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MODELING SEDIMENT AND PHOSPHORUS YIELDS USING THE HSPF MODEL IN THE DEEP HOLLOW WATERSHED, MISSISSIPPI

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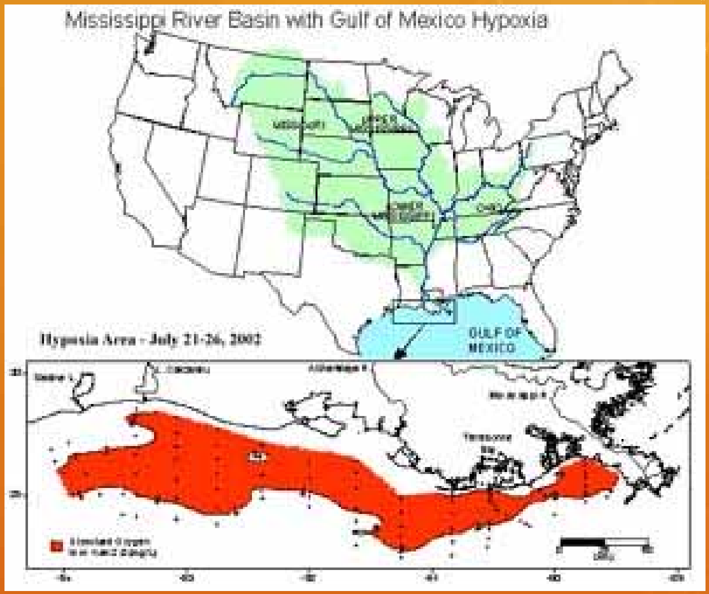
Outline

- Background
- Objectives
- Study Area
- HSPF
- Methods
- Results
- Conclusions

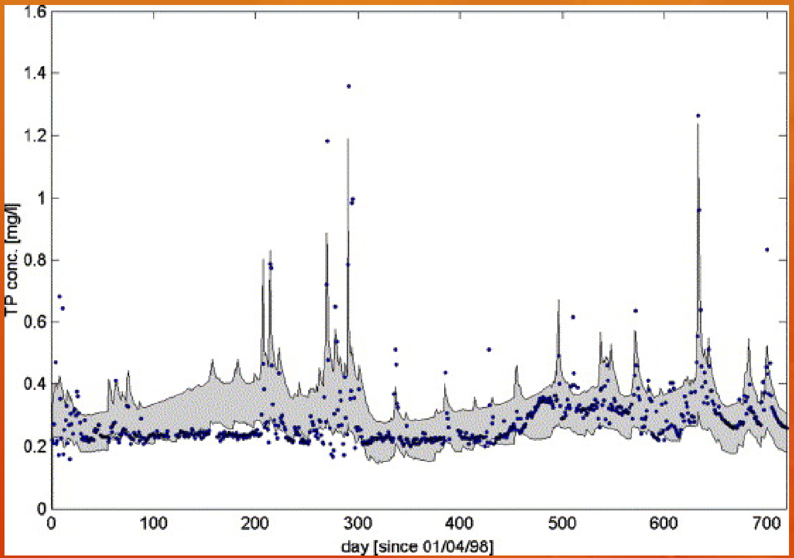
Background

- The impact of excess nutrient loads on eutrophication of waterbodies, including the increasingly frequent occurrences of harmful algal blooms and hypoxia, is well known and well documented.
- The Mississippi River/Gulf of Mexico Hypoxia is also a major environmental issue, and key components of the 2008 Gulf Hypoxia Action Plan are
  - the development and implementation of state nutrient reduction strategies (BMPs, LID)
  - reduce existing scientific uncertainties (Modeling, Monitoring, and Research) regarding source, fate, and transport of nitrogen and phosphorus in the surface waters of the Mississippi/Atchafalaya River Basin to continually improve the accuracy of management tools and efficacy of management strategies for nutrient reductions.



Background

- Effective implementation of nutrient load reductions requires that analytical tools be available to accurately estimate loads from watersheds and waterbodies as a function of hydrologic conditions.
- Hydrologic models have widely been used to accurately estimate outflows from watersheds, and to a lesser degree sediment and nutrient loads.
- Factors impacting runoff of nutrients are not well understood and as a consequence predictions of nutrient loads are highly uncertain.
- The processes associated to sediment and phosphorus transport from agricultural fields are complex due to crop management including tillage, fertilization, and harvest.



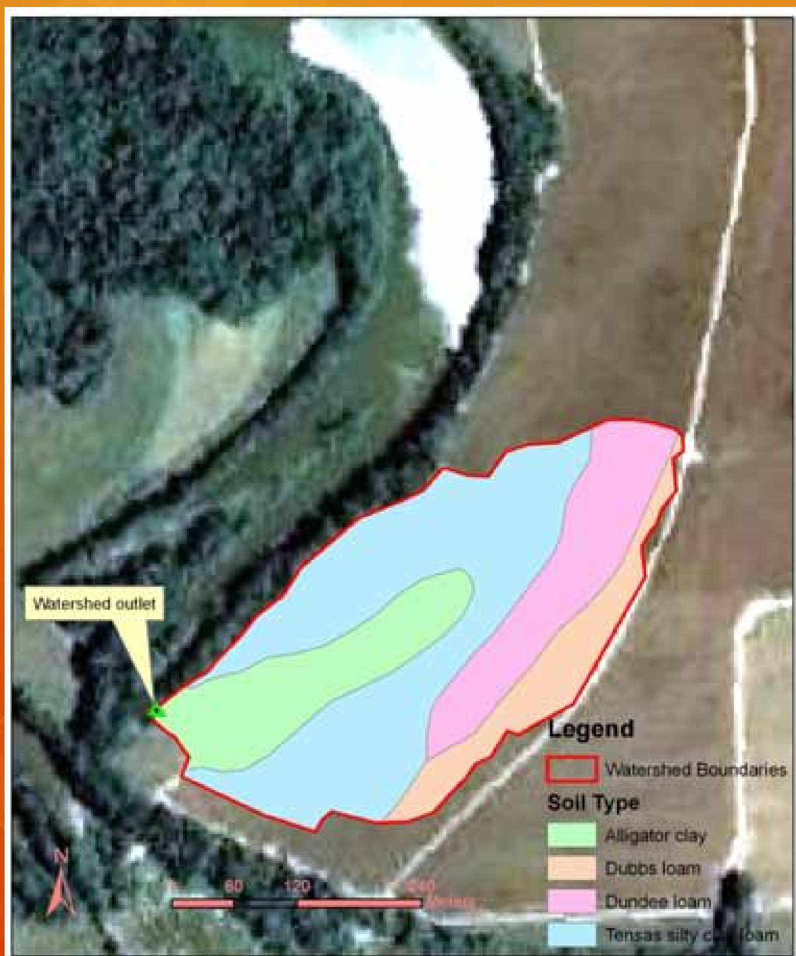
Evaluation of two hybrid metric-conceptual models for simulating phosphorus transfer from agricultural land in the river enborne, a lowland UK catchment. Journal of Hydrology Volume 304, Issues 1–4, 10 March 2005, Pages 366–380

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2004, A Science Strategy to Support Management Decisions Related to Hypoxia in the Northern Gulf of Mexico and Excess Nutrients in the Mississippi River Basin: prepared by the Monitoring, Modeling, and Research Workgroup of the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, U.S. Geological Survey Circular 1270, 58 p.

