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EVALUATION OF TWO NUTRIENT INPUT METHODS OF HSPF: MONTHLY DATA BLOCK AND MANUAL TIME SERIES

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ABSTRACT

Use of AGCHEM modules within Hydrological Simulation Program Fortran (HSPF) requires extensive efforts of time series data preparation. In this research, two nutrient input methods, Monthly Data Block and Manual Time Series, were compared and evaluated with a developed St. Louis Bay watershed water quality model. The results indicated that HSPF responded to nutrient input very well and there was much difference in the generated nutrient loadings between these two methods. The Monthly Data Block method is easier to use but it misrepresents nutrient distribution, cannot preserve intended mass balance, and cannot simulate field fertilization practice. Monthly Data Block approach is suitable to provide nutrient inputs from atmospheric deposition. Manual Time Series method is more accurate and flexible to input nutrient from any sources, but is very time-consuming, especially for long time simulation. The users should understand the characteristics of model functions to ensure the correct input of boundary loading since correct input of nutrient boundary loadings has strong impacts on in-stream nutrient modeling.

1. INTRODUCTION

Hydrological Simulation Program Fortran (HSPF) is an extensively used watershed hydrology and water quality model (Ritter et al., 2001). One of the most attractive features of HSPF is its ability to simulate complex physical, chemical, and biological processes occurring in croplands (Bicknell, 2001). HSPF can be used to simulate various water quality constituents including Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), sediment, nutrients, bacteria, pesticide, and conservative substance. The AGCHEM module of HSPF has been successfully applied to nutrient processes in several studies (Bicknell et al., 1984; Moore et al., 1988; Donigian et al., 1994; Im, et al., 2003; Filoso, et al., 2004; Saleh and Du, 2004; Liu et al., 2005). However, the advantages and disadvantages of different nutrient input methods have not been examined. Basically, there are three methods available: Special Action Block, Monthly Data Block and Manual Time Series. Our objective is to evaluate the Monthly Data Block and Manual Time series methods with a developed watershed model for St. Louis Bay in Mississippi. This comparison is useful since model calibration can be a meaningless exercise without correct input of boundary loadings as indicated by Chapra (2003). Specification of input parameters in Special Action Block has been documented by Bicknell et al. (2001), and will not be discussed here.

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2. STUDY AREA DESCRIPTION

For our purposes we will use an HSPF simulation of hydrology and nutrient processes in St. Louis Bay watershed of Mississippi (Huddleston et al., 2006). St. Louis Bay watershed is located in the Gulf Coast region of Mississippi. The total drainage area is approximately 500,000 acres (Figure 1). There are two major tributaries, the Wolf and Jourdan Rivers. This area has a humid, subtropical climate characterized by long, hot summers and temperate winters. The average annual temperature is 20˚C; the average annual precipitation is approximately 65 inches. The soils in most of the watershed are sandy loam textures, with scattered pockets of loamy soils throughout and along the banks of Wolf River. Much of the land near the coast is composed of silt loam soils (Huddleston et al., 2003). The elevation ranges from 16 to 417 feet. The majority of the study area remains relatively undeveloped with over half of the land area covered by forests. Even though agricultural land covers approximately 2 percent of the total area, it is very important to this study because cropland management practices can be a significant source of nutrient loading (Huddleston et al., 2003). The main crops in the study area are hay, soybean, wheat, and corn.

