# Runoff Quality Effects of Simulated Conservation Practice Scenarios in a Mississippi Delta's Watershed

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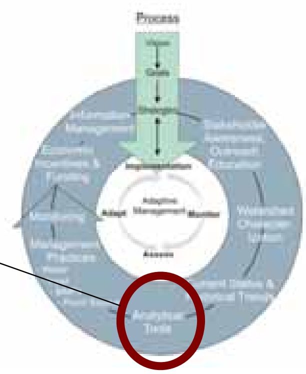
# Background

The Mississippi River/Gulf of Mexico Hypoxia task force released the Gulf Hypoxia Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico and Improving Water Quality in the Mississippi River Basin in June 2008.

A Planning Team co-led by Delta F.A.R.M and the Mississippi Department of Environmental Quality (MDEQ) and formed by about 30 representatives from agencies organizations and stakeholders groups identified 12 critical elements for a Delta nutrient reduction strategy.

This study is a component of the activities orientated to the evaluation and selection of appropriate analytical tools that can be used to develop the most efficient and effective action plans for areas within the Mississippi Delta Region.


(FTN Associates, 2009)

# APEX

Developed as an extension of the Environmental Policy Integrated Climate (EPIC) model.

Written in FORTRAN ( PC and UNIX platform).

Evaluate various land management strategies considering sustainability, erosion, economics, water supply and quality, soil quality, plant competition, weather and pests.

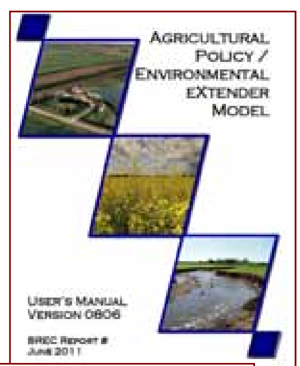
Management capabilities: irrigation, drainage, furrow diking, buffer strips, terraces, waterways, fertilization, manure management, lagoons, reservoirs, crop rotation and selection, pesticide application, grazing and tillage.

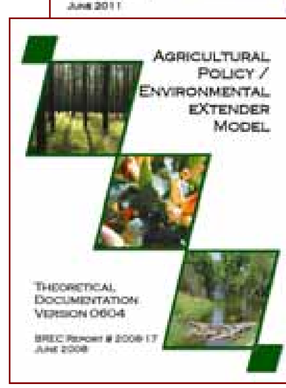
Databases: weather simulation, soils, crops, tillage, fertilizer, and pesticides.

Interfaces: WINAPEX, ARCAPEX, IAPEX

Widely tested for their ability to simulate different agricultural management practices at both field and watershed scales.

- 2nd Resource Conservation Act (1980-1987)
- 3rd Resource Conservation Act (HUMUS) (1992-1996)
- USDA-National Nutrient Loss Database (NNLD) (2001-2004)
- Conservation Effects Assessment Program (CEAP) (2003-present)
- Accepted by USDA and EPA and is used in most major U.S. universities and more than 20 foreign countries.



# Objective

To predict the effect of changing land use and changing management practices scenarios on runoff quantity/quality and crop productivity in an 11.3 ha agricultural subwatershed located in the Mississippi Delta region.

Model performance evaluation :

- Comparison of observed and simulated data over 4 years for runoff, soil and phosphorus loadings, crop yield and soil properties change under a reduced tillage scenario.

Effect of changing land uses and management practices :

- Comparison of predicted conservational scenarios over a simulated conventional tillage scenario.
- Conservational scenarios regarding land use change involved the establishment of an individual crop along the entire area and the establishment of managed and unmanaged pastures.
- Scenarios representing changes in management practices included the establishment of cover crops after crop harvesting, the establishment of reduced tillage scenarios and no P fertilization.

# Study Area

Deep Hollow Lake watershed (Leflore County, MS) - 82 ha. Model evaluation 11.3 ha.

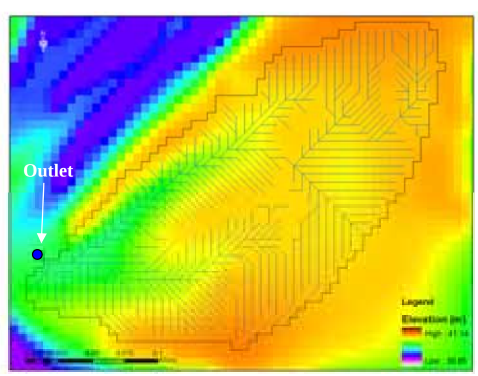
Dataset: water quality, agricultural operations and crop production from a monitored subwatershed (field) - USGS.

Mississippi Delta Management System Evaluation Area (MDMSEA) Project from 1995 to 2003.

Very flat slopes and drains to the Deep Hollow Lake, an oxbow lake cutoff from the Yazoo River with a surface area of 5.4 ha.

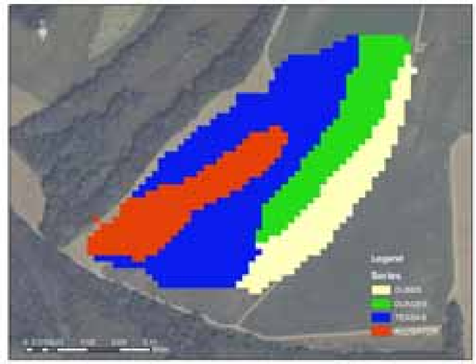
28% of the entire area was forest and the rest of the extension was used to grown row crops.