Objectives

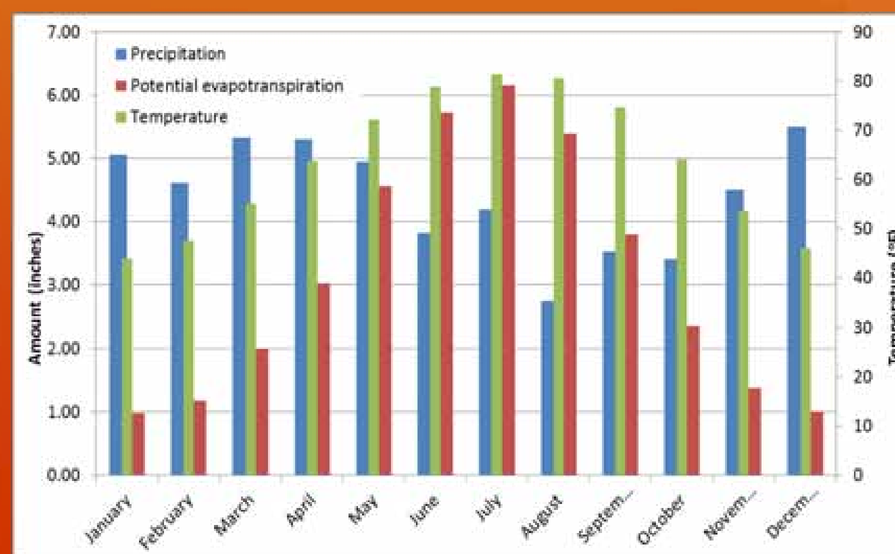
- This research evaluated the ability of the Hydrological Simulation Program – FORTRAN (HSPF) to simulate storm, seasonal, and long-term runoff, sediment, and phosphorus transport at the farm scale in the Deep Hollow drainage area, Mississippi.
- The main goal was to demonstrate the usefulness of HSPF as a computer tool for future environmental management and planning in the Mississippi Delta region.

Study Area

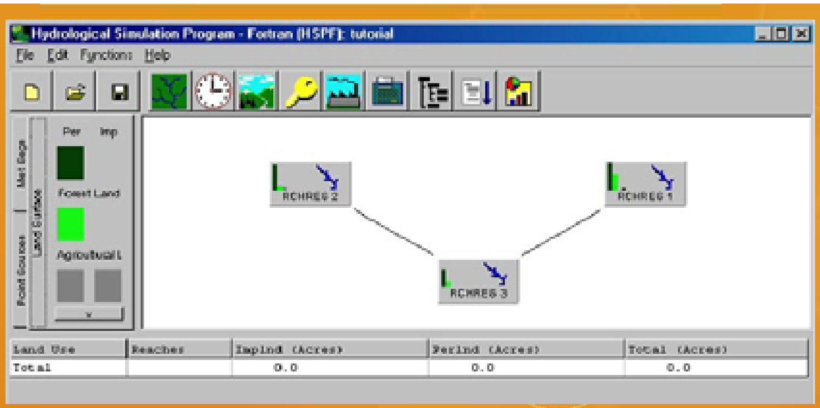


Deep Hollow drainage area is located in Leflore County, MS.

Study Site	Deep Hollow
Drainage Area (ha)	11.3
Slope (%)	0.3
Land Cover	Cotton (76%) Soybeans (24%) Winter wheat
Major Soil Type	Dundee loam (19%) Tensas silty clay loam (49%) Dubbs loam (13%) Alligator clay (19%)
Management Practice	Reduced tillage and winter cover crop. 9.5 Kg P/ha on 10/6/1998
Field Data Collection	USGS (1996-2000)
Hydrologic Soil Group	13% B, 19% C and 68% D
Runoff Potential	High

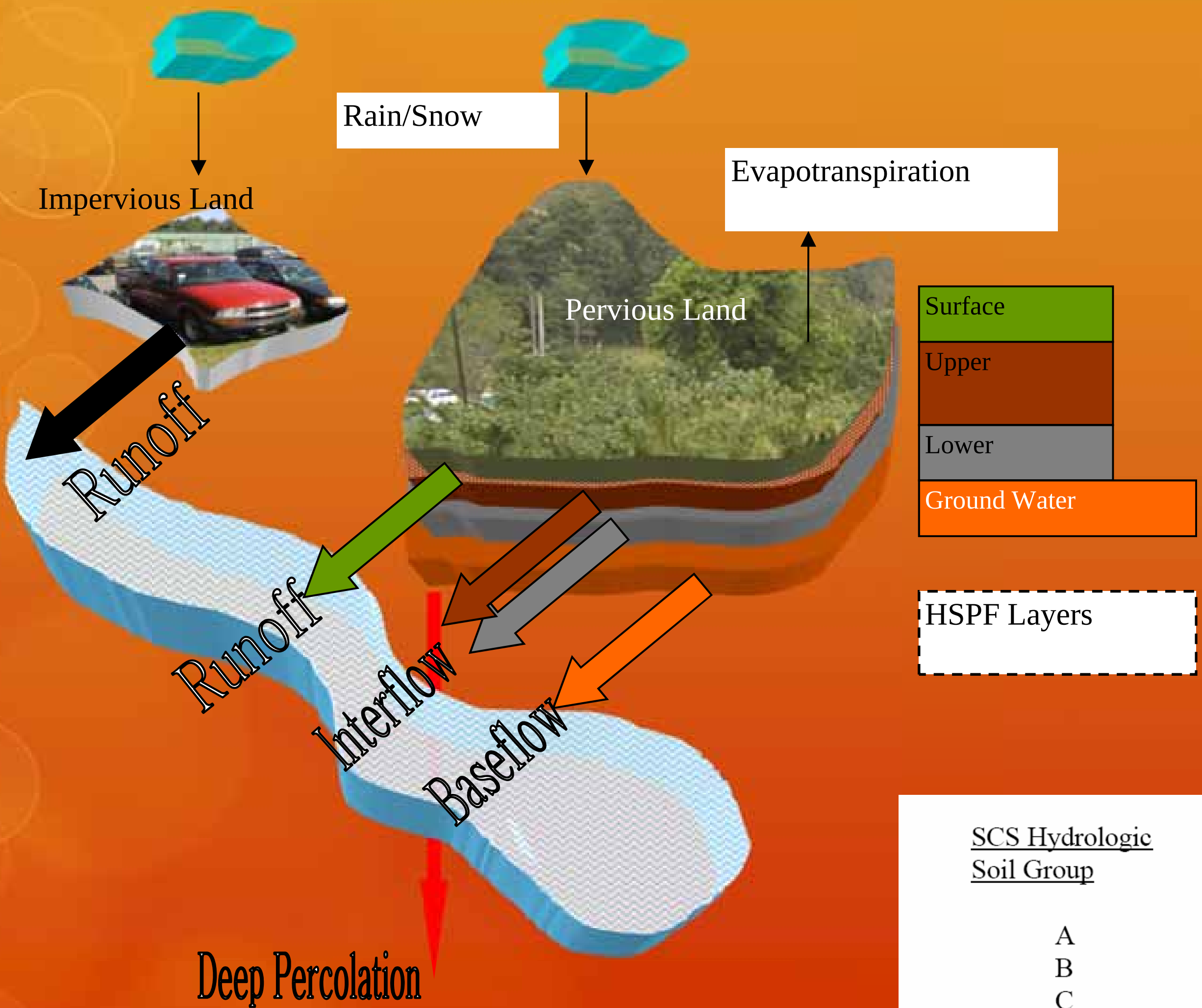


HSPF



- HSPF: Hydrological Simulation Program - FORTRAN
  - Modular program with capacity of simulation hydrologic cycle, erosion, sediment transport, nutrients, pesticides, and in-stream water quality
  - Used successfully since 80's in USA, Canada, Europe, Australia, and Africa.
  - Supported by EPA through the BASINS decision support system
  - http://water.epa.gov/scitech/datait/models/basins/index.cfm