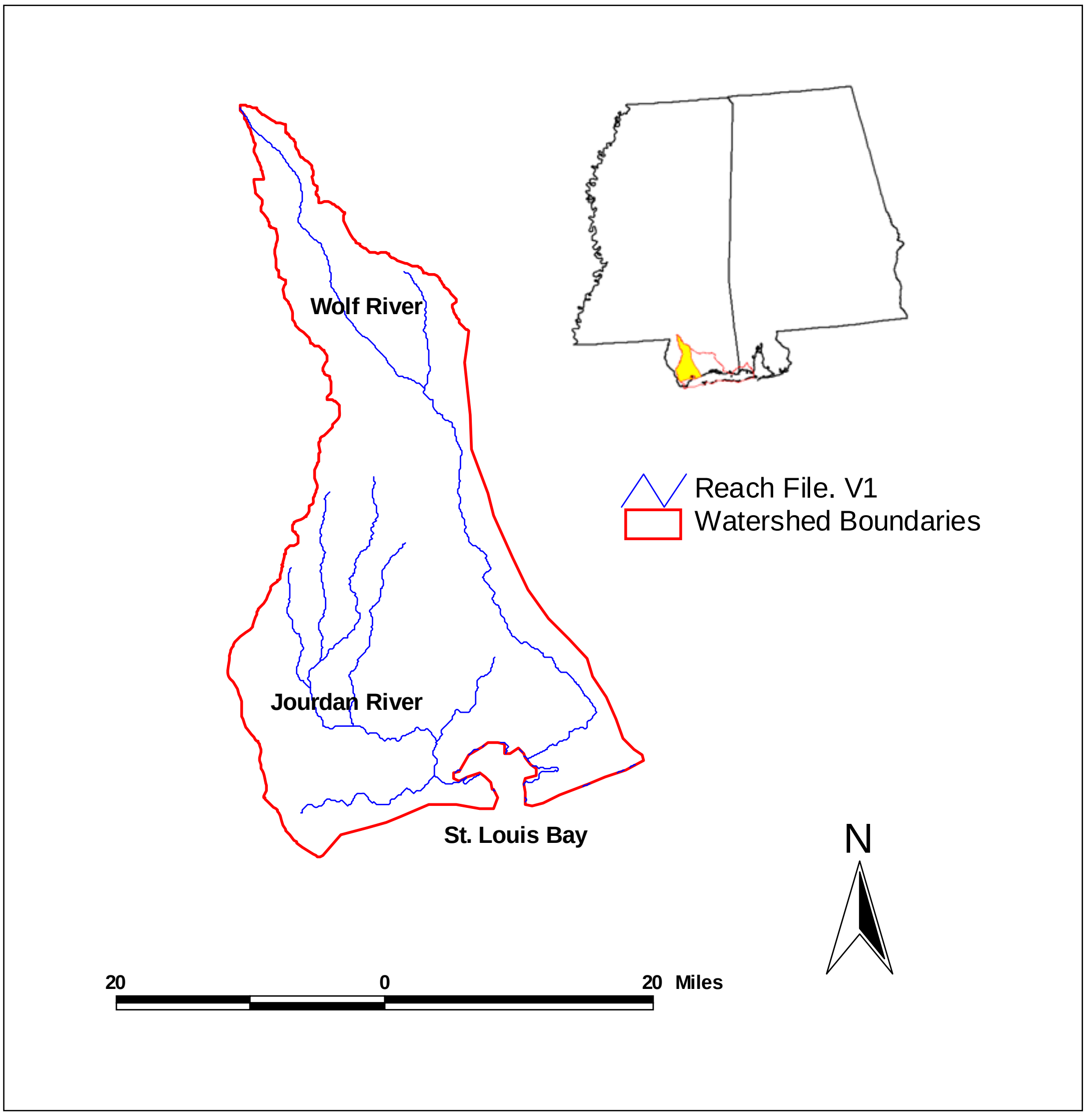

Figure 1. Location of St. Louis Bay watershed.

3. MODEL DESCRIPTION

The St. Louis Bay watershed model was initially developed for the purpose of Total Maximum Daily Load (TMDL) determination of fecal coliform. The detailed development of hydrologic input parameters and hydrologic calibration processes were described by Huddleston et al. (2001). The model was later extended to simulate DO, BOD, and nutrients (Huddleston et al., 2003; Huddleston et al., 2006). The simulation period spans 36 years, from 1965 to 2001. The observed water quality data used for model calibration was obtained from both the Mississippi Department of Environmental Quality (MDEQ) and USGS. The calibration site was at USGS gauge station 02481510 (Figure 2).

For nutrient simulation, the modeled non-point sources included atmospheric deposition, fertilization practices, and manure application. The simulated point sources included permitted discharge obtained from the National Permitted Discharge Elimination System (NPDES), failing septic systems, and direct contribution by cattle. The nutrient loadings from non-croplands were simulated using PQUAL module, which uses a simplified method based on the nutrient accumulation and removal rates over the land segments. AGCHEM modules were used to simulate the nutrient cycle occurring in the cropland. For modeling purposes, the soils were segmented into four layers with each layer associated with different flow and nutrient processes (Table 1). The determination of soil depths for each layer was described by Huddleston et al. (2003). The nutrient input to the model requires specific chemical speciation forms. For example, nitrogen must be in the form of nitrate, ammonium, or organic nitrogen, and phosphorus as phosphate or organic phosphorus. In addition, the nutrients must be distributed among the soil layers. For example, the nutrient input from fertilization practices can be applied only to the surface or upper layers depending on the typical or representative local fertilization practices. We consulted Extension Service personnel of Mississippi State University to come up with representative practices for such a large study area. The detailed development of nutrient input parameters based on fertilization practices for wheat, corn, soybean, and hay cropland was described by Liu et al. (2005). For the St. Louis Bay watershed model, there are more than 50 nutrient input time series, and each time series spans 36 years with a daily interval. The HSPF model domain considered herein was confined to the Wolf River watershed including the sub-watersheds labeled as 018, 019, and 020 (Figure 2).

Table 1. Soil layer division for watershed modeling.

