Oklahoma Clean Lakes & Watersheds Association

27th Annual Conference

***Managing Water Resources in Ever Changing Times— Striking A Balance***

# Evaluating the least cost selection and placement of crops and agricultural management practices in the Five-Mile Creek area of Fort Cobb Watershed

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# Introduction

- Main cause of water quality impairment in the USA is due to human induced Non-Point Source (NPS) Pollution.
- Most of the water bodies in the US are impaired by NPS pollutions and **sediment** ranks fifth (USEPA, 2016).

- **Reduces ecosystem health**
- **Threatens drinking water supply**
- **Reduces reservoir capacity**
- **Increases dredging cost**
- **Increases the cost of drinking water treatment**
- **Changes soil properties, removes plant nutrients, and consequently endangers the sustainability of crop yields**

# Problem Statement

- **Southern Great Plains of the United States**
  - Stressing the landscape
  - Increasing uncertainty and risk in agricultural production
  - Impeding optimal agronomic management of crop, pasture, and grazing systems

(Garbrecht, et al., 2014)

*Wishart, 2004*

- **Watersheds located in this region issues of NPS pollution**

- The Fort Cobb Reservoir and contributing streams are impaired water bodies ⇨ listed on Oklahoma 303(d) list, as not meeting water quality standards
- Impaired by turbidity and phosphorus
- Too much sediment in water leads
  - Taste and odor problems
  - Reduced aquatic animal food
  - Increased dredging cost.

# Problem Statement

| **Source** | **Management Practices** |
| --- | --- |
| ❑ Upland areas (farms and fields) erosion | ▪ Contour<br>▪ Conservation tillage<br>▪ Strip cropping |
| ❑ Streams and waterways erosion | ▪ Pond<br>▪ buffer strip<br>▪ small check dam |
| ❑ Rill erosion and amount of upland sediment loading to and erosion in ephemeral channels | ▪ Changing tillage systems<br>▪ Replacing cover crop with grass<br>▪ Avoiding overgrazing<br>▪ Conservation tillage<br>▪ grassed waterway |

# Objective

## Evaluating the Least Cost Selection of Crop and Agricultural Management Practices in the Five Mile Creek area of Fort Cobb Watershed

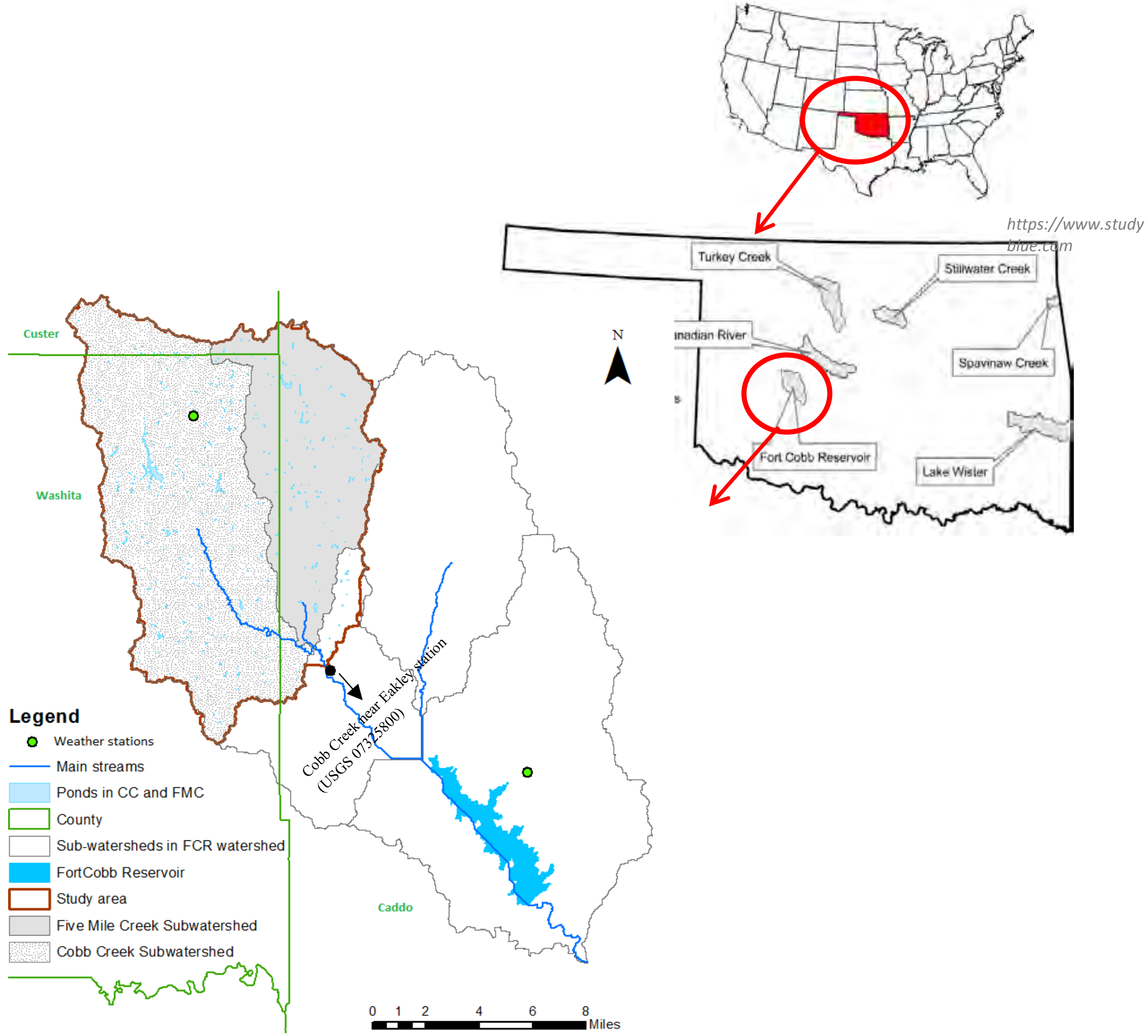
- Four important questions are addressed in this study:

1. How do no-till rotations involving wheat and other crops can affect sediment and phosphorous loads
2. Which crop/BMPs are the most profitable to irrigated areas and dryland producers while meeting reduced sediment and phosphorous targets
3. How does the cost of sediment and phosphorous abatement increase as sediment and phosphorous losses from crop and pasture land are decreased
4. How do soil type and land slope affect the economics of BMPs and crop choice

# Study Area

## Fort Cobb watershed

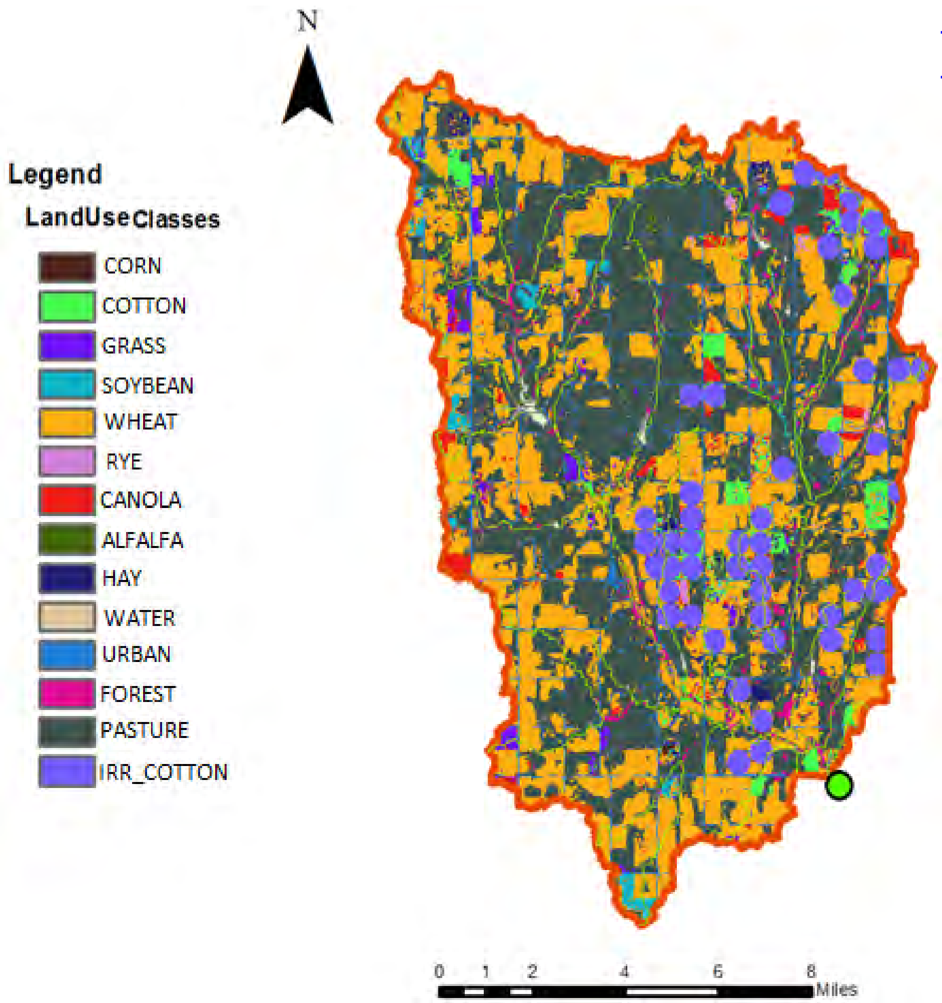
- Located in west-central Oklahoma, United States
- Rural agricultural catchment
- Issues of NPS pollution (suspended solids, siltation, nutrients (N, P), and pesticides)
- Watershed area is 813 km$^2$