Cotton (79%) and Soybean (21%)



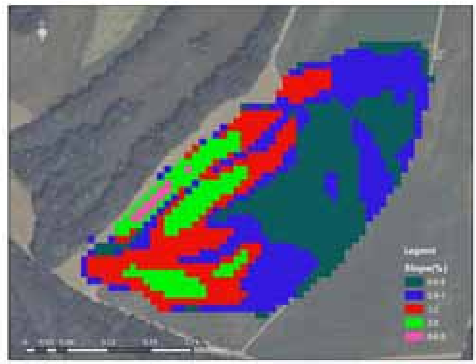
Soil series distribution at the studied subwatershed within the Deep Hollow Lake watershed in Mississippi

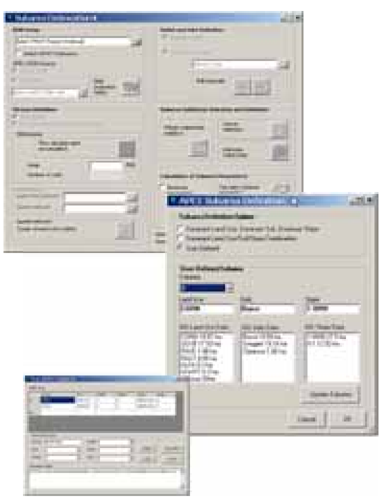
| Soil Type | Hydrologic Soil Group | Area (Ha) | % Area |
|---|---|---|---|
| Tensas Silty Clay Loam | D | 5.02 | 44.42 |
| Dundee Loam | C | 2.10 | 18.58 |
| Dubbs Very Fine Sandy Loam | B | 2.07 | 18.32 |
| Alligator Clay | C | 2.11 | 18.67 |

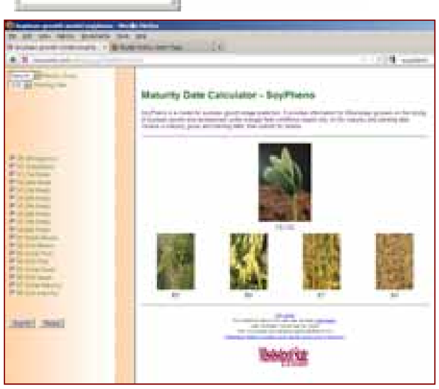


Land slope distribution at the 11.3 ha studied subwatershed within the Deep Hollow Lake watershed in Mississippi.

| Slope (%) | Area (Ha) | % Area |
|---|---|---|
| 0 - 0.5 | 3.58 | 31.68 |
| 0.5 - 1 | 3.73 | 33.01 |
| 1 - 2 | 2.50 | 22.12 |
| 2 - 5 | 1.37 | 12.12 |
| 5 - 6.5 | 0.12 | 1.06 |







# Model Setup

ArcAPEX interface: initial input parameters required by APEX based upon the area delimitation, subarea, land use/soil/slope analysis, and weather data.

Subwatershed boundaries were delineated by the interface based upon a 10-m by 10-m DEM.

Major inputs to setup the model:

Soil parameters - OMC, pH, STP, $NO_3$-N, and exchangeable cations (K, Ca, and Mg). SSURGO.

Weather - USGS – (15 min) daily rainfall time series dataset monitored at the field – Greenwood and Moorhead (1996 – 1999).

Cropping systems and field management

- Reduced tillage implementation (subsoiling and rebuilding rows in the fall and no-till planting in the spring
- Establishment by aerial seeding of a cover crop (winter wheat) in the late fall, which was chemically burned in spring;
- Crop yields and agricultural operations including tillage, planting, harvesting, fertilization, cover crop planting, and pesticide usage were mainly obtained from Yuan and Bingner (2002) and Yuan et al. (2009);
- Harvesting crops - Maturity Date Calculator (SoyPheno) and literature

# Model Setup

Soil properties data (Source: Yuan et al., 2009)

| Soil parameter | | Reported value |
|---|---|---|
| Organic Matter (%) | | 1.1 |
| pH | | 5.7 |
| STP (Mehlich III, ppm) | | 49.5 |
| Nitrogen ($NO_3$-N) (ppm) | | 39.5 |
| Exchangeable Cations | K (ppm) | 355.4 |
| | Ca (ppm) | 1,339.4 |
| | Mg (ppm) | 244.0 |

**Methods & Equations**

- Penmann-Monteith (Evapotranspiration)
- Curve Number (Runoff)
- Rational Method (Peak runoff rate)
- MUSS (Soil Erosion)
- EPIC – (P enrichment ratio)
- Vadas (Soluble P)

Assigned land use codes and curve numbers used in the model simulations

| Land Use | LU Code | Description | CN | | | |
|---|---|---|---|---|---|---|
| | | | HSG | | | |
| | | | A | B | C | D |
| Cotton & Soybean | 2 | Row Crops (Poor) | 72 | 81 | 88 | 91 |
| Winter Wheat | 8 | Small grain straight row (Poor) | 65 | 76 | 84 | 88 |
| Fallow | 1 | Fallow (Poor) | 77 | 86 | 91 | 94 |
| Pasture | 20 | Pasture (Poor) | 68 | 79 | 86 | 89 |