Model Soil Layers	Depths (inches)	Associated hydrological and nutrient processes
Surface Layer	0 - 0.5	Surface runoff, fertilization, atmospheric deposition, manure application, plant uptake, evapotranspiration
Upper Layer	0.5 – 6.5	Interflow, fertilization, plant uptake, manure application, evapotranspiration
Lower Layer	6.5 – 47.5	Evapotransporation, plant uptake
Groundwater Layer	47.5 – 133.5	Ground water

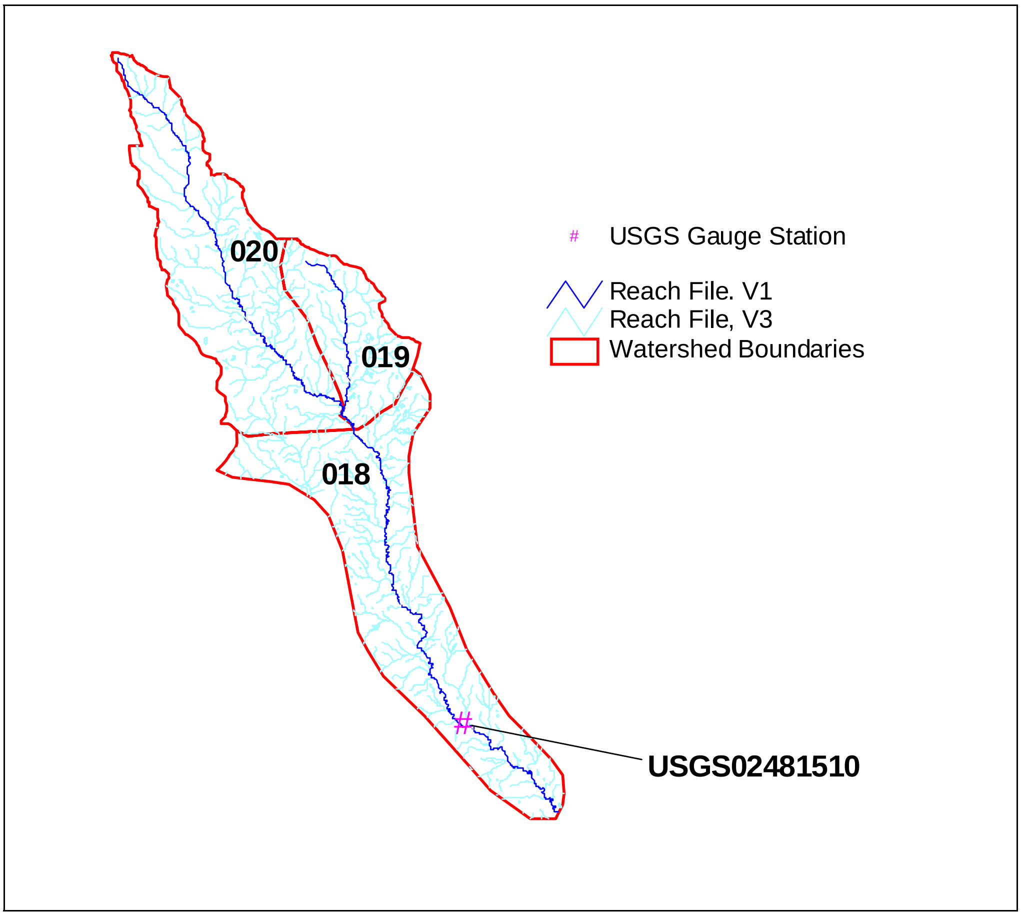

Figure 2. Modeling domain of the Wolf River watershed and location of U.S. Geological Survey water quality station.

4. EVALUATION OF INTERPOLATION FUNCTION OF MONTHLY DATA BLOCK

It is very easy to use Monthly Data Block to input the developed nutrient time series into HSPF. A monthly table is constructed first to specify the daily application rate at the start of each month. Then a linkage is needed between the constructed monthly table and target land segments. HSPF uses a linear interpolation function to generate the daily nutrient input based on the given application rate for the start of a given month and the subsequent month. The interpolation function is given by:

$$DAYVAL = MVAL1 + (MVAL2 - MVAL1) * (RDAY - 1) / RNDAYS \qquad (1)$$

where DAYVAL represents the interpolated amount of nutrients for a particular day (lb/day); MVAL1 is the amount of applied nutrients at the start of current month (lb/day); MVAL2 indicates the amount of applied nutrients at the start of the subsequent month (lb/day); RDAY represents day of the month, and RNDAY indicates number of days in the current month.

A simple modeling scenario was devised to evaluate this interpolation function. The hay cropland in sub-watershed 018 was arbitrarily selected to run the test simulation. It was assumed that phosphate fertilizer is applied only in March at a rate of 3.0 lb/day. The constructed monthly table is shown in Table 2. Hence, the total input of phosphate should be 93.0 lb/month, which is obtained by multiplying the daily rate with the number of days in March. However, the interpolation function does not generate the intended amount of input phosphate fertilizer. The generated daily input of phosphate for the water year 1965 for hay cropland is shown in Figure 3. Obviously, the interpolation function distributed nearly half of the applied phosphate to February even though the users did not intend to. Hence, the Monthly Data Block cannot represent the temporal distribution of applied nutrients. In addition, the summation of the generated daily phosphate loading was 88.5 lbs, not the intended application rate of 93.0 lbs. So, Monthly Data Block cannot preserve the intended mass of input nutrients. Another disadvantage is that Monthly Data Block cannot simulate field fertilization practices since it uses a daily rate. However, in field fertilizer is often applied once, or twice a month, not daily.