Average annual basin values

| Parameter | Historical |
|---|---|
| Precipitation (mm) | 805.0 |
| Max temperature (C) | 22.2 |
| Min temperature (C) | 8.6 |

# Study Area

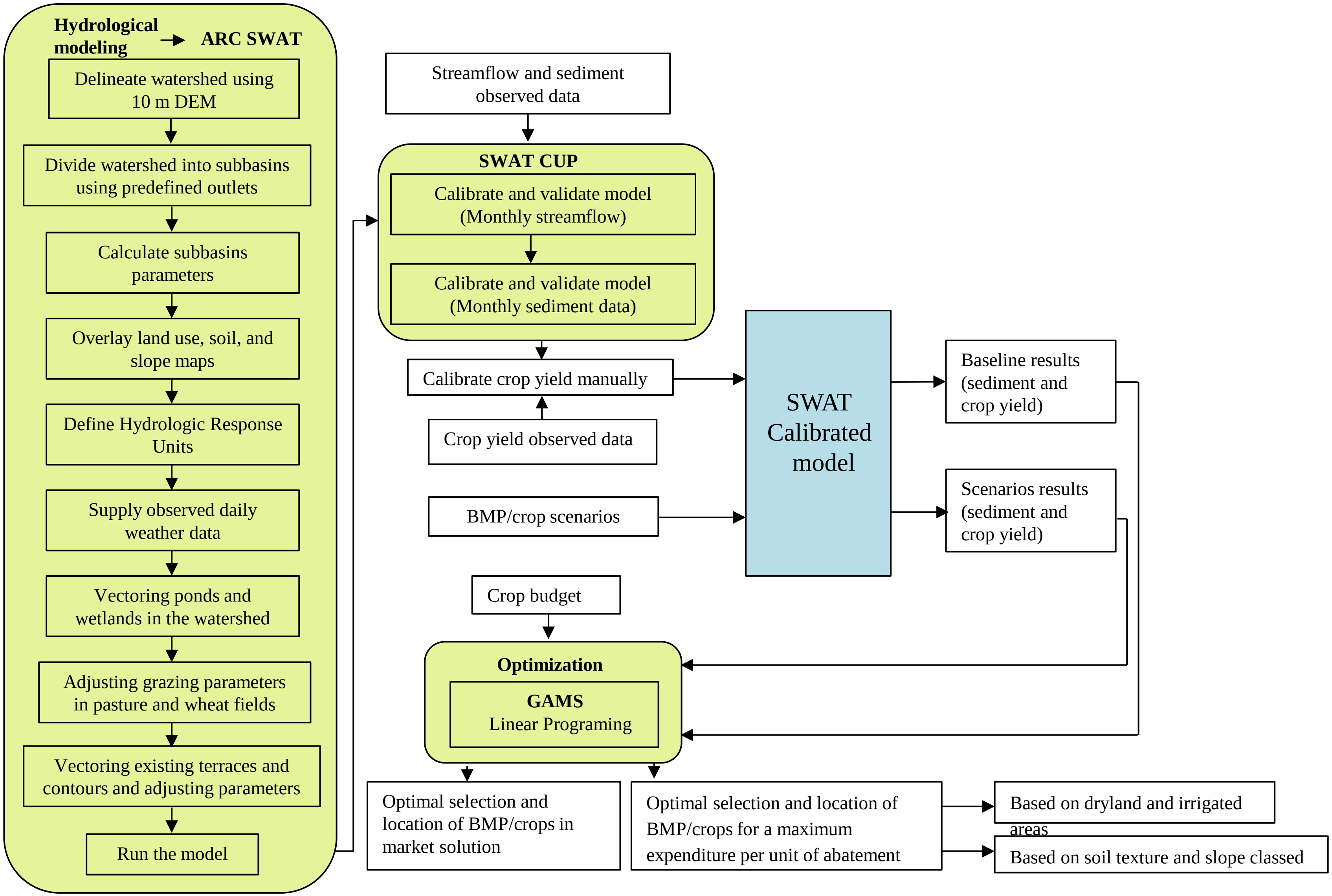



## Land Cover within the watershed

United States Department of Agriculture (USDA)
National Agricultural Statistics Service (NASS)

| Land use | | Percentage of cover |
|---|---|---|
| Pasture | | 41 |
| Cropland | | 50 |
| Main Crop land | wheat | 30 |
| | Irrigated cotton | 12.5 |
| | Dryland cotton | 3.5 |
| | Grain sorghum | 1.5 |
| Other | | 9 |