# Model Setup

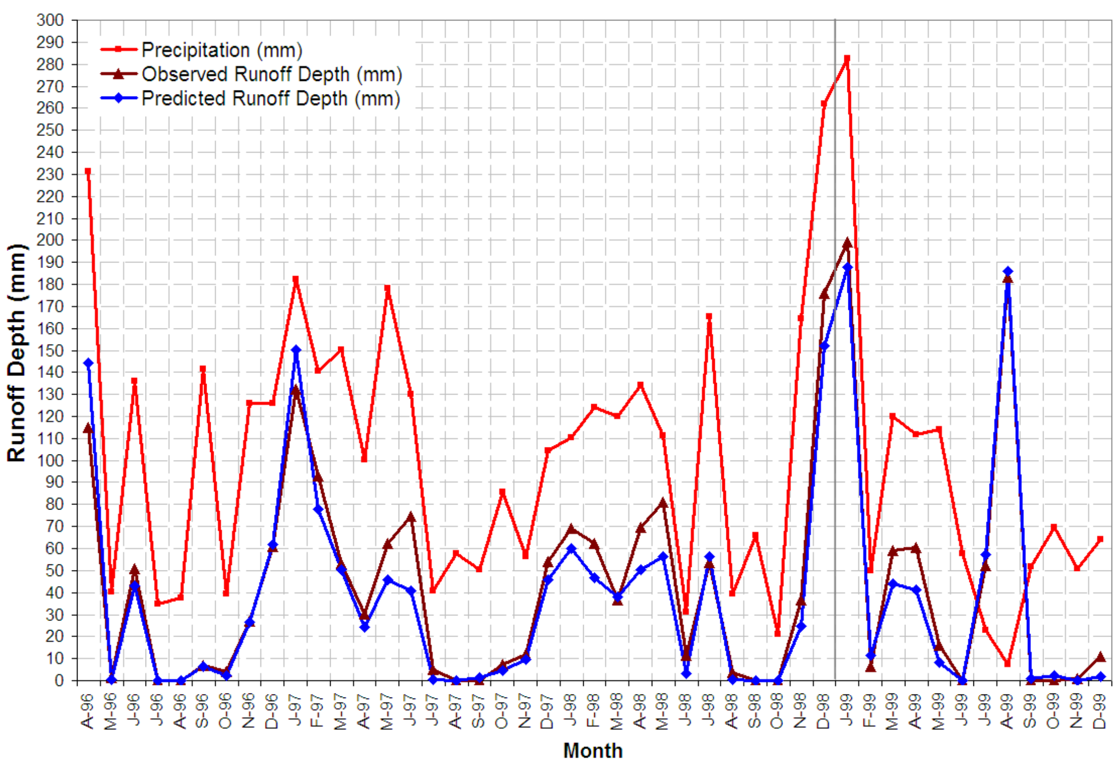
APEX input parameters and their ranges of sensitivity*.

| Description | Parameter | Range | Calibrated values** |
|---|---|---|---|
| Initial Input of condition to Curve Number | CN2 | 20 - 90 | |
| Curve Number Index Coefficient | CNIC (Parm 42) | 0.5 - 5.0 | 2.5 |
| RUSLE C Factor exponential residue coefficient | RCFC (Parm 46) | 0.5 - 5.0 | 0.8 |
| RUSLE C Factor exponential crop height coefficient | RCF (Parm 47) | 0.01 - 3.0 | 0.8 |
| Runoff Curve Number initial abstraction | RCNIA (Parm 20) | 0.05 - 0.4 | 0.2 |
| Peak runoff rate-rainfall energy adjustment factor | APM | 0.1 - 1.0 | 1.0 |
| Crop residue runoff | (Parm 37) | 0 - 2 | 0.2 |
| Soluble phosphorus runoff coefficient | (Parm 8) | 10 - 20 | 20 |
| Soluble phosphorus runoff exponent | (Parm 30) | 1 -1.5 | 1.0 |
| Organic N and P sediment transport exponent | (Parm 32) | 1 - 1.2 | 1.1 |
| P upward movement by evaporation coefficient | (Parm 59) | 1 - 20 | 1.0 |

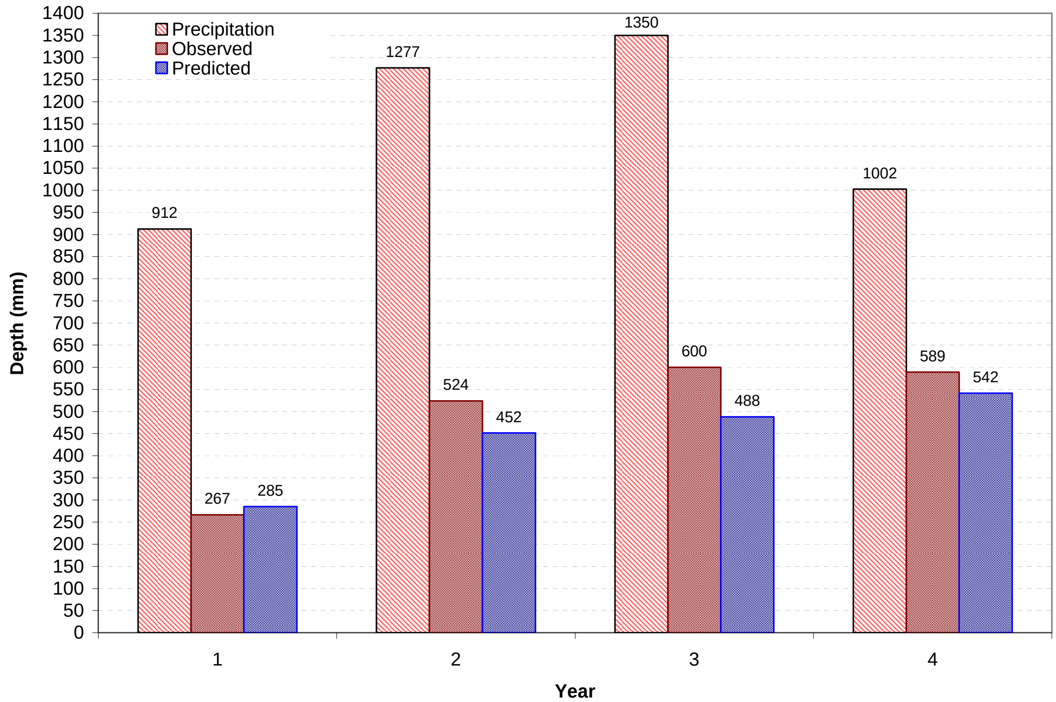
*Ranges of sensitivity presented by Steglich and Williams, 2008 and evaluated by Yin et al., 2009, Mudgal et al., 2010 and Wang et al., 2006, 2011.
**The rest of the parameters are APEX defaults