Table 2. Devised run test of interpolation function within Monthly Data Block.

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Daily Rate (lb/day)			3.0									

In order to examine the effects of application timing on the errors of input nutrient introduced by the interpolation function, 12 test runs were made. The daily application rate of 3.0 lb/day was applied in each month of the year. The errors for nutrient input for each run were then calculated. The results indicated that application timing strongly impacts errors of created nutrient inputs. Calculated errors ranged from underestimation by 4.8% to overestimation by 5.4% (Table 3). Under the condition that the number of days in the current month is more than the previous month, Monthly Data Block underestimates the boundary loadings, and in the reverse situation, Monthly Data Block produces an overestimation (Table 3).

The errors introduced by the interpolation function depend on the difference in the number of days between the current month and previous month (Table 3). For the tests on January and August applications, the interpolation function introduced the lowest errors because there is no difference in the number of days between current and previous months. For the tests on February and March, the highest errors occurred because of the magnitude in the difference in the number of days between current and previous months for February and March (Table 3). However, Monthly Data Block is suitable for nutrient input from atmospheric deposition, because there is continuous input for each month. In this case, the errors can be balanced as indicated by the paired errors of overestimation and underestimation in adjacent months (Table 3). The nutrient from fertilization is a discreet process, so the errors introduced by the interpolation function cannot be balanced.

Over the total cropland area and the entire simulation period in the model, the interpolation function overestimated phosphate application by 65, 135 lbs (Table 4). In the Wolf River watershed, cropland only covers approximately 5,000 acres. However, for some agriculturally intensive watersheds, errors of boundary loadings introduced by Monthly Data Block could be high enough to degrade the reliability of the constructed watershed model.

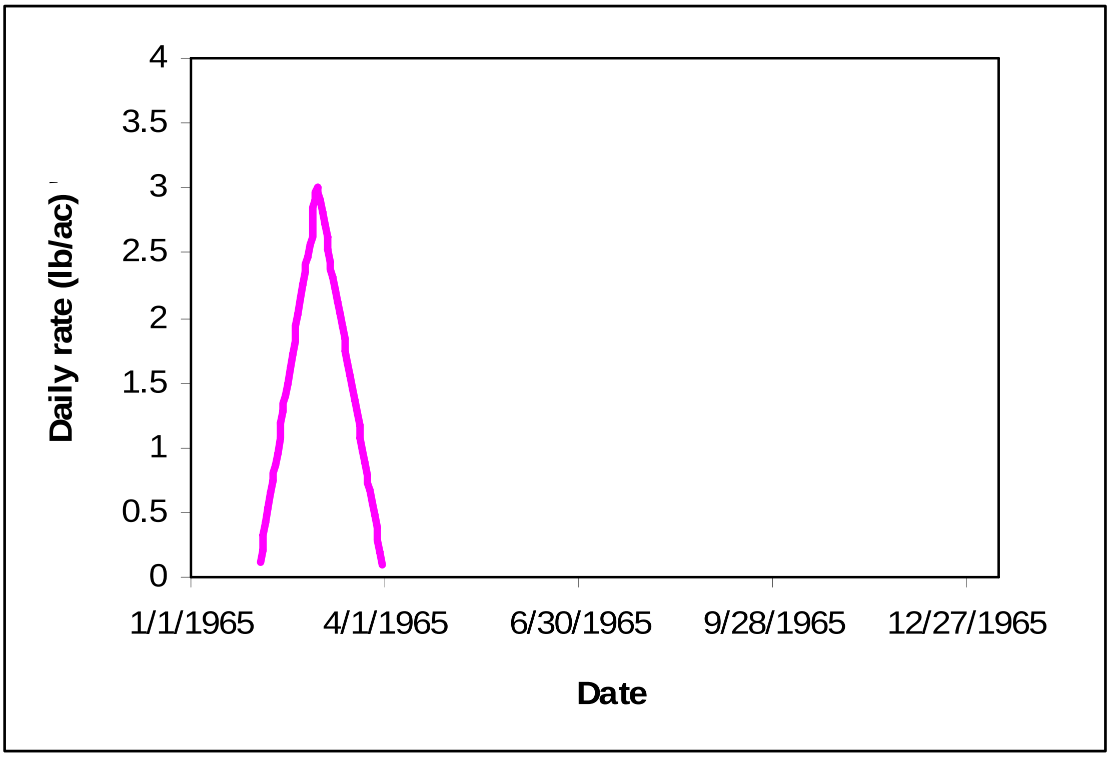

Figure 3. Generated phosphate fertilizer boundary loadings by Monthly Data Block.