HSPF: Hydrologic Components

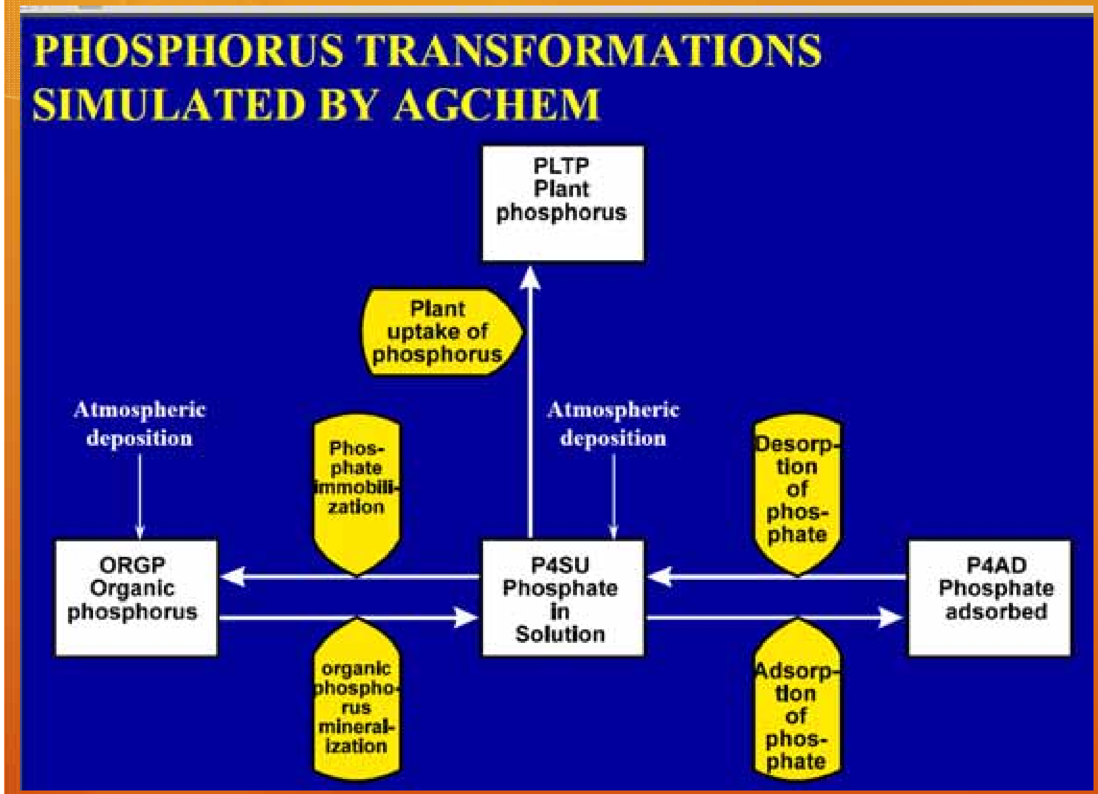


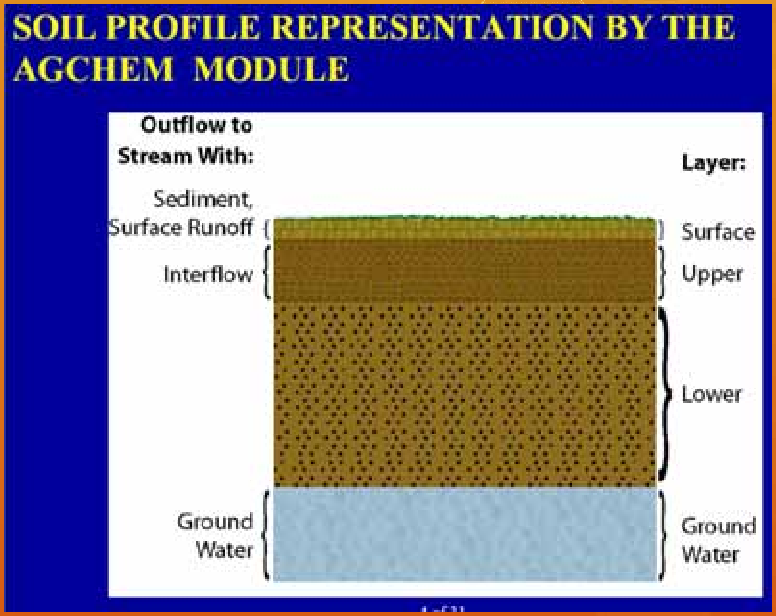
SCS Hydrologic Soil Group	INFILT Estimate (in/hr)	INFILT Estimate (mm/hr)	Runoff Potential
A	0.4 - 1.0	10.0 - 25.0	Low
B	0.1 - 0.4	2.5 - 10.0	Moderate
C	0.05 - 0.1	1.25 - 2.5	Moderate to High
D	0.01 - 0.05	0.25 - 1.25	High

HSPF: Soil Erosion and Transport Components

Overland Erosion/Deposition	*Power Relation*	
	(Negev, Meyer and Wischmeier, Foster)	
Channel Sediment Transport	*Sand:*	*Power function, Toffaleti and Colby Equations*
	Silt-Clay: Critical shear stress	

HSPF: Phosphorus Components





Mineralization, immobilization, and plant uptake reactions are simulated using temperature dependent, first-order kinetics.

Phosphorus adsorption and desorption can be simulated by either first-order kinetics or by the Freundlich method.

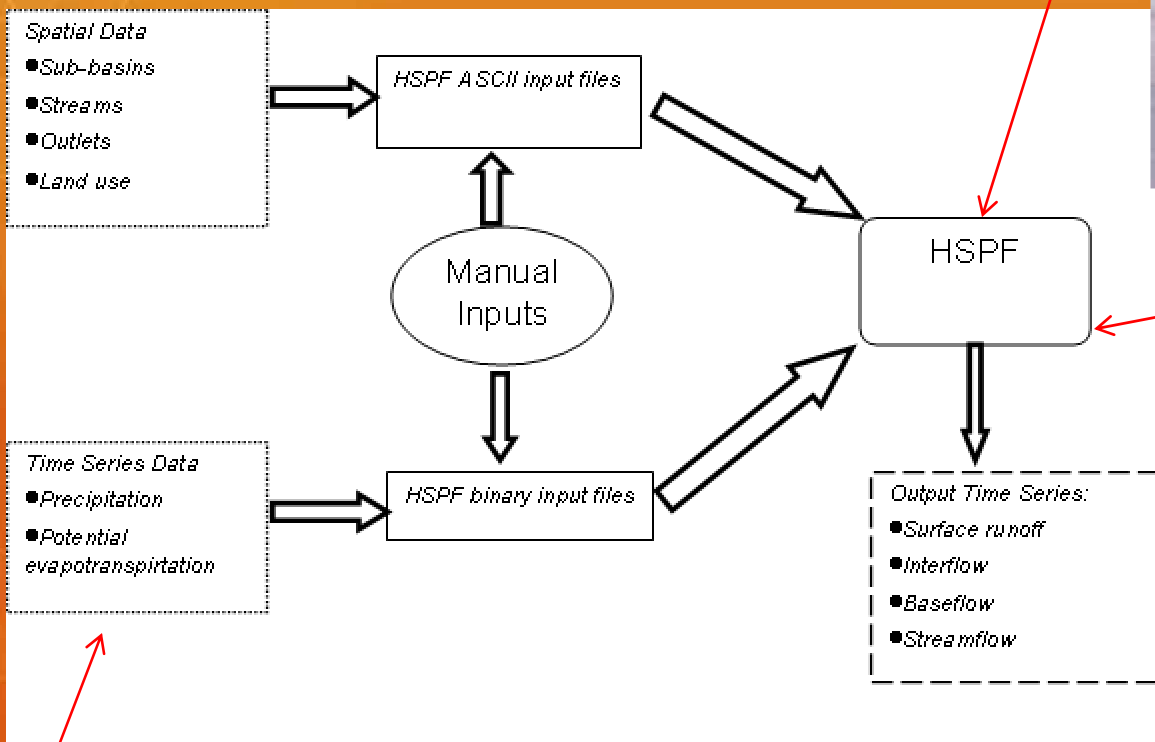
Detailed inputs of agricultural farm management activities including tillage, cultivation, fertilization, and harvest are handled through the model's special actions module.

HSPF simulates phosphorus as sediment-attached, dissolved in surface runoff, and as concentrations in the interflow and ground water compartments.