# Modeling:
# APEX performance

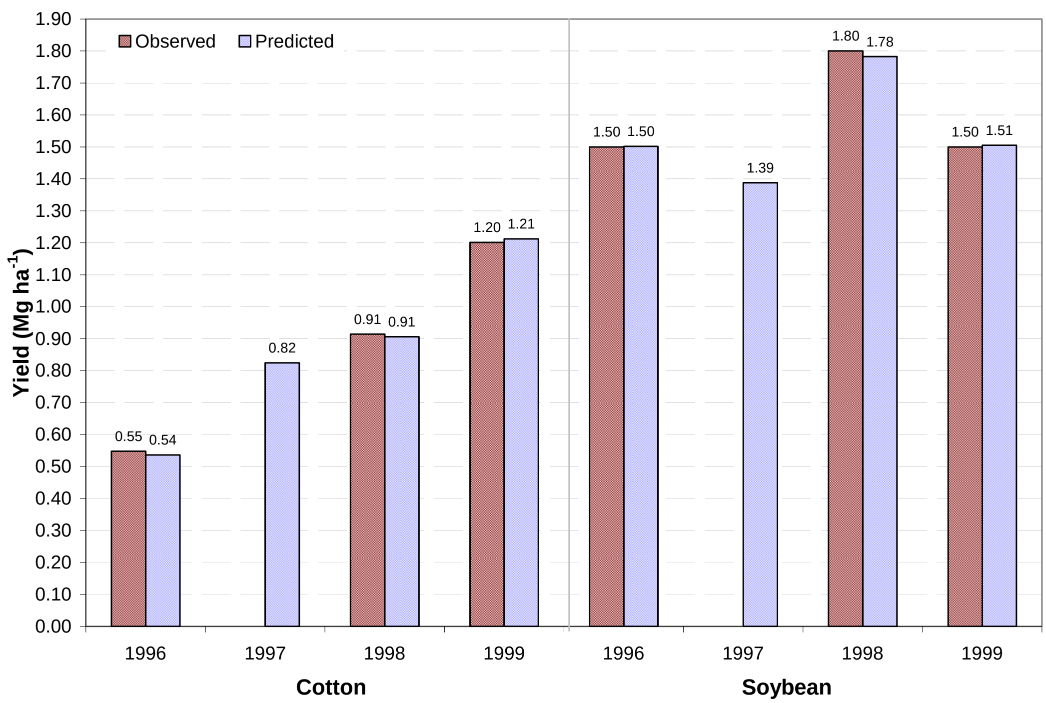
## Runoff



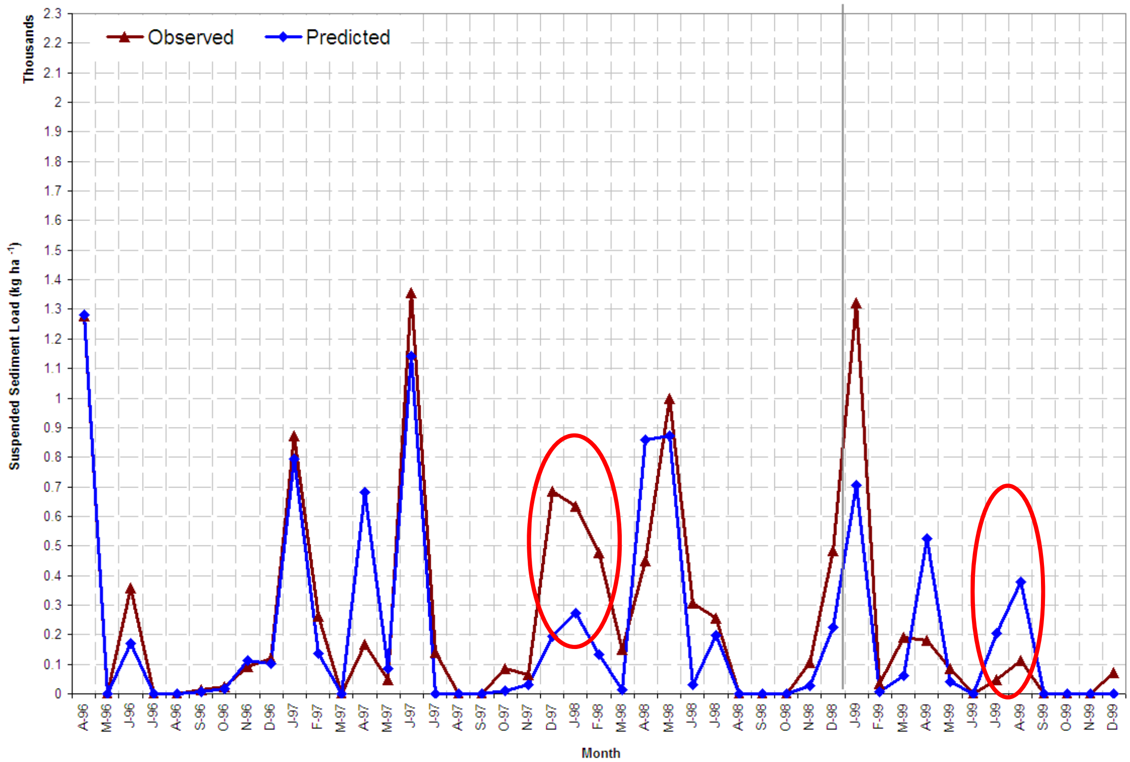
# Runoff

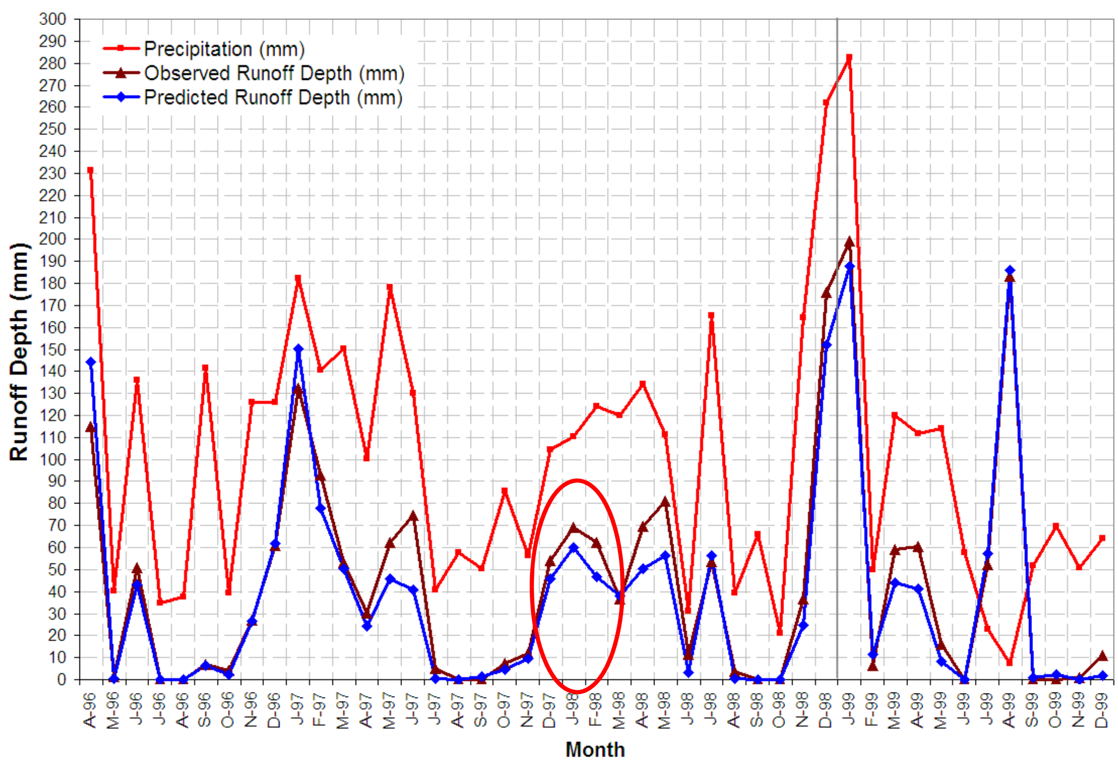



