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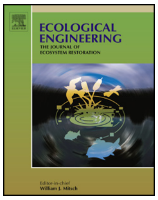

Estimating effects of reforestation on nitrogen and phosphorus load reductions in the Lower Yazoo River Watershed, Mississippi

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ABSTRACT

Surface water quality in the Lower Mississippi River Basin (LMRB) and the adjacent Gulf of Mexico has degraded over the past several decades primarily due to deforestation to agricultural lands and the loss of wetlands. This study investigated the benefits of reforestation upon nitrate–nitrogen ($NO_3^- - - -N$) and orthophosphate (PO_4^{3-}) load reductions in the Lower Yazoo River Watershed (LYRW) within the LMRB using the BASINS-HSPF model. The model was calibrated and validated with available experimental data prior to its applications. Two simulation scenarios were then performed: one was chosen to predict the $NO_3^- - - -N$ and PO_4^{3-} loads without reforestation and the other was selected to estimate the impacts of reforestation upon $NO_3^- - - -N$ and PO_4^{3-} load reductions following the conversion of 25, 50, 75, and 100% of the agricultural lands (with most lands near or in the batture of the streams) into forests. In general, an increase in forests reduced $NO_3^- - - -N$ and PO_4^{3-} loads and occurred because forest soils enriched in organic matter absorb water and nutrients and reduce the surface water runoff. Overall, a two-fold increase in forest land would result in approximately two-fold decrease in annual average $NO_3^- - - -N$ and PO_4^{3-} loads. On average, over a 10-year simulation, the specific $NO_3^- - - -N$ and PO_4^{3-} load reductions were, respectively, 0.06 and 0.004 ton/ha/y. Although the annual average $NO_3^- - - -N$ and PO_4^{3-} loads always decreased with increasing forest land conversion, the optimal specific $NO_3^- - - -N$ and PO_4^{3-} load reductions were found at a 75% reduction of agricultural land for the simulation conditions used in this study. Additionally, the annual average $NO_3^- - - -N$ load was about 16 times higher than that of PO_4^{3-} in the LYRW. This study suggests that reforestation in or around the batture of streams is a beneficial practice for $NO_3^- - - -N$ and PO_4^{3-} load reductions.

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1. Introduction

Water quality in the Mississippi River Basin (MRB) and the adjacent Gulf of Mexico (GOM) has degraded over the past several decades primarily due to deforestation and wetland loss. Eutrophication of GOM with nitrogen (N) discharged from the MRB has been well documented (Goolsby, 2000; Rabalais et al., 2002; Mitsch et al., 2006; Alexander et al., 2008). The use of N fertilizer for agricultural practices has been dramatically increased in the MRB since 1950s and a significant amount of the excessive nitrate–N ($NO_3^- - - -N$) are routed through drainage tiles, ditches, streams, and rivers into the GOM (Goolsby, 2000; National Research Council, 2000; Mitsch et al., 2001; Bianchi et al., 2010). Goolsby (2000) estimated the N source and flux to the GOM from the MRB and found that the major cause for the eutrophication of GOM is the increase in N delivery, especially $NO_3^- - - -N$. The concentrations of $NO_3^- - - -N$ have increased several folds during the past 100 years in streams from the MRB, and the annual delivery of $NO_3^- - - -N$ from the MR to the GOM has nearly tripled since the late 1950s (Goolsby et al., 1999). Goolsby (2000) also found that the average concentration of $NO_3^- - - -N$ in the MRB is 1.45 g N/L and its export to the GOM is about 1,000,000 ton/y.

It has been estimated that the major excess nutrients are derived from corn and soybean farms runoff in the Midwest of the USA, animal feedlots, sewage treatment plants, and industrial sources (MART, 2006; Mitsch et al., 2001; Bianchi et al., 2010). The mean annual flux is about 1.2 million metric tons of N and 0.15 million metric tons of phosphorus (P) (Aulenbach et al., 2007). Of which about 22% for N and 34% for P are from point sources (MART, 2006). The increase in delivery of $NO_3^- - - -N$ can enhance the production of organic carbon in the GOM. Rabalais et al. (1999) assessed that an atom of N from the Mississippi River is recycled

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about four times in the GOM before it is lost from the water column. Therefore, an approximately 0.95 million metric tons of $NO_3^- - - -N$ discharged annually from the MRB (Goolsby et al., 1999) could potentially produce more than 20 million metric tons of organic carbon annually in the GOM, which could lead to the dissolved oxygen (DO) depletion in water column and to the elevated extent and severity of seasonal hypoxic zones ($DO < 2$ mg/L). The hypoxic zone will cause stress or death in bottom-dwelling organisms that cannot leave the zone (Rabalais et al., 2002; Lohrenz et al., 2008).

While the flux of N may have decreased since 1990 in the MRB, the flux of P has remained steady (Turner et al., 2008). Although $NO_3^- - - -N$ is traditionally considered as the most important nutrient for phytoplankton growth, phosphorus could be a limiting factor for phytoplankton (Sylvan et al., 2006). When oxygen concentration in bottom water decreases, phosphate can be released rapidly from the sediment (Sutula et al., 2004; Howarth and Marino, 2006). If the phosphate can be mixed upward to the pycnocline (the layer where density change with depth is at a maximum), it can fuel phytoplankton production in areas that would otherwise be considered P-limited. Therefore, the release of P from sediments may have a significant role in maintaining primary production (Sutula et al., 2004).