HSPF: Summary

Model Parameters

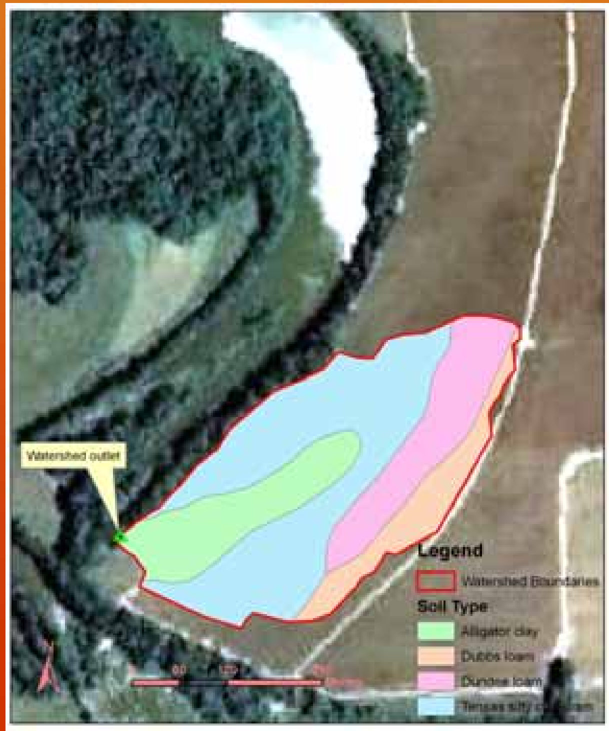
GIS



15-minute, hourly

Methods

- **Model Setup**
  - Six hydrologic respond units - HRUs based on similarity of land cover and hydrologic soil groups –HSGs.
  - Detailed crop management information (tillage, fertilization, harvest) was found in Yuan et al. (2001) and Yuan and Bingner (2002).
  - USGS site-collected 15-minute rainfall data were used in this study.
  - Hourly climate time series (maximum and minimum air temperatures, dew point, wind, solar ration, and cloud cover) were extracted from the NOAA Greenwood Leflore Airport station, located 16.7 km from the drainage area.
  - All climate data were converted to 15-minute time series by equally dividing the hourly values.
  - only pervious land segment algorithms (water budget and runoff components; sediment production and removal; and phosphorus fate & runoff) were used in this research.
  - Phosphorus transformations were simulated using the PHOS AGCHEM module.



Methods

- ***Phosphorus Processes***

Table 14. Initial phosphorus in soil layer

Layer	*Organic Phosphorus – ORGP (kg/ha)*	*Adsorbed Phosphate - P4AD (kg/ha)*	*Solution Phosphate - P4SU (kg/ha)*	*Phosphorus Stored in Plants – PLTP (kg/ha)*
Surface	112.09	50.44	5.60	0.00
Upper	56.04	50.44	5.60	0.00
Lower	56.04	50.44	5.60	0.00
Groundwater	56.04	50.44	5.60	0.00

Cotton phosphate uptake was set at 2.77 kg/ha (Yuan and Bingner, 2002).

Soybean phosphate uptake was set at 14.42 kg/ha (Yuan and Bingner, 2002).

Winter wheat phosphate was set at 4.49 kg/ha (Liu, 2006).

Monthly fractions of total annual P uptake were developed using data from Liu (2006) for soybean and winter wheat and from Schwab et al. (2000) for cotton.

The soil layer fraction of monthly uptake rate was developed based on the crop growth stage and the typical depth of crop root. It was assumed that more than 90% of the monthly phosphate uptake came from upper and lower soil layers. The amount of uptake in the groundwater zone was set as zero.

Methods

- **Approach for Model Calibration and Validation**
  - Model outputs were evaluated against runoff, total suspended sediments, and dissolved & total phosphorus time series collected at the outlet of the drainage area by USGS (USGS 0728711620 Unknown Lake Tributary No 2 Near Sidon, MS).
  - Model parameter calibration was performed from January 1, 1997 to December 31, 1998.
  - Validation was performed using the USGS runoff, sediments, and phosphorus data and on site precipitation time series from January 1, 1999 to December 31, 1999.
- **Model Evaluation**
  - Numerical criteria: the relative error (RE), the root mean square error (RMSE), the coefficient of determination (R^2), and the Nash-Sutcliffe coefficient (NS). Scatter plots were used to evaluate observed versus simulated variables.

Target	*Timing*	*Statistic*	*Performance Rating*				*Source*
			Poor	*Fair*	*Good*	*Very Good*	
Runoff	Storm-by-storm	R^2	<0.61	0.62-0.72	0.73-0.81	0.82-1.00	This study
		NS	<0.40	0.40-0.55	0.55-0.70	0.70-1.00	This study
		MRE (%)	>±30	±20-±25	±15-±20	<±15	This study
	Long-term	R^2	0.52-0.64	0.65-0.76	0.77-0.85	0.86-1.00	Duda et al., 2012
		NS	<0.50	0.50-0.65	0.65-0.75	0.75-1.00	Moriasi et al., 2007
		MRE (%)	>±25	±15-±25	±10-±15	<±10	Duda et al., 2012; Moriasi et al., 2007
Sediment load	Storm-by-storm	R^2	<0.50	0.50-0.60	0.60-0.75	0.75-1.00	This study
		NS	<0.35	0.35-0.47	0.47-0.65	0.65-1.00	This study
		MRE (%)	>±35	±30-±35	±25-±30	<±25	This study
	Long-term	R^2	<0.55	0.55-0.65	0.65-0.80	0.80-1.00	This study
		NS	<0.50	0.50-0.65	0.65-0.75	0.75-1.00	Moriasi et al., 2007
		MRE (%)	>±45	±30-±45	±20-±30	<±20	Duda et al., 2012
Phosphorus load	Storm-by-storm	R^2	<0.40	0.40-0.55	0.55-0.70	0.70-1.00	This study
		NS	<0.30	0.30-0.45	0.45-0.65	0.65-1.00	This study
		MRE (%)	>±35	±30-±35	±25-±30	<±25	This study
	Long-term	R^2	<0.45	0.45-0.65	0.65-0.80	0.80-1.00	This study
		NS	<0.40	0.40-0.65	0.65-0.75	0.75-1.00	This study; Moriasi et al., 2007
		MRE (%)	>±35	±25-±35	±15-±25	<±15	Duda et al., 2012

Results

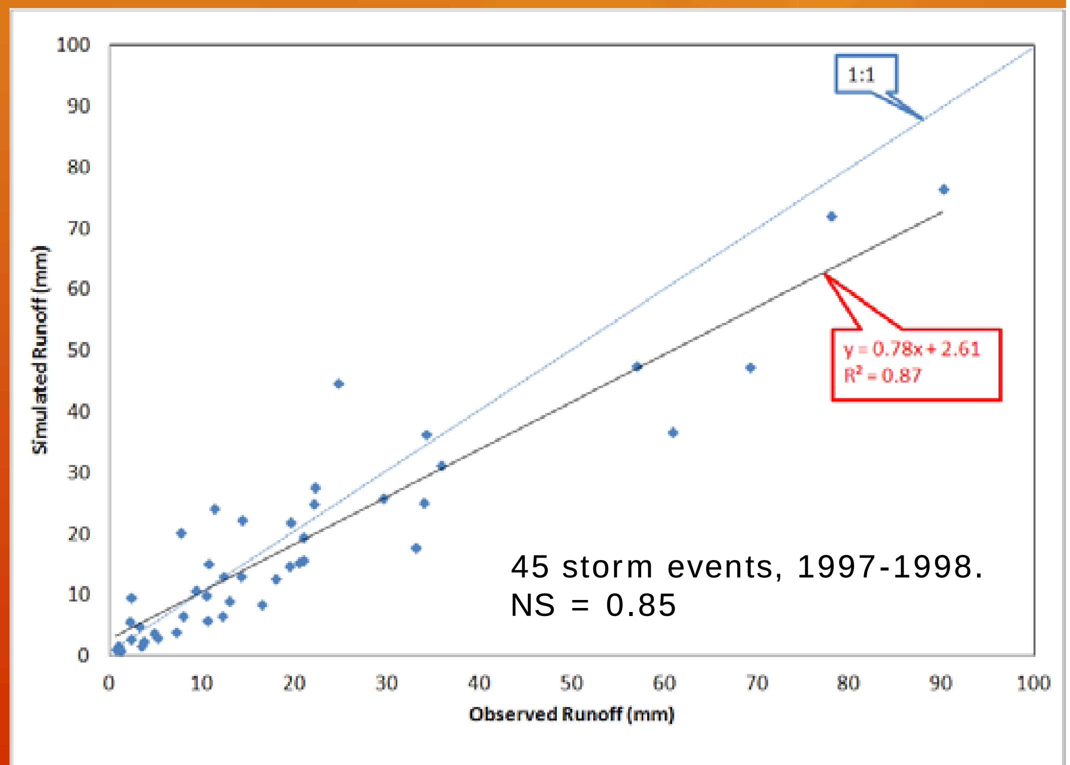
- ***Hydrologic Processes: Runoff Calibration***