# Methodology



# Methodology

## ❑ SWAT model

Soil and Water Assessment tool (SWAT)

- The amount of water and sediment and phosphorous yield, crop yield in each BMP/crop scenario

| Data | Data source |
|---|---|
| Elevation | 10 m USGS Digital Elevation Model |
| Soil | Soil Survey Geographic Database- SSURGO soil data |
| Land use | US Department of Agriculture crop layer, national Agricultural Statistics Service (NASS) (USDA, 2014) |
| Slope | Manually classified into 4 classes |
| Weather data (precipitation, temperature, wind speed, relative humidity, and solar radiation) | USGS weather stations, MESONET, airport values (C349422 and C341504) |
| Water bodies (ponds) | U.S. Army Corps of Engineers National Inventory of Dams (NID). |
| cattle stocking rate | NASS data for a 1996–2015 period |
| Irrigated areas | 2014 one-meter resolution aerial images |
| Management operation | relevant and consultation with local OSU Cooperative Extension Service and Conservation District personnel |

# Methodology

## SWAT model calibration and validation

- **Streamflow and sediment**
  - Calibration: 1991–2000
  - Validation: 2001–2010

Monthly USGS observations of streamflow and suspended sediment concentration and phosphorous in Cobb Creek near Eakely gage (USGS 07325800)

- **Crop yield**

A combination of the OSU variety trial data from 2001 to 2016 and the county level NASS data (1986–2005)

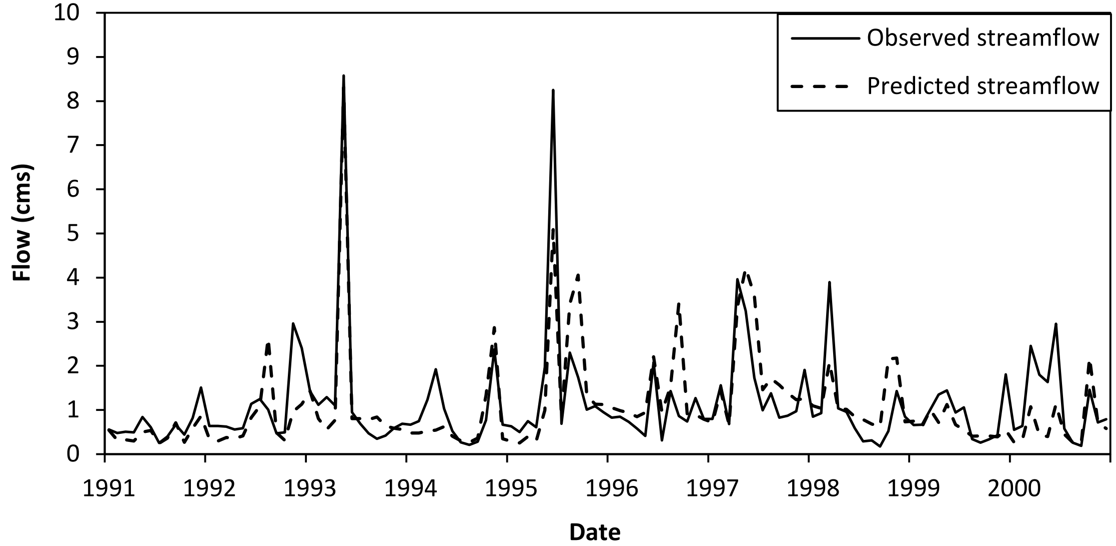
- **Statistical matrices:**
  - Coefficient of determination ($R^2$)
  - Nash-Sutcliffe efficiency (NS)
  - Percentage bias (PB)