# Crops Yield



# Sediment Loads



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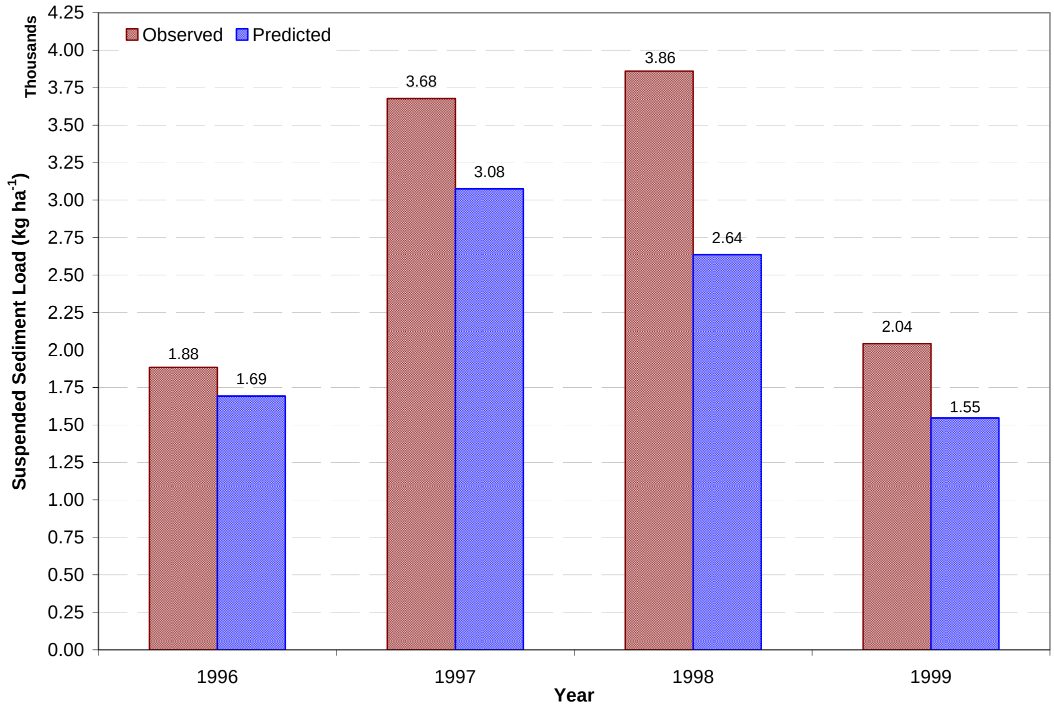
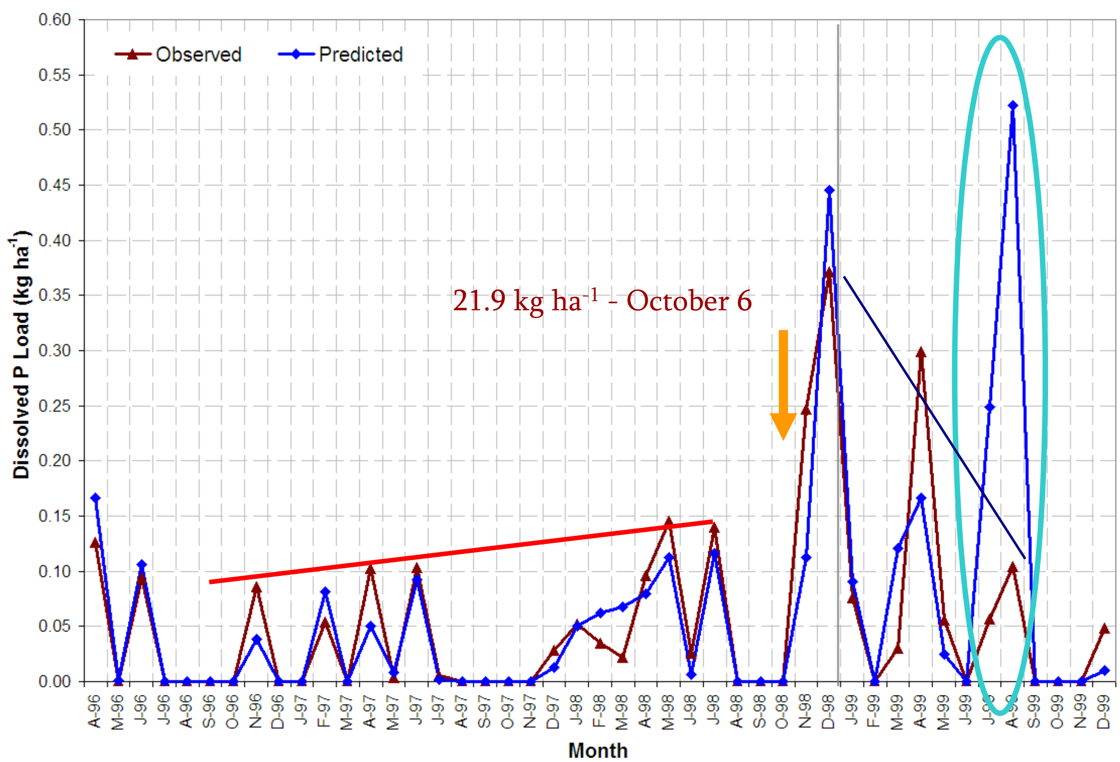



