferential flow paths. *J. Environ. Qual.* 38(2): 473-484.
6. Haan, C.T., B.J. Barfield, and J.C. Hayes. 1994. *Design Hydrology and Sedimentology for Small Catchments.* Academic Press, Inc.
7. Heeren, D.M., R.B. Miller, G.A. Fox, D.E. Storm, T. Halihan, and C.J. Penn. 2010a. Preferential flow effects on subsurface contaminant transport in alluvial floodplains. *T. ASABE* 53(1): 127-136.
8. Heeren, D.M., R.B. Miller, G.A. Fox, D.E. Storm, A.R. Mittelstet, and C.J. Penn. 2010b. Impact of preferential flow paths on alluvial groundwater flow patterns and phosphorus transport in the Ozark Ecoregion. ASABE Paper No. 1008729. St. Joseph, Mich.: ASABE.
9. Lacas, J.-G., M. Voltz, V. Gou, N. Carluer, and J.-J. Gril. 2005. Using grassed strips to limit pesticide transfer to surface water: A review. *Agron. Sustain. Dev.* 25(2): 253-266.
10. McCarty, G., and J. Angier. 2001. Impact of preferential flow pathways on ability of riparian wetlands to mitigate agricultural pollution. In *Proc. 2nd Intl. Symp. On Preferential Flow: water Movement and Chemical Transport in the Environment*, 53-56. D. Bosch and K. King. Eds. St. Joseph, Mich.: ASAE.
11. Miller, R.B., D.M. Heeren, G.A. Fox, T. Halihan, D.E. Storm, and A.R. Mittelstet. 2010. Geophysical mapping of preferential flow paths across multiple floodplains. ASABE Paper No. 1008730. St. Joseph, Mich.: ASABE.
12. Murphy, J., and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* 27: 31-36.
13. Neitsch, S.L., J.G. Arnold, .R. Kiniry, R. Srinivasan, and J.R. Williams. 2002. Soil and water assessment tool user's manual, version 2000. Temple, TX: Grassland, Soil and Water Research Laboratory, Agricultural Research Service.
14. NRCS (Natural Resource Conservation Service). 1994. The phosphorus index: A phosphorus assessment tool. United States Department of Agriculture, Natural Resources Conservation Service. http://nrcs.usda.gov/TECHNICAL/ECS/nutrient/pindex.html, *accessed* on April 14th, 2010.
15. NRCS (Natural Resource Conservation Service). 2009. National Ag. Imagery Program Mosaic: 2008. Datagateway Database. Washington, D.C.: USDA. Available at: http://datagateway.nrcs.usda.gov/GatewayHome.html. Accessed 15 March 2010.

16. Poletika, N.N., P.N. Coody, G.A. Fox, G.J. Sabbagh, S.C. Dolder, and J. White. 2009. Chlorpyrifos and atrazine removal from runoff by vegetated filter strips: Experiments and predictive modeling. *J. Environ. Qual.* 38(3): 1042-1052.
17. Polyakov, V., A. Fares, and M.H. Ryder. 2005. Precision riparian buffers for the control of nonpoint-source pollutant loading into surface water: A review. *Environ. Rev.* 13(3): 129-144.
18. Popov, V.H., P.S. Cornish, and H. Sun. 2005. Vegetated biofilters: The relative importance of infiltration and adsorption in reducing loads of water-soluble herbicides in agricultural runoff. *Agric. Ecosyst. Environ.* 114(2-4): 329-347.
19. Pote, D.H., T.C. Daniel, and P.B. DeLaune. 2009. Total phosphorus and total dissolved phosphorus in water samples. In *Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters*, 113-114. J.L. Kovar and G.M. Pierzynski, eds. Blacksburg, Va.: SERA-IEG 17, Virginia Tech University.
20. Reichenberger, S., M. Bach, A. Skitschak, and H.-G. Frede. 2007. Mitigation strategies to reduce pesticide inputs into ground- and surface water and their effectiveness: A Review: *Sci. Total Environ.* 384: 1-35.
21. Sabbagh, G.J., G.A. Fox, A. Kamanzi, B. Roepke, and J.Z. Tang. 2009. Effectiveness of vegetative filter strips in reducing pesticide loading: Quantifying pesticide trapping efficiency. *J. Environ. Qual.* 38(2): 762-771.
22. Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, and R. Parry. 2003. Agricultural phosphorus and eutrophication. 2nd ed. ARS-149. USDA, Washington, DC.
23. Sims, J.T., and A.N. Sharpley. 2005. *Phosphorus: Agriculture and the environment. Agronomy monograph no. 46.* Madison, Wisconsin, USA.
24. Soil Conservation Service. 1972. "Hydrology," Sect.4, Soil Conservation Service National Engineering Handbook. U.S. Department of Agriculture, Washington, DC.
25. Storm, D.E., P.R. Busteed, A.R. Mittelstet, and M.J. White. 2009. Hydrologic modeling of the Oklahoma/Arkansas Illinois River basin using SWAT 2005: Final report submitted to the Oklahoma Department of Environmental Quality. Biosystems and Agricultural Engineering Department, Division of Agricultural Sciences and Natural Resources, Oklahoma State University, October 8, 2009.
26. White, M. 2007. Development and validation of a quantitative phosphorus loss assessment tool. Ph.D. Dissertation, Oklahoma State University, Stillwater, OK.
27. White, M.J., D.E. Storm, M.D. Smolen, and H. Zhang. 2009. Development of a quantitative pasture phosphorus management tool using the SWAT model. *Journal of the Americna Water Resources Association* 45(2): 397-406.
28. White, M.J., D.E. Storm, P.R. Busteed, M.D. Smolen, H. Zhang, and G.A. Fox. 2010. A quantitative phosphorus loss assessment tool for agricultural fields. *Environmental Modeling and Software* (In Press).
29. Zhang, H., D.W. Hamilton, and J. Payne. 2009. Using poultry litter as fertilizer. Oklahoma Cooperative Extension Service PSS-2246, Oklahoma State University. http://www.poultrywaste.okstate.edu/files/pss-2246web.pdf, Accessed April 16th, 2010.