# Results of model calibration

## SWAT model calibration and validation (USGS 07325800)

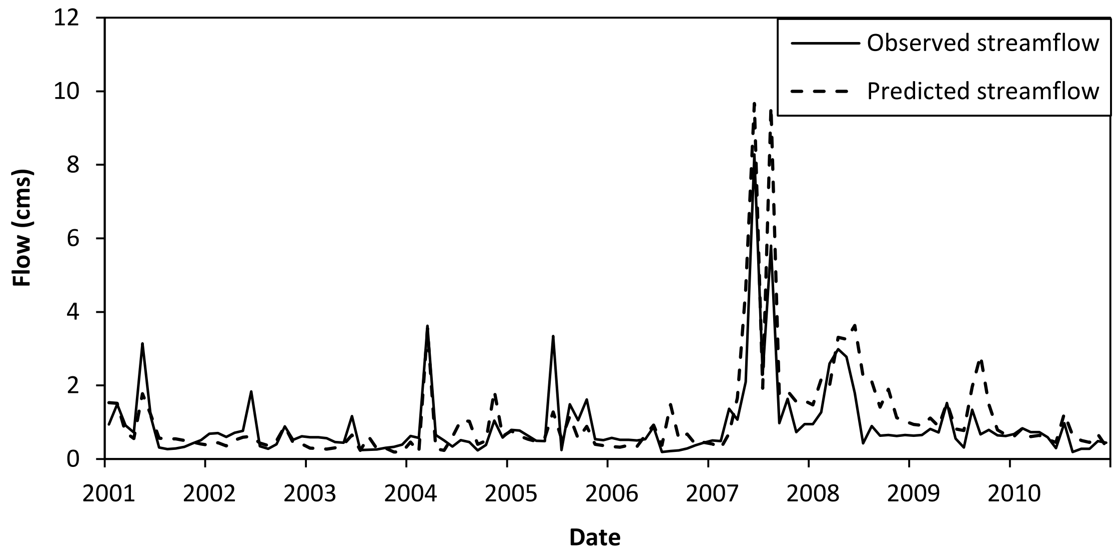
### Calibration of streamflow

- Warm up time period: 1987-1990
- Calibration time period: 1991-2000
- $R^2$ = 0.64
- NS = 0.61
- PB = <1




### Validation of streamflow

- Validation time period: 2001-2010
- $R^2$ = 0.79
- NS = 0.75
- PB = <1




### Calibration of crop yield

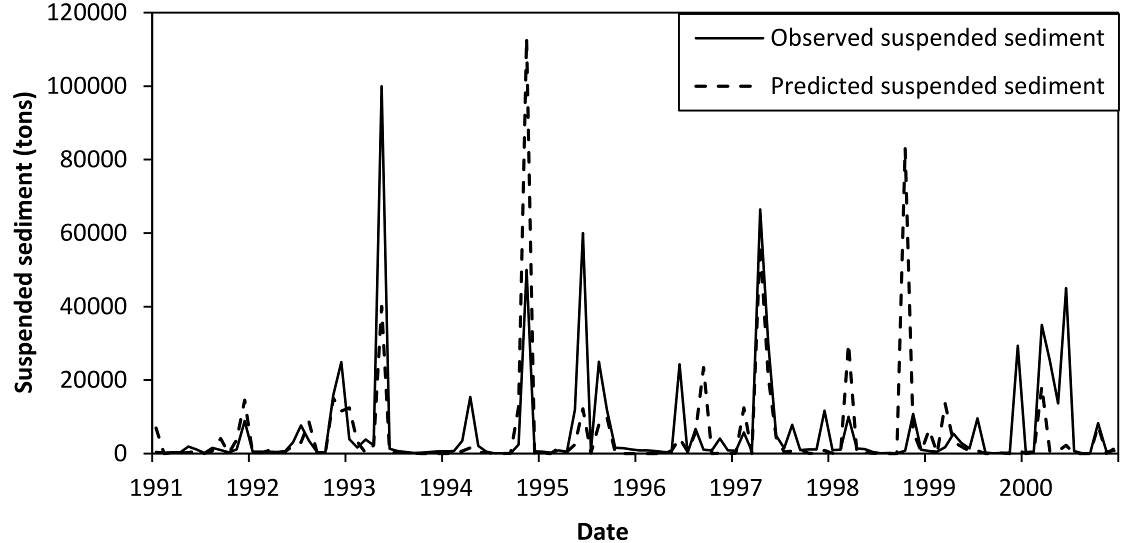
- County level (for Caddo, Custer, and Washita ) NASS data for the years 2001 to 2015 (USDA, 2015)