# Dissolved Phosphorus Loads



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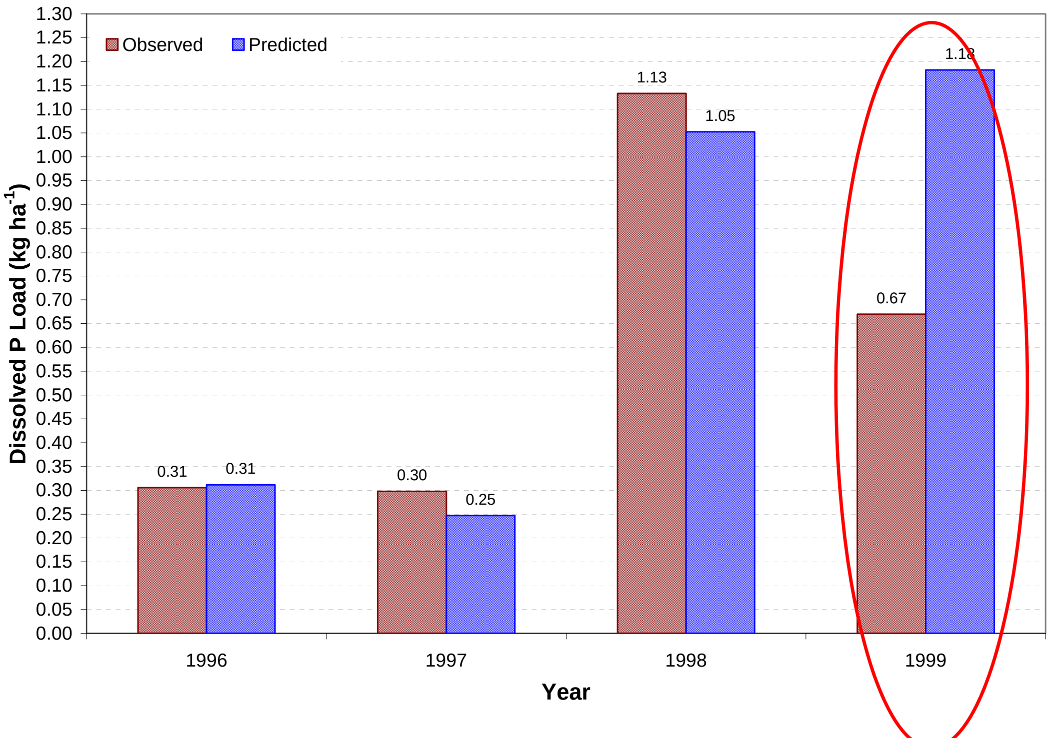



# Soil Properties

Observed and predicted soil properties after four years of reduced tillage and establishment of winter cover crops for a subwatershed in the Hollow Deep watershed in Mississippi.

| Land use | Eroded soil thickness (mm) | | Soil test phosphorus in top 5 cm (ppm) | | pH | |
|---|---|---|---|---|---|---|
| | Mean (SD) | Range | Mean | (SD) | Mean | (SD) |
| Cotton/winter wheat | 2.1 (1.1) | 0.4 - 5.3 | 51.1 [a] | (4.16) | 6.54 [a] | (0.05) |
| Soybean/winter wheat | 2.1 (0.6) | 1.1 - 3.4 | 38.0 [b] | (0.99) | 6.45 [b] | (0.05) |
| Cotton/winter wheat (Yuan et al., 2000) | - | | 54.9 | (28.1) | 6.70 | (0.50) |

# Model Performance

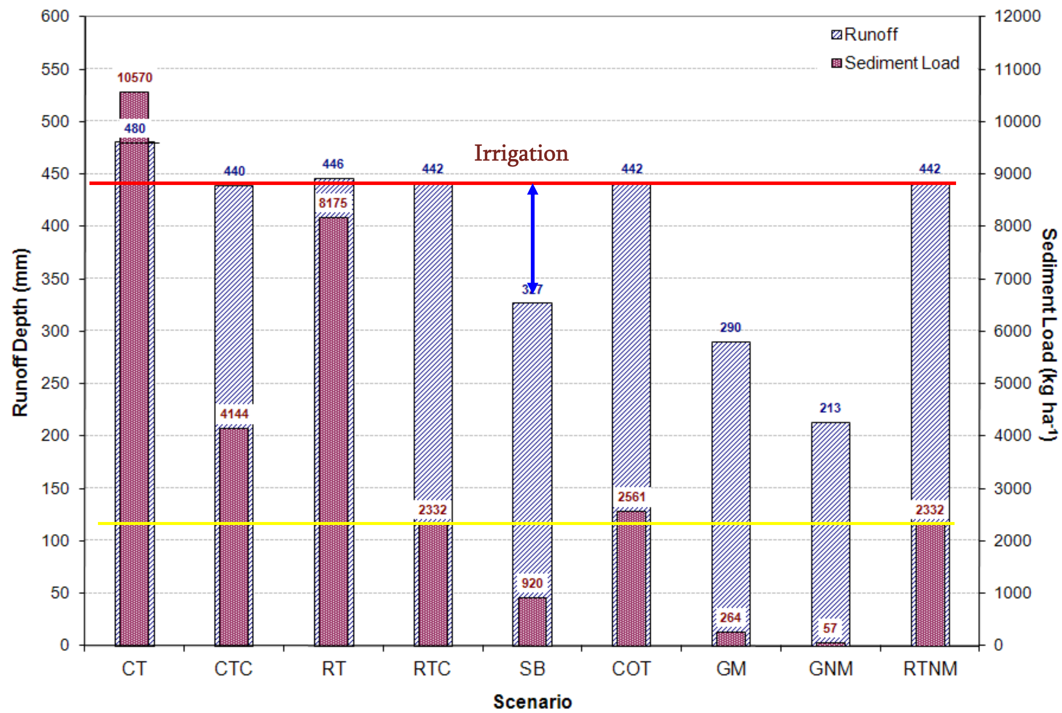
Model evaluation statistics for observed and predicted daily, monthly and annual runoff, sediment and phosphorus loading and crop yield for the 1996-1999 simulation period.