Table 3. Calibrated hydrologic parameters

HRU	*Land cover*	*LZSN (mm)*	*INFILT (mm/hr)*	*LSUR (m)*	*SLSUR*	*UZSN (mm)*	*INTFW*	*IRC (1/d)*
123	Cotton	152.4	0.254	121.9	0.005	7.62	1.60	0.30
132	Soybeans	152.4	0.254	121.9	0.005	7.62	1.60	0.30
141	Cotton	152.4	1.27	121.9	0.005	7.62	1.60	0.30
151	Cotton	152.4	2.54	121.9	0.005	7.62	1.60	0.30
152	Cotton	152.4	0.254	121.9	0.005	7.62	1.60	0.30
162	Soybeans	152.4	0.254	121.9	0.005	7.62	1.60	0.30

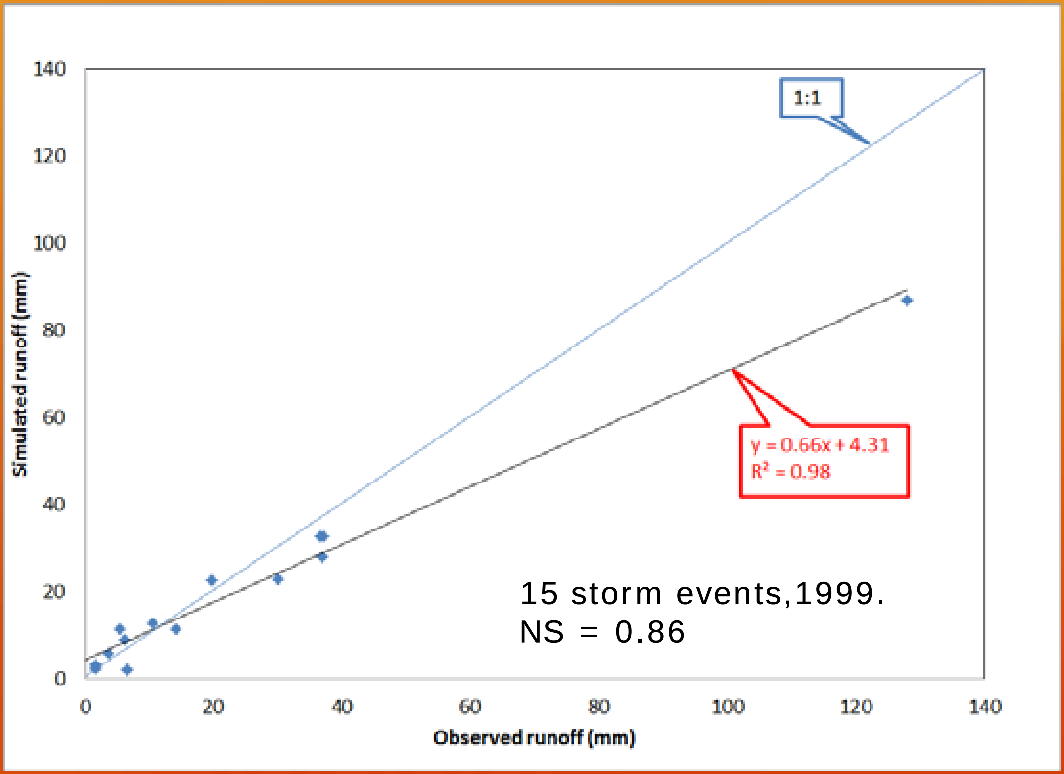
Table 4. Calibrated monthly hydrologic parameters

Parameter	*JAN*	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*
CEPSC	0.05	0.05	0.05	0.08	0.01	0.03	0.1	0.1	0.1	0.05	0.01	0.05
Manning's n (Cotton)	0.30	0.30	0.26	0.23	0.20	0.20	0.23	0.23	0.23	0.23	0.25	0.25
Manning's n (Soybeans)	0.26	0.26	0.22	0.19	0.18	0.18	0.20	0.20	0.20	0.20	0.22	0.22
LZETP	0.07	0.07	0.07	0.09	0.15	0.15	0.2	0.2	0.2	0.2	0.08	0.08



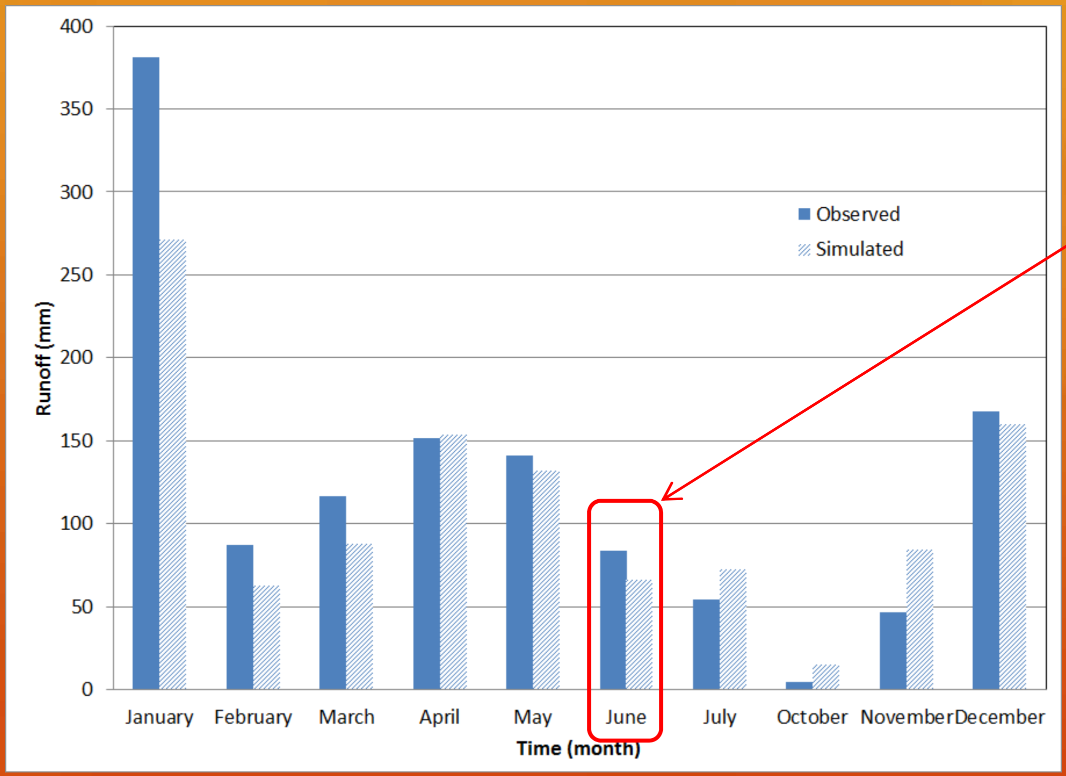
Results

- ***Hydrologic Processes: Runoff Validation***



Results

- ***Hydrologic Processes:*** **Seasonal and Long-Term Runoff Performance**



Closed values

Total runoff values by month (1997-1999)

The R^2 and NS goodness-of-fit values of 0.94 and 0.84, respectively were very good indications of the robustness of the HSPF model in simulating rainfall-runoff processes at the farm scale in the Mississippi Delta region.