# Results of model calibration

## ❑ **SWAT model calibration and validation** (USGS 07325800)

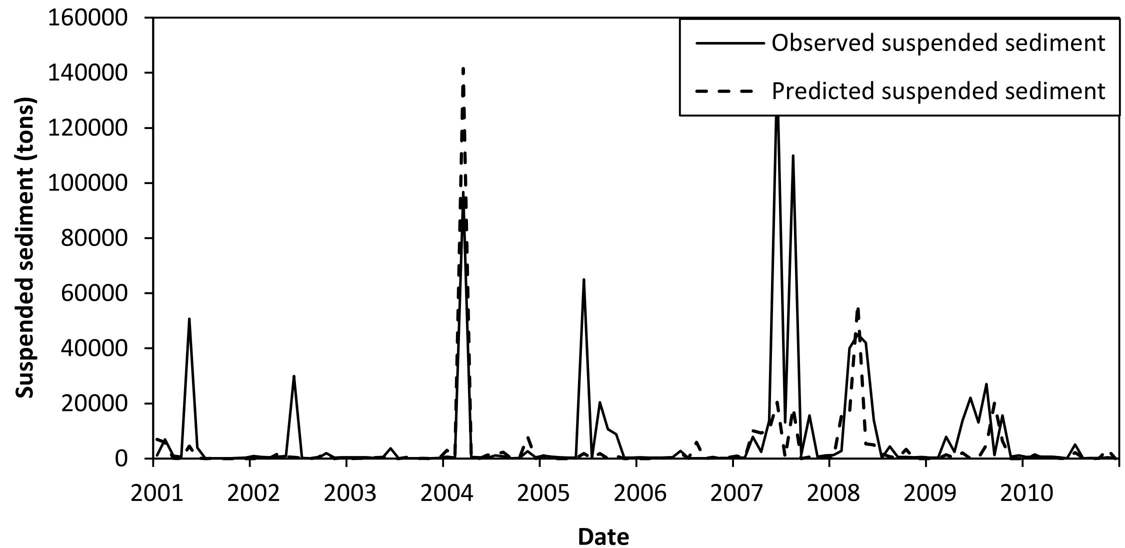
### Calibration of sediment

- Warm up time period: 1987-1990
- Calibration time period: 1991-2000
- $R^2$ = 0.35
- MNS = 0.37
- PB = <20