| Scenario | | Observed RTC | | Predicted RTC | | p-value** (>0.025) | NSE (>0.4) | $R^2$ (>0.5) |
|---|---|---|---|---|---|---|---|---|
| Parameter | Time basis | Mean | SD | Mean | SD | | | |
| Runoff Depth (mm) | Annual<br>Monthly<br>Daily | 495<br>44<br>1.50 | 156<br>51<br>8.29 | 442<br>40<br>1.32 | 111<br>51<br>7.67 | 0.150<br>0.070<br>0.002 | 0.95<br>0.95<br>0.72 | 0.95<br>0.95<br>0.87 |
| Sediments (kg ha-1) | Annual<br>Monthly<br>Daily | 2,866<br>255<br>159 | 1,047<br>374<br>205 | 2,332<br>207<br>130 | 637<br>333<br>204 | 0.120<br>0.130<br>0.100 | 0.70<br>0.53<br>0.42 | 0.95<br>0.72<br>0.72 |
| Dissolved P (kg ha-1) | Annual<br>Monthly<br>Daily | 0.60<br>0.05<br>0.06 | 0.40<br>0.08<br>0.06 | 0.69<br>0.06<br>0.07 | 0.49<br>0.11<br>0.11 | 0.470<br>0.540<br>0.470 | 0.42 (0.84)*<br>0.07 (0.73)*<br>0.35 (0.63)* | 0.85 (0.97) *<br>0.66 (0.91)*<br>0.47 (0.75)* |
| Soybean Yield (kg ha-1) | Annual | 1.60 | 0.17 | 1.54 | 0.16 | 0.680 | 1.00 | 1.00 |
| Cotton Yield (kg ha-1) | Annual | 0.89 | 0.33 | 0.87 | 0.29 | 0.890 | 1.00 | 1.00 |

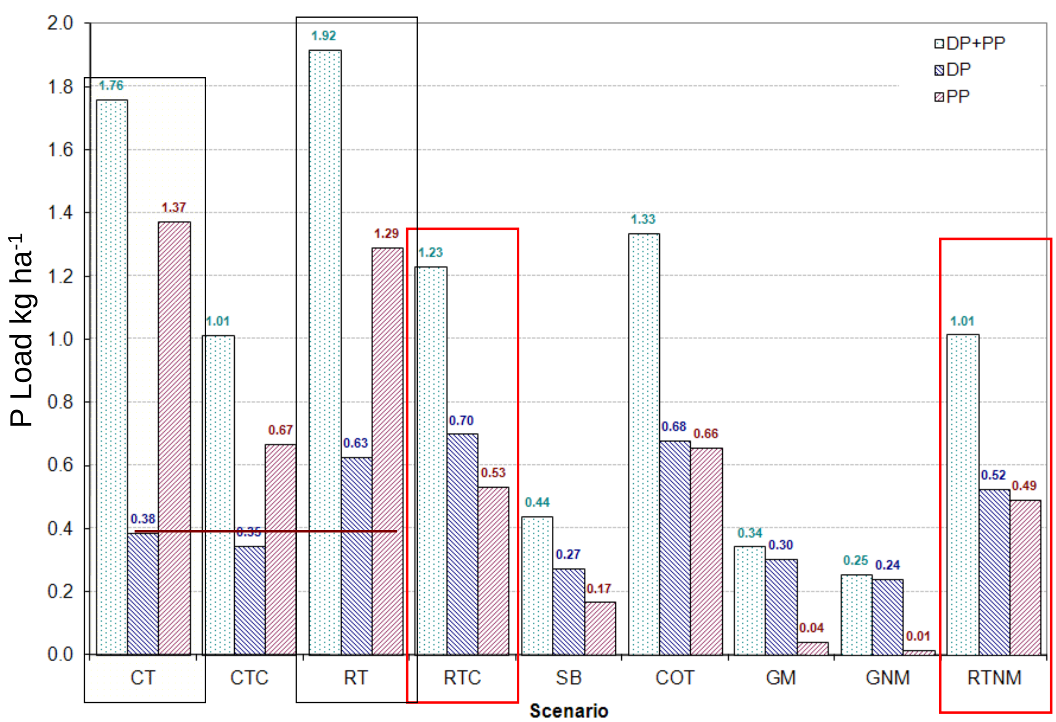
* Obtained statistical parameters without including phosphorus loadings from irrigation-runoff events in the 4th year of simulation.
** Hypothesis H0: the difference between the paired predicted and observed values is not significantly different from zero. H0 is rejected if the p-value is less than the level of significance ($\alpha/2 = 0.025$).