Deforestation to agricultural lands in the MRB has tremendous impacts on nutrient loads to aquifers, streams, and coastal waters. A 500% increase in agricultural N fertilizer application from 1950–1970 to 1980–1996 is the primary contributor to a 200% increase in $NO_3^- - - -N$ export from the MRB to the GOM (Goolsby and Battaglin, 2001), while states within the U.S. Corn Belt are major contributors to nutrient loading (Schilling and Zhang, 2004). Schilling and Zhang (2004) reported that $NO_3^- - - -N$ export from the Raccoon River catchment, Iowa is the highest out of 42 Mississippi River sub-catchments evaluated in a GOM hypoxia study. Alexander et al. (2008) reported that about 70% of the N and P exported to the GOM is from agricultural practices such as the elevated fertilizer application, the extended corn and soybean growth, and the increased surface water runoff (Howarth et al., 2002; Zhang and Schilling, 2006). For the N load into the GOM, corn and soybean cultivation accounts for 52% and atmospheric deposition accounts for 16%. For the P load into the GOM, pasture and rangelands account for 37%, corn and soybean cultivation 25%, other crops 18%, and urban sources 12%. These authors further stated that the amount of in-stream P and N loads into the GOM increases with stream size although reservoir trapping of P causes large local- and regional-scale differences.

Despite numerous efforts devoted to investigating the relationships between the ecological and environmental consequences of deforestation and the benefits of reforestation in the MRB (Harris, 2006), our literature search revealed that the impacts of reforestation on nutrient loads in the MRB are still poorly understood. With an increased appreciation of the importance of drinking water quality to public health and raw water quality to terrestrial life, there is a great need to further examine these issues. Since the dynamics of nutrient variation and load reduction in a given watershed are complex, it is very difficult to quantify them by experimentation alone for different types of land uses, for a variety of soil and hydrological conditions, and for all possible combinations of surficial driving forces. Therefore, a need exists to employ the modeling approach for this purpose.

Recently, we have published a study regarding the impacts of reforestation upon sediment load and water outflow in the Lower Yazoo River Watershed (LYRW), Mississippi (Ouyang et al., 2013). In this companion study, our focus was to estimate potential impacts of reforestation upon $NO_3^- - - -N$ and PO_4^{3-} load reductions in the same watershed. Specific objectives of this companion study were to: (1) extend the site-specific BASINS-HSPF model for LYRW to include the $NO_3^- - - -N$ and PO_4^{3-} load predictions; (2) calibrate and validate the $NO_3^- - - -N$ and PO_4^{3-} components of the model using the field measured data; and (3) apply the model to investigate the role of reforestation (i.e., a conversion of agricultural land near bank into forests) on $NO_3^- - - -N$ and PO_4^{3-} load reductions in the LYRW.

2. Materials and methods

2.1. Study sites

The LYRW is located in the south Yazoo River Basin (YRB), Mississippi, USA (Fig. 1). This watershed consists of 61% forest land and 31% agriculture land with soil types of sand, loam, and clay. Surface water pollution within the YRB includes excess nutrients, sediments, heavy metals, and herbicides, which are the results of storm water runoff, discharge from ditches and creeks, groundwater seepage, aquatic weed control, naturally-occurring organic inputs, and atmospheric deposition (Nett et al., 2004; Pennington, 2004; Aulenbach et al., 2007; Alexander et al., 2008; Shields et al., 2008). An elaborate description of the study site can be found in our previous study (Ouyang et al., 2013).

2.2. Model development and data acquisition

The site-specific BASINS-HSPF model developed for hydrological processes and sediment load for the LYRW from our previous study (Ouyang et al., 2013) was extended to incorporate the $NO_3^- - - -N$ and PO_4^{3-} transport and load in this companion study. The HSPF modules such as PERLND, IMPLND, and RCHRES used in this study were the same as those used in the previous study. Additionally, those sub-modules related to $NO_3^- - - -N$ and PO_4^{3-} transport and load, including PQUAL from PERLND, IQUAL from IMPLND, and RQUAL from RCHRES, were also turned on. The PQUAL sub-module is used to simulate the fate, transport and load of nutrients (e.g., $NO_3^- - - -N$ and PO_4^{3-}) and other pollutants frompervious lands into streams under different land use patterns, whereas the IQUAL sub-model is used to simulate the fate, transport and load of nutrients and other pollutants from impervious lands into streams. The RQUAL sub-module is used to simulate the routing of nutrients and other pollutants within reaches. The physicochemical processes of N and P used in HSPF model include nitrification, denitrification, sorption, precipitation, leaching, and loading. Detailed information about the structure, functions, and limitations of these modules and sub-modules is beyond the scope of this study, but can be found from HSPF User's Manual and elsewhere (Donogian et al., 1984; Bicknell et al., 2001; Ouyang et al., 2013; Sommerlot et al., 2013). Fig. 1 shows the modeled domain for the LYRW used in this study.

Data collection for the LYRW, including watershed descriptions, meteorological conditions, hydrologic processes, and sediment load, were presented in our previous study (Ouyang et al., 2013). The new dataset required for this companion study is the $NO_3^- - - -N$ and PO_4^{3-} concentrations from the LYRW outlet. The data were downloaded from the USGS station (07288955) in Yazoo River BL Steele Bayou near Long Lake, Mississippi (Fig. 1).

2.3. Model calibration and validation

The hydrologic and sediment components of the BASIBS-HSPF model for the LYRW have been calibrated and validated in our previous study (Ouyang et al., 2013). In this study, we only need to