### Validation of sediment

- Validation time period: 2001-2010
- $R^2$ = 0.38
- NS = 0.47
- PB = <40

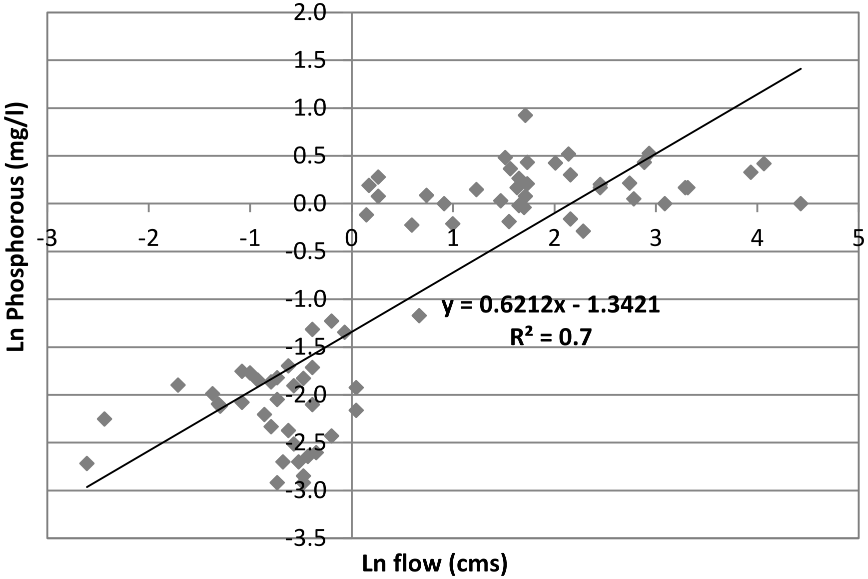


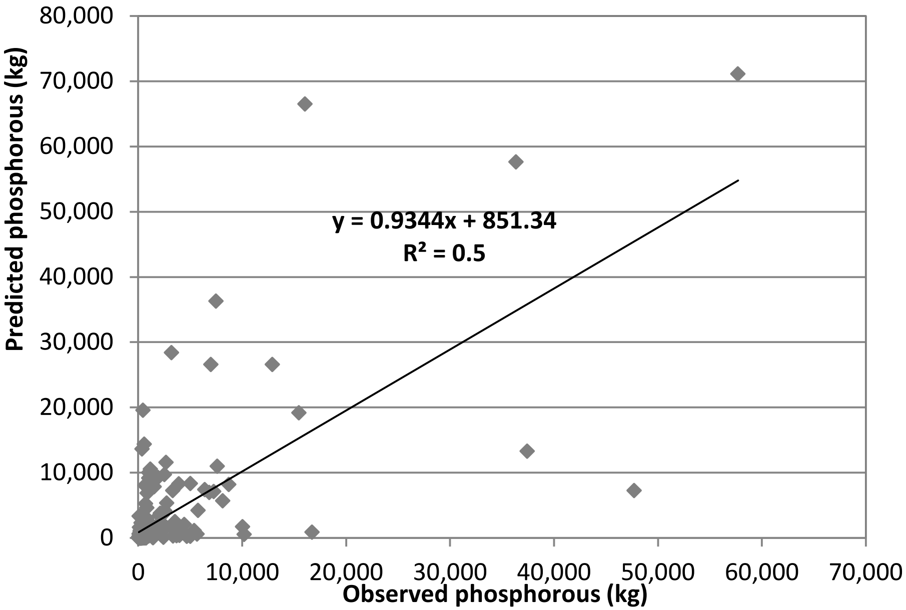

Since there were some gaps in observed sediment data, we were not able to adequately calibrate SWAT for sediment concentration.

# Results of model calibration

- **SWAT model calibration and validation** (USGS 07325800)

**Phosphorous results**



# Methodology

## Crops and Agricultural Best Management Practices

| Code | BMP Scenario | Description |
|---|---|---|
| **BL** | Baseline | Simulation under the calibrated and validated model with 14 land uses, 8 $km^2$ FMC under contour farming |
| **S1** | Non-contour conservation tillage | BMP applied to cotton, grain sorghum, and winter wheat. No changes made to hay and alfalfa. Data obtained from NASS (2014), Storm et al. (2003) and Storm et al. (2006). Total three simulations, one for reach crop. |
| **S2** | Conservation tillage on contour | Applied contours on scenarios 1; 97 $km^2$ additional contours as compared to the baseline scenario. Resulted three simulations, one for each crop. |
| **S3** | Non-contour no-till<br>i. No-till wheat in rotation with canola<br>ii. No-till wheat as cover crop for cotton<br>iii. No-till wheat as cover crop for grain sorghum | All tillage practices were removed while management practices were kept the same; applied to cotton, grain sorghum and winter wheat.<br>Because of weed and disease problems associated with continuous no-till wheat, wheat was rotated with (i) canola, (ii) cotton and (iii) grain sorghum. Total five simulations, one for each crop. |
| **S4** | No-till on contour | Applied contours on Scenario 3. resulted five simulations, one for each crop. |
| **S5** | Conversion to pasture | All crops were converted to Bermuda grass pasture. A combination of three grazing start months (May, June and July) and two stocking rates (1,200 and 1,600 kg) were applied. Total of six simulations. |

# Methodology

## Optimization: Linear Programming

- Market solution
- Tax solution ($100/ton for sediment and $0.3/kg ph)

Identifying the most cost-effective combination of crops and BMPs, **maximizes revenue** of producers while insuring sediment and phosphorous from the watershed does not exceed a specified target

$$Maximize\ revenue = \left[\sum_{s=1}^{S}\sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K}\left((P_i . Y_{shik}) - C_{shik}\right) \times X_{ik}\right]$$

**Subject to:**

$$\sum_{s=1}^{S}\sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K} SED_{shik} \times X_{shik} \leq SED_{limit}$$

$$\sum_{s=1}^{S}\sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K} Ph_{shik} \times X_{shik} \leq PHS_{limit}$$