Results

- ***Soil Erosion Processes:*** **Calibration of Suspended Sediment Loads**

Soil detachment

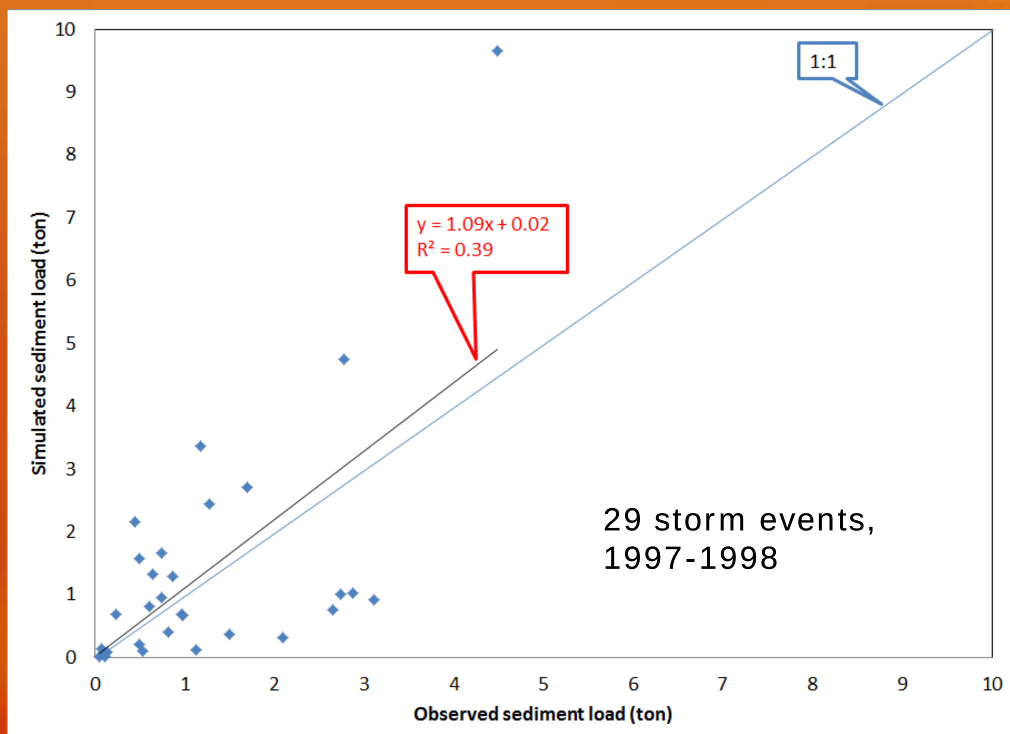
washoff

Table 8. Calibrated soil erosion parameters by soil type

HRU	*Land Cover*	*Soil Type*	*KRER*	*JRER*	*AFFIX (1/day)*	*KSER*	*JSER*
123	Cotton	Tensas silt clay loam	0.37	2.0	0.05	0.06	2.0
132	Soybeans	Tensas silt clay loam	0.37	2.0	0.05	0.06	2.0
141	Cotton	Dundee loam	0.55	2.0	0.05	0.06	2.0
151	Cotton	Dubbs very fine Sandy loam	0.43	2.0	0.05	0.06	2.0
152	Cotton	Alligator clay	0.24	2.0	0.05	0.06	2.0
162	Soybeans	Alligator clay	0.24	2.0	0.05	0.06	2.0

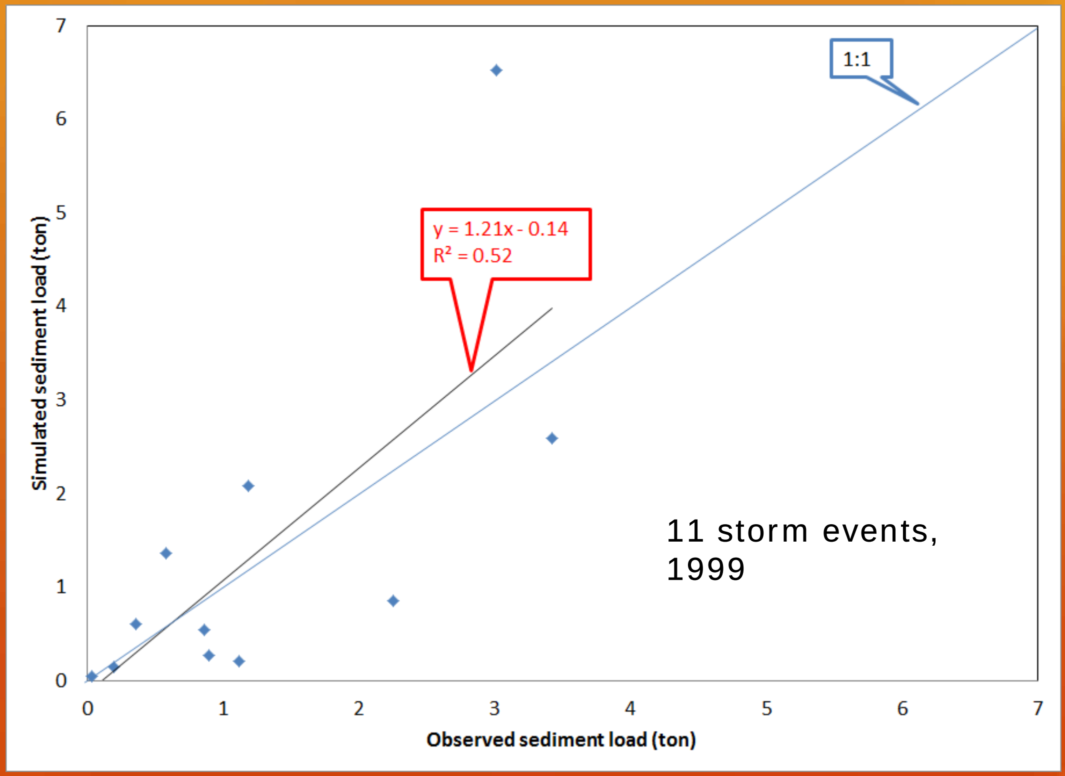
Table 9. Calibrated monthly values for erosion related cover

Parameter	*JAN*	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*
Cover	0.80	0.80	0.95	0.95	0.20	0.40	0.90	0.95	0.95	0.80	0.80	0.80



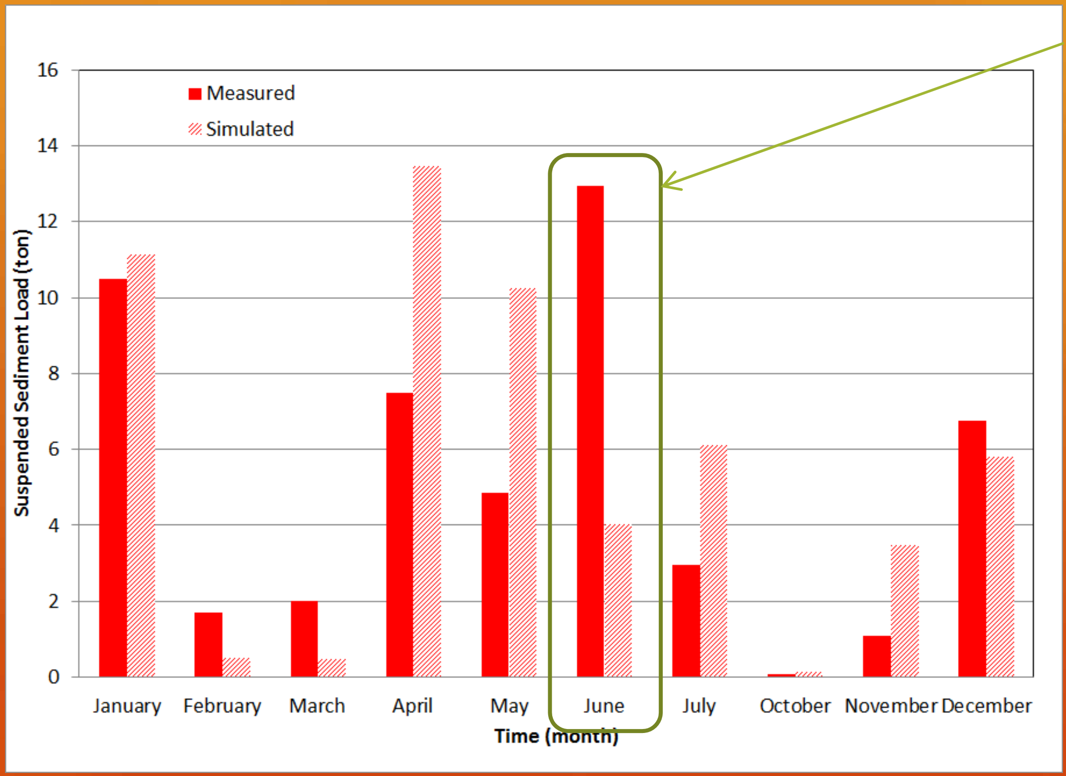
Results

- ***Soil Erosion Processes:*** **Validation of Suspended Sediment Loads**



Results

- ***Soil Erosion Processes:* Seasonal and Long-Term Sediment Load Performance**



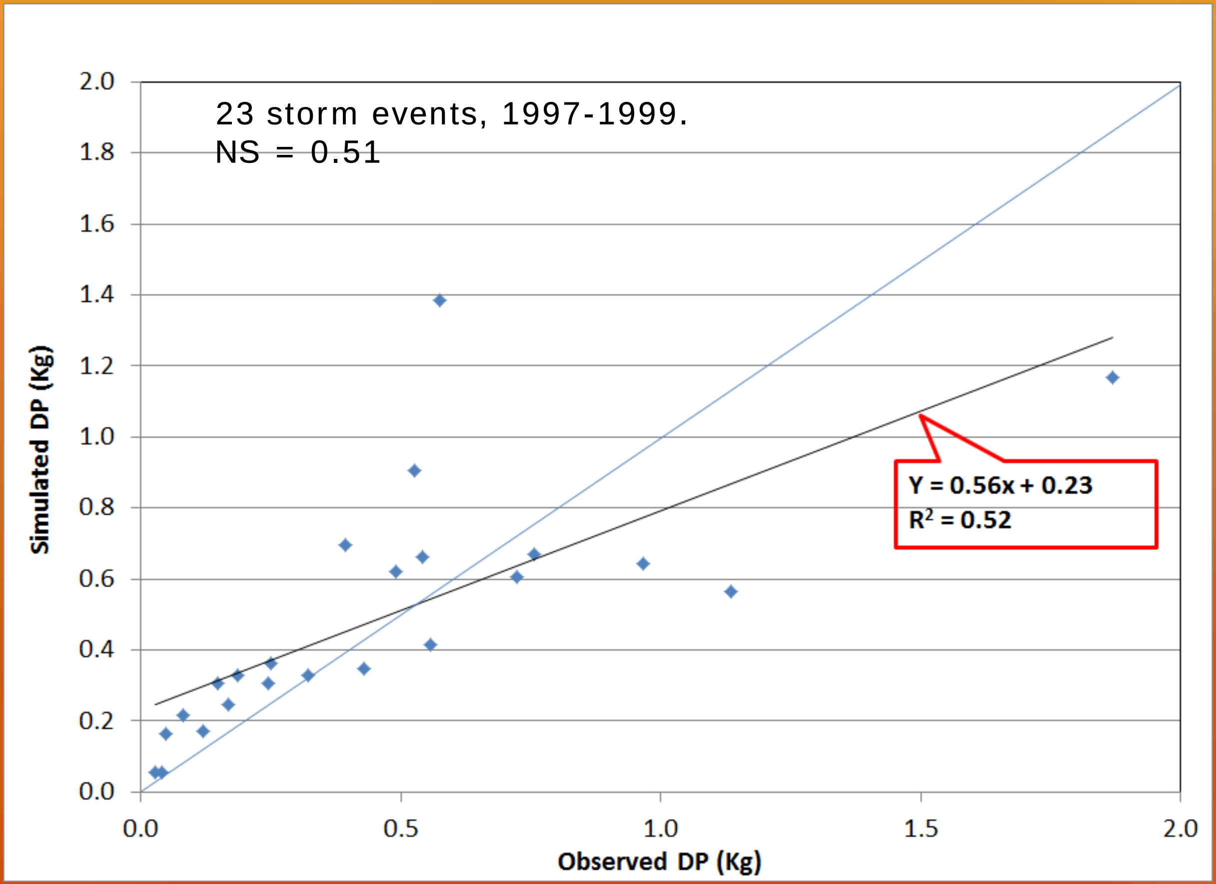
From the field report published by Yuan and Bingner (2002), it was found that herbicide was applied early on June every year. However, no additional soil detachment values were input into the model.

Total suspended sediment load by month, 1997-1999

The model was able to simulate close values in the wet season (December and January) and dry season (October).

Results

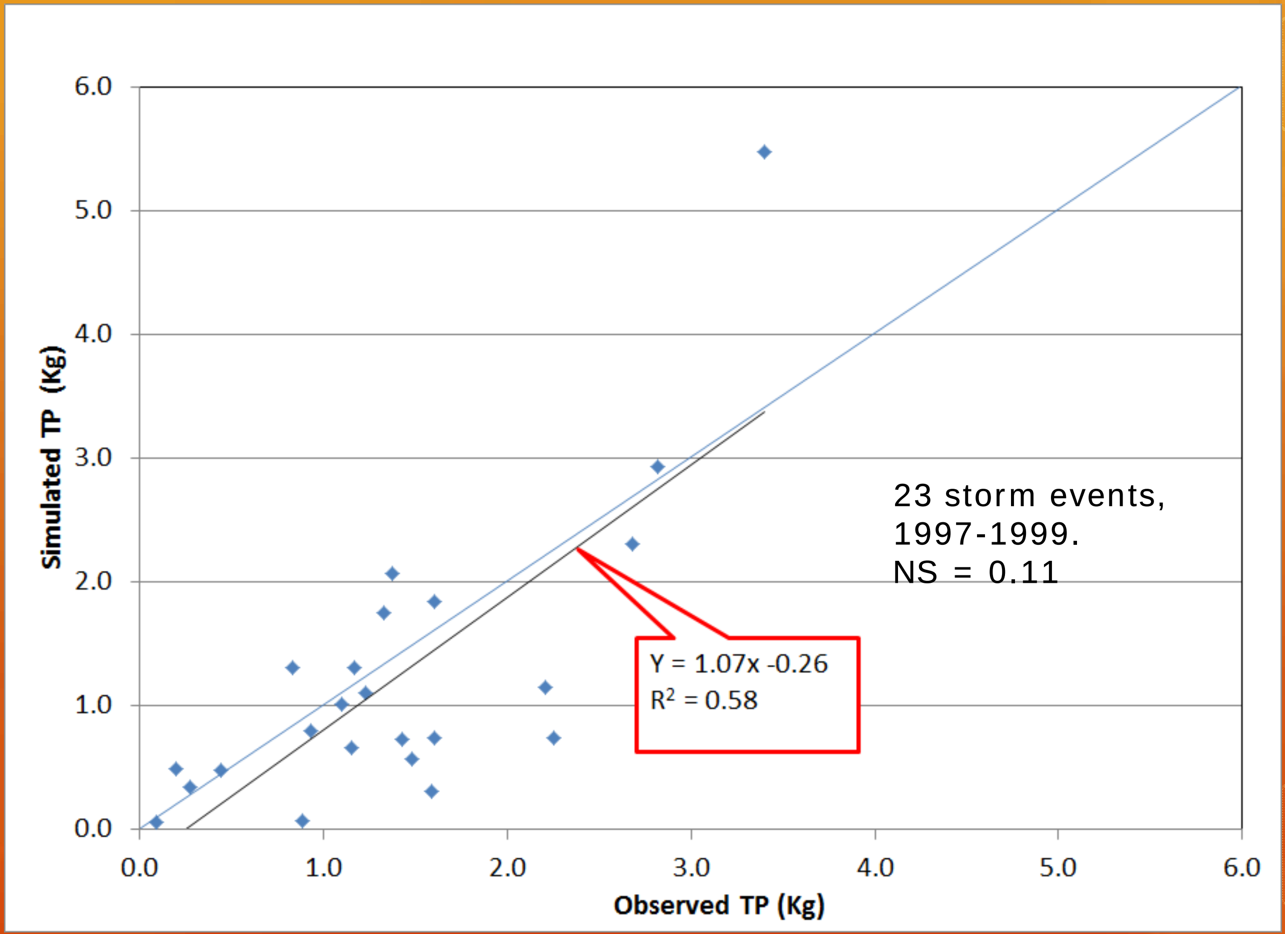
- ***Phosphorus Processes:*** **Calibration and Validation of Dissolved Phosphorus Loads**