# Modeling: Scenario Analysis

# Runoff and Sediment Load




# Phosphorus Loads



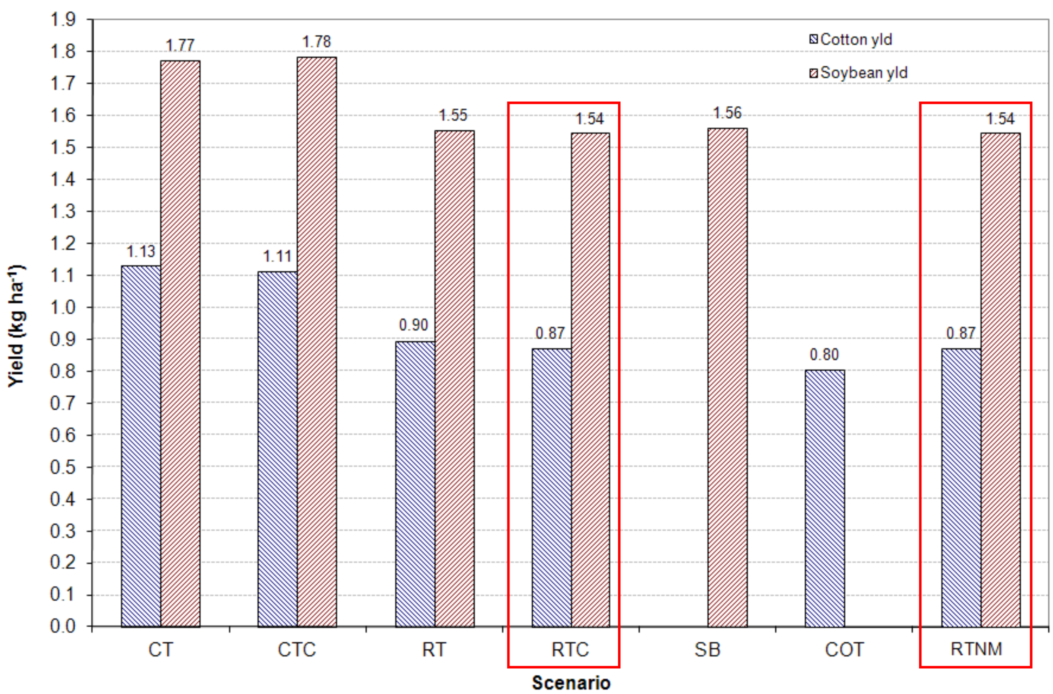
# Soil Phosphorus

Predicted annual soil test phosphorus levels in the Deep Hollow watershed after four years of management under reduced tillage.

| Year* | Cotton | | Soybean |
|---|---|---|---|
| | RTC | RTNM | RTC - RTNM |
| 1996 | 41.8 | 41.8 | 41.2 |
| 1997 | 41.1 | 41.1 | 40.5 |
| 1998 | 54.5 | 42.3 | 40.5 |
| 1999 | 51.1 | 43.4 | 38.0 |
| Average | 47.1 (6.80) | 42.1 (6.47) | 40.0 (1.60) |
| p- value | 0.001 | | |

*Predicted soil test phosphorus value at the end of the year

# Crops Yield



# Conclusions

APEX is a useful tool for simultaneously evaluating yielded water quantity, water quality, crops productivity and soil properties change (soil quality) under conservational scenarios and management practices in the Mississippi Delta.

Benefits of conservational management practices (CTC, RT and RTC) based on comparison with the baseline scenario (CT) were quantified as reduction of runoff ranging from 7.1% to 8.5%, sediment loads ranging from 22.7% to 77.9%, and sediment attached phosphorus ranging from 6% to 61.3%.

Benefits of land use change practices (COT, SB, GM, GUM) ranged from 8.1% to 55.7% in reduction of runoff, from 75.8% to 99.5% in reduction of sediment loads, and from 52.2% to 98.9% in reduction of PP.

The benefits of establishing RTC as an adequate soil and water conservation practice on agricultural fields has to be cautiously evaluated and better analyzed with an environmental concern, due to the potential increase in DP loads in runoff that this practice could promote. As an alternative to reduce nutrient loads under the specific site conditions, a nutrient management strategy can be taken by reducing or eliminating P fertilization during a minimum of a 5-yr term (although a further period of modeling could indicate the opportunity to increase this term).

Results indicated that soil P levels were higher and not importantly decreased by nutrient extraction. Adding fertilizers to crops when they do not need it only becomes in an environmental risk associated to an increase in potential phosphorus loss.

# Conclusions

Accurate results were obtained in this study under the need to calibrate a non extensive number of input parameters.

The APEX model includes a complete set of databases (soils, tillage, fertilizers, pesticides and crops), different methods to predict hydrology, soil, crops and nutrients processes, and default values and validated ranges of use for the multiple parameters estimated by an extensive sensitivity analysis.

APEX is a very useful tool capable of simulating conservation practices and scenario analysis for evaluating the impacts of conservation programs under agricultural production in the Mississippi Delta region. However, further research with additional data sets is needed to evaluate the applicability of APEX for other cropping and conservation practice conditions in the region, including expanded information about soil properties and runoff depth and quality measurements.

The APEX model and the ArcAPEX interface can be satisfactorily considered as appropriate tools at field and watershed scales to develop action plans to enhance the nutrient reduction strategy within the Mississippi Delta region.

- support this enhancement when used along the characterization of study areas at field and watershed scales;
- estimation of runoff quantity and quality export and changes in soil quality conditions;
- identification of the response of considered management practices and assessment of the effects of management and land use changes on nutrient reduction;
- and the identification of potential location and clustering of management practices for collecting monitoring data, among other tasks.

# Next Steps

Improve Modeling:

- Adjust SS and DP losses
- PP and TP losses calibration
- Pesticides application
- Nitrogen losses
- Multianual prediction

Modeling BMPs:

- Vegetative filter strips (Deep Hollow)
- Low grade weirs
- Reservoirs

# Acknowledgements


- This work was supported by Mississippi State University through the Watershed Assessment Tools: MS Delta Evaluation Project, which is a component of the Mississippi Delta Nutrient Management: Positioning Resource Management Agencies for Effective Delivery and Implementation Project.

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