Table 3. Errors of generated boundary loadings introduced by Monthly Data Block.

Month	Intended (lb/ac)	Generated (lb/ac)	Error (lb/ac)*	Percentage (%)*
JAN	93	93.03	+0.03	+0.04
FEB	84	88.54	+4.54	+5.41
MAR	93	88.54	-4.46	-4.79
APR	90	91.53	+1.53	+1.70
MAY	93	91.53	-1.47	-1.58
JUN	90	91.53	+1.53	+1.70
JUL	93	91.53	-1.47	-1.58
AUG	93	93.03	-0.03	+0.04
SEP	90	91.53	+1.53	+1.70
OCT	93	91.53	-1.47	-1.58
NOV	90	91.53	+1.53	+1.70
DEC	93	91.53	-1.47	-1.58

* Note: + indicates over-estimation and – indicates underestimation.

Table 4. Errors of phosphate fertilizer input introduced by interpolation function for St. Louis Bay watershed model.

Crop	Area (acre)	Error in generated nutrients input by Monthly-Data-Block (lb)*
Wheat	253	-1,866.38
Soybean	693	-1,8680.00
Corn	87	+981.74
Hay	4024	+84,699.39
Total	5057	+65,134.75

*Note: + indicates overestimation and – indicates underestimation.

5. COMPARISON OF MODELING PERFORMANCE BETWEEN USING MONTHLY DATA BLOCK AND MANUAL TIME SERIES

Both Monthly Data Block and Manual Time Series were used to input the phosphorus loadings into the model, and simulated phosphate concentrations were compared at the outlet of Wolf River in water year 2000. Simulations of non-cropland and point-source phosphate contributions were kept unaltered to make sure that the differences in the simulated phosphate concentrations were the result of nutrient input methods.

Two modeling scenarios were devised by using Manual Time Series. For modeling scenario 1, the monthly phosphorus boundary loadings were partitioned from monthly rates to equal daily rates. For modeling scenario 2, the loadings were assumed to be applied once at the middle of the month (the 15th day of the month) in order to simulate actual fertilization practices. For each scenario, the simulated phosphate stream concentrations by Manual Time Series were compared with those by Monthly Data Block.

Hay cropland contributes the majority of phosphorus loadings compared with other crops. Therefore, generated phosphorus boundary loadings from hay cropland were compared to examine the differences between Monthly Data Block and Manual Time Series. The developed phosphate input for hay cropland from fertilization is shown in Table 5.

Table 5. Developed phosphate fertilizer input for hay cropland (lb/month).

Soil Layer	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Surface				33.84	33.84	33.84						
Upper												

5.1 Construction of Manual Time Series

As an alternative to Monthly Data Block, the user can construct the nutrient input time series manually. We refer to this method as Manual Time Series. When using Manual Time Series, model users specify the amount of applied nutrient for each day over the entire simulation period. Manual Time Series affords the flexibility to simulate daily, weekly, or monthly application practices. However, the preparation of the input dataset is very time-consuming, especially for long simulation period. VBA\Excel is a comparatively simple tool to help prepare datasets using MACROs. The steps of constructing the manual daily time series were 1) creation of several MACROs to generate the nutrient input time series; 2) making a script to read the generated time series into the model; and, 3) establish a linkage between the constructed time series and the target land segments.

5.2 Modeling Scenario 1 Results

In modeling scenario 1, monthly application of phosphate in April, May, and June to hay cropland was equally distributed into daily rates by Manual Time Series (Figure 4). There were only slight differences in the generated phosphate boundary loading in April and May between Monthly Data Block and Manual Time Series. However, there was a large difference for March and June. Monthly Data Block distributed some of the applied phosphate to March (Figure 4). Hence, Monthly Data Block method artificially introduced phosphate inputs in March and decreased the phosphate loadings in June by half (Figure 4).