Period	R^2	NS
Calibration	0.53	0.50
Validation	0.91	0.53

Results

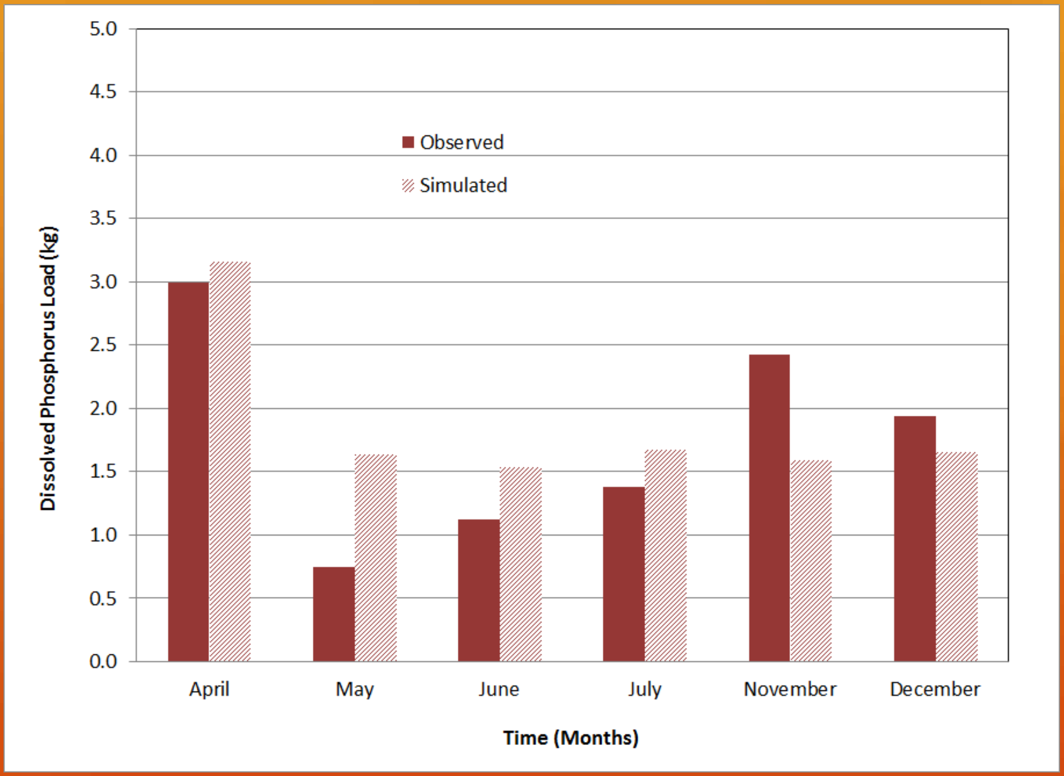
- *Phosphorus Processes:* Calibration and Validation of Total Phosphorus Loads



Period	R^2	NS
Calibration	0.60	0.04
Validation	0.86	0.30

Results

- **Seasonal and Long-Term Dissolved Phosphorus Load Performance**

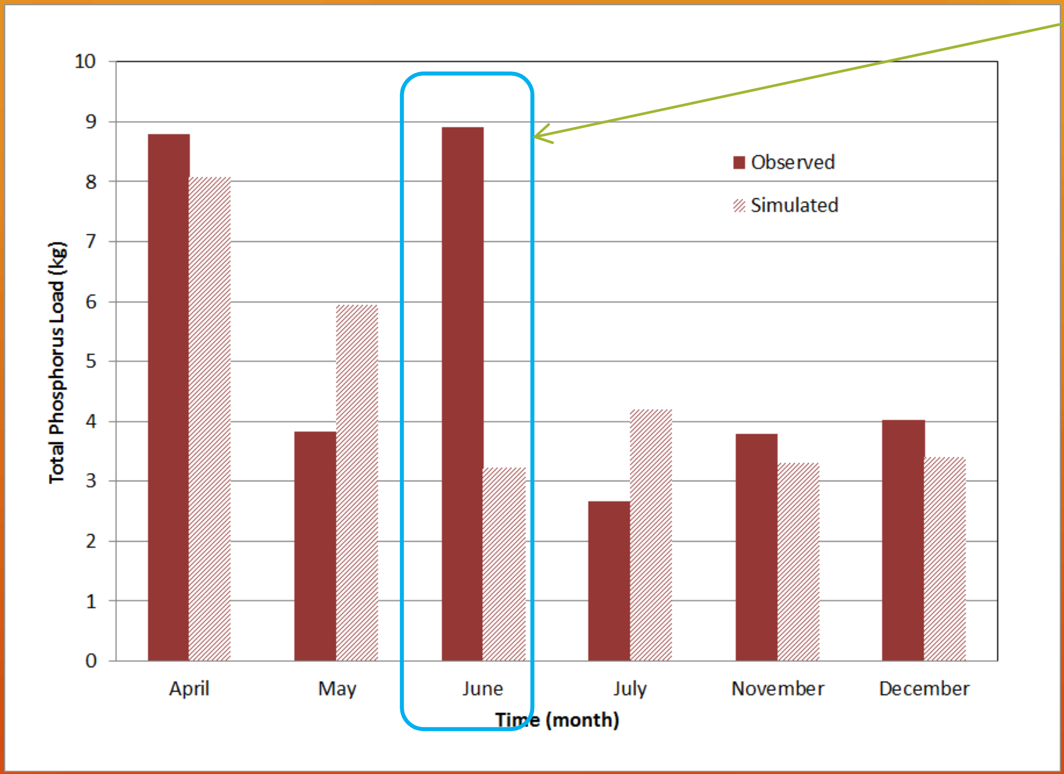


Dissolved P load by month, 1997-1999

	R^2	NS
Monthly	0.50	0.48
Annual	0.98	0.94

Results

- **Seasonal and Long-Term Total Phosphorus Load Performance**



Low simulated TSS

TP load by month, 1997-1999

	R^2	NS
Monthly	0.69	0.66
Annual	0.99	0.76

Without June data

Results

- **Model Limitations**
  - Ponding at the outlet of the drainage area was not simulated
  - There is no particle discretization of HSPF soil erosion values from land surface.
  - Although organic residues were left in the fields as conservation tillage practice, the effects of crop residue on phosphorus concentrations in runoff were not simulated.
  - Irrigation was scheduled in the study area but the model did not simulate it. Runoff and sediment from irrigation could deplete the phosphorus pools in the study area.
  - Atmospheric deposition of phosphorus was not simulated.

Conclusions

- The study demonstrated that the HSPF model is a capable modeling tool for evaluating runoff, soil erosion, and total phosphorus processes at the farm scale in the Mississippi alluvial valley, mainly for analysis on long term basis (monthly, seasonal, or annual).
- Results from this study are significant at the scale of this drainage area (11.29 ha), but more study is needed to determine whether processes are accurately predicted.
- The results of this research would be helpful in providing initial parameter values and guidelines for future applications of HSPF in similar agricultural drainage areas in the Mississippi Delta region.

Acknowledgments

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Thanks!

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