$\sum_{i=1}^{I}\sum_{k=1}^{K} X_{ik} \leq Ta_{sh},$ for all s and h

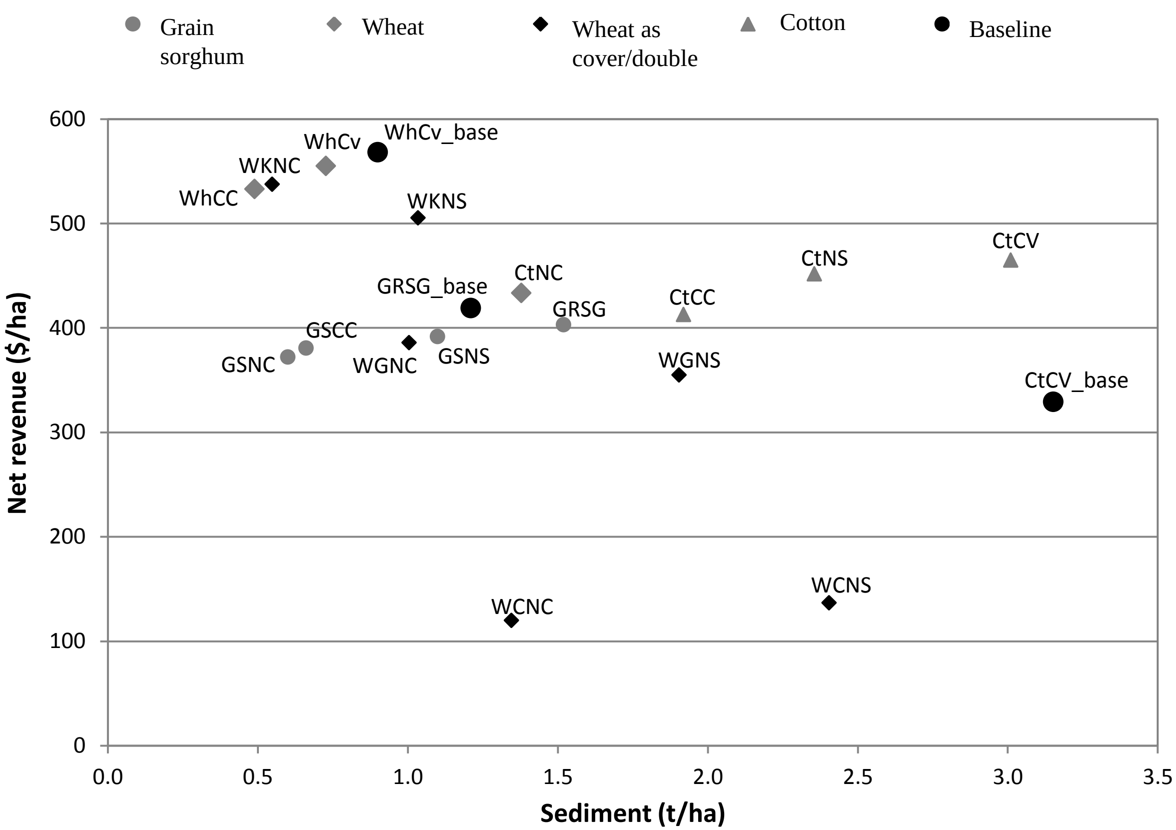
$X_{ik} \geq 0$

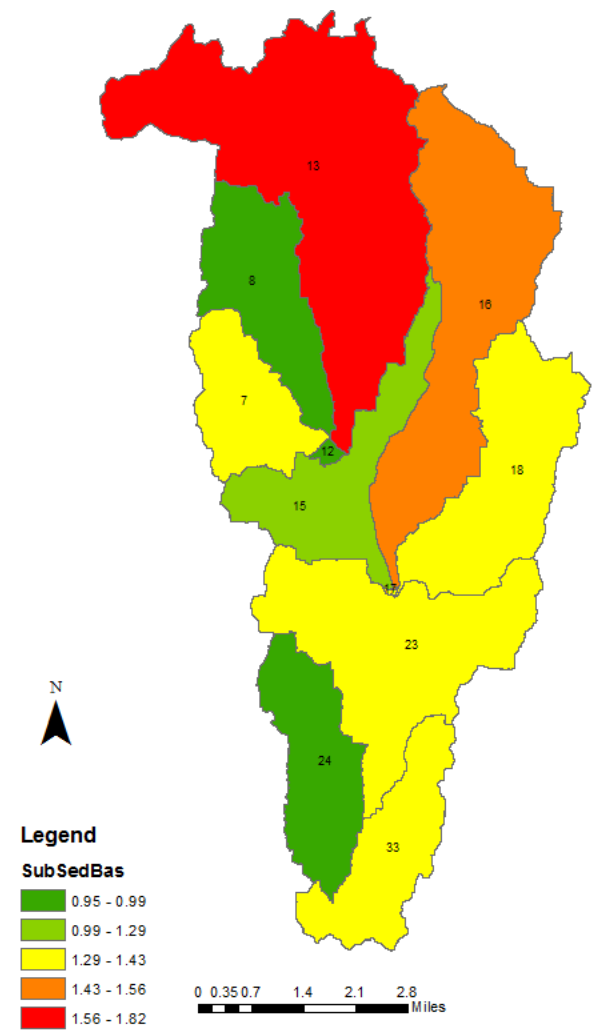
- Costs for Caddo County were calculated by the Machsel program and the Oklahoma State University's enterprise budget software, developed