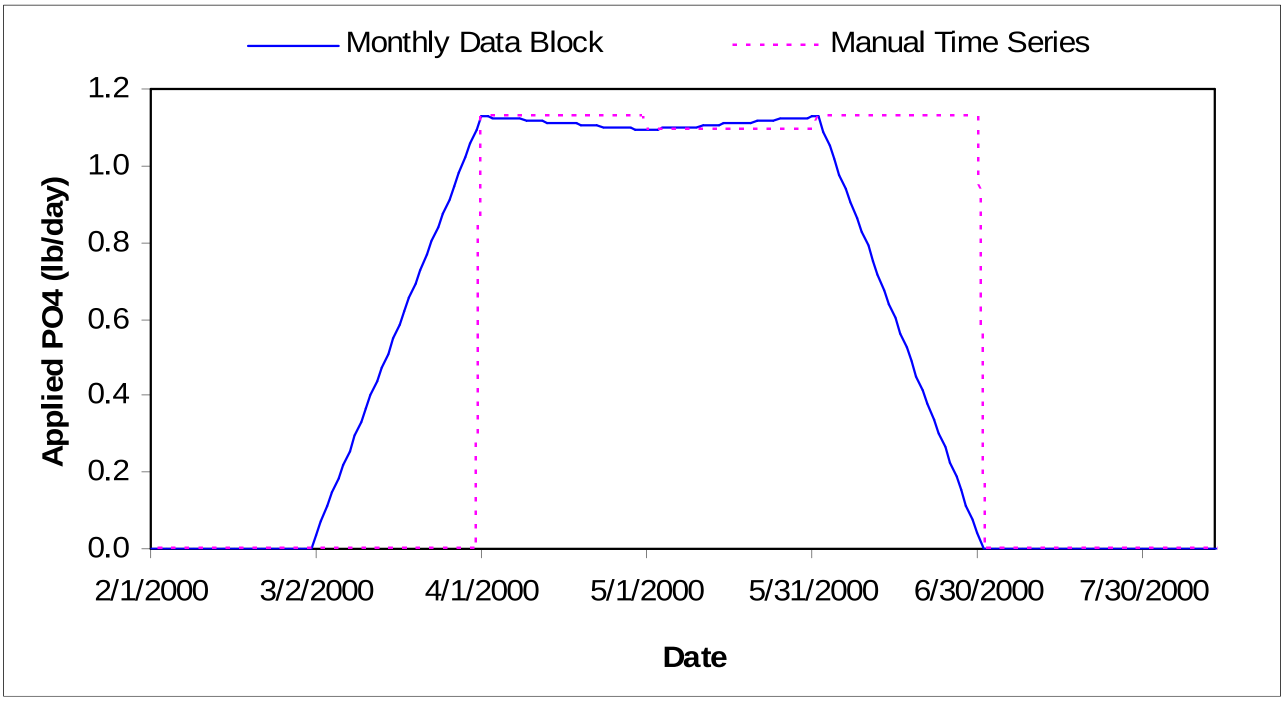

Figure 4. Comparison of generated PO_4 boundary input by using Monthly-Data Block and Manual Time Series in modeling scenario 1.

The watershed model responded very well to the nutrient boundary inputs. In April and May, there were small differences in simulated concentrations of phosphate between using Monthly Data Block and Manual Time Series (Figure 5). The simulated in-stream phosphate concentrations by Monthly Data Block were much higher in March and relatively lower in June than Manual Time Series (Figure 5).

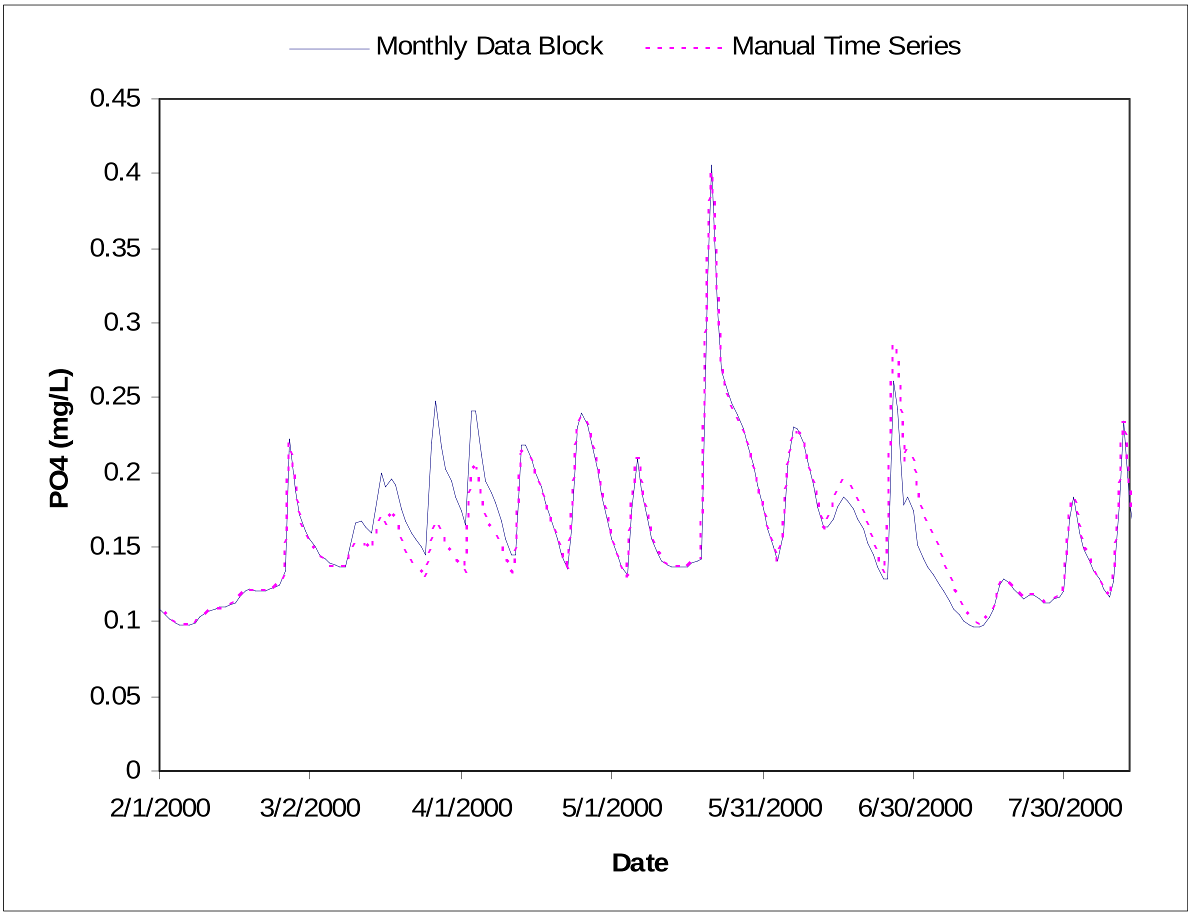

Figure 5. Comparison of simulated phosphate between Monthly Data Block and Manual Time Series in modeling scenario 1.

5.3 Modeling Scenario 2 Results

In modeling scenario 2, there is a great difference in the phosphate boundary loadings between Monthly Data Block and Manual Time Series. The three discrete points indicate phosphate applications by Manual Time Series, whereas Monthly Data Block uses the daily rate and applies some nutrients in the previous month, March (Figure 6). The different phosphate boundary loadings by these two methods resulted in the differences in modeled in-stream phosphate simulations (Figure 7). The field fertilization practices were simulated very well by Manual Time Series method; three high peak phosphate simulations responded to three high single-day applications of phosphate (Figure 7). In March, the simulated phosphate concentrations by Monthly Data Block were higher than those by Manual Time Series since the Monthly Data Block distributed some phosphate to March. Obviously, if we ignored the discrete applications of phosphate as with the Monthly Data Block approach, we may lose the ability to simulate some extreme events (Figure 7).

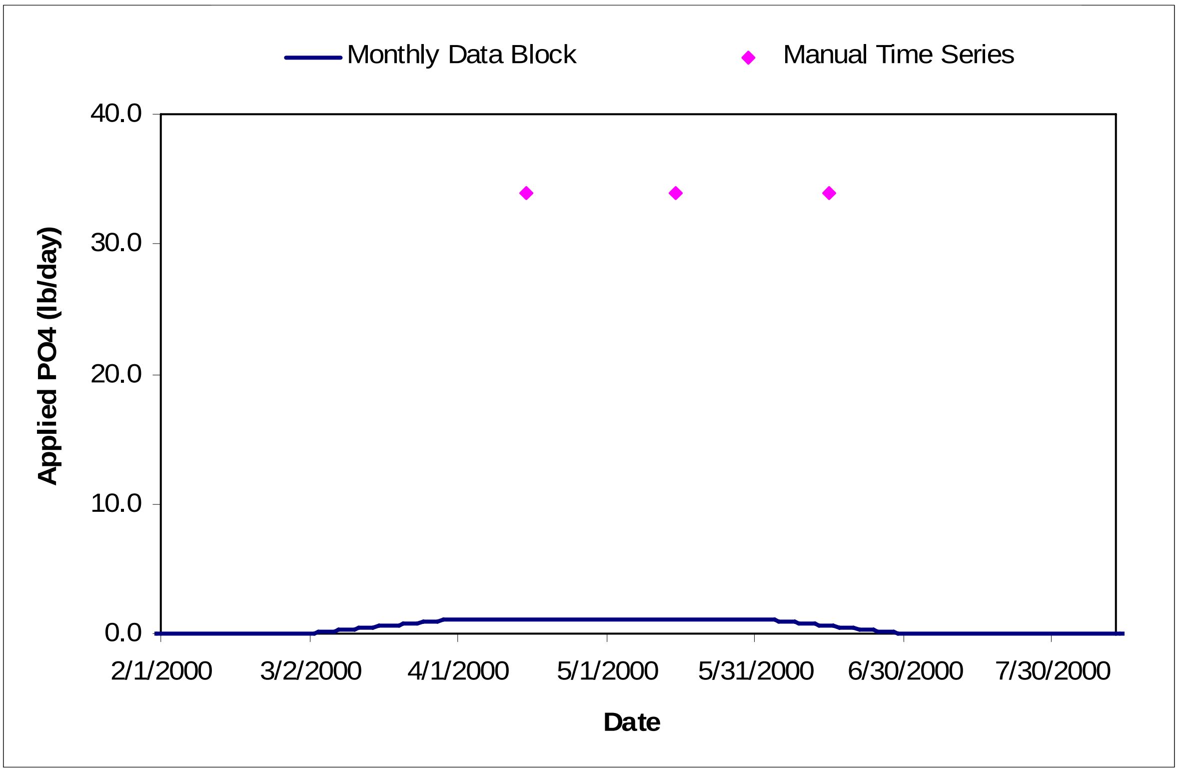

Figure 6. Comparison of generated PO_4 input between Monthly Data Block and Manual Time Series in modeling scenario 2.

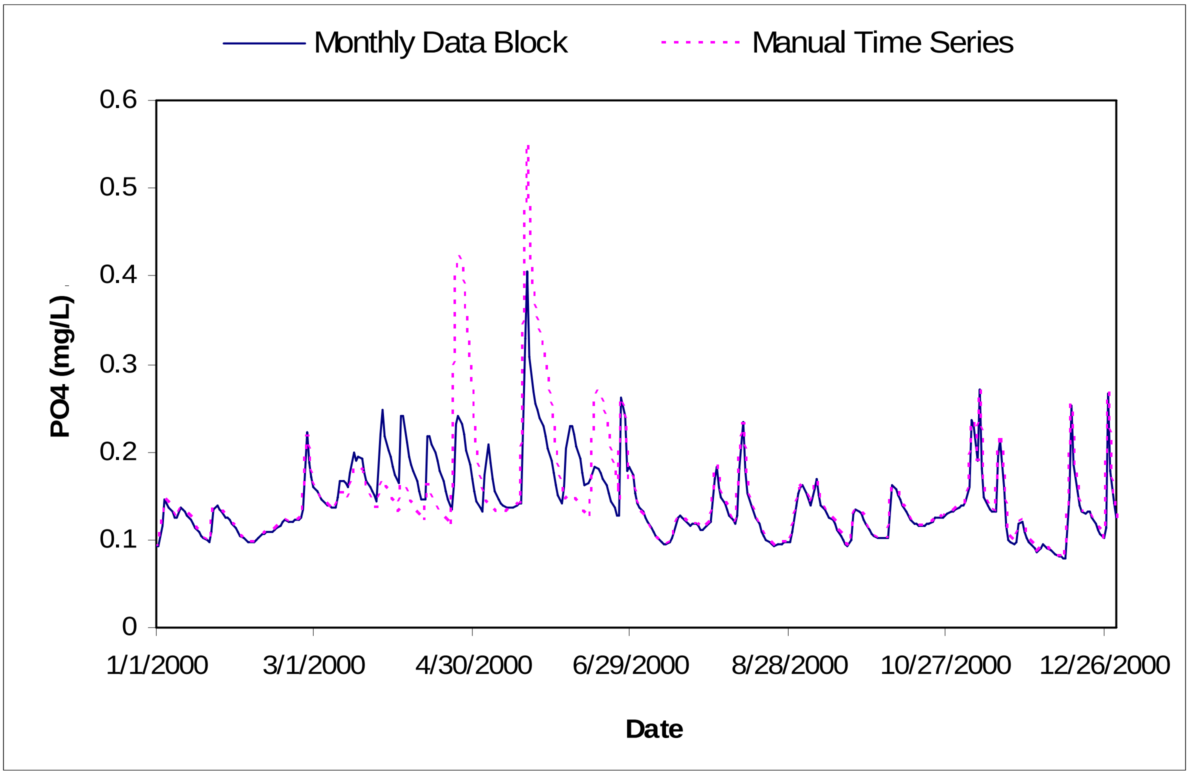

Figure 7. Comparison of simulated PO_4 between Monthly Data Block and Manual Time Series in modeling scenario 2.

6. CONCLUSIONS

The developed St. Louis Bay watershed model responded very well to the nutrient boundary loadings. There is a significant difference in the generated boundary loadings between two nutrient input methods: Monthly Data Block and Manual Time Series. The Monthly Data Block misrepresents the temporal distribution of applied nutrients by distributing some nutrients into the previous month. In addition, the Monthly Data Block cannot conserve the intended input mass. Another disadvantage is that Monthly Data Block cannot simulate the field fertilization practices because field fertilization practices normally last only a few days. However, Monthly Data Block is easy to use. Monthly Data Block is appropriate to nutrient inputs from atmospheric deposition since the errors introduced by the interpolation function can be balanced. Manual Time Series method affords a flexible approach to provide nutrient inputs from any sources. The disadvantage of Manual Time Series is that the preparation of datasets is very time-consuming, especially for long term simulation.

Both Monthly Data Block and Manual Time Series methods are valid and supportive techniques. In developing model users should understand characteristics of model functions and make sure that the developed nutrient inputs have been correctly entered into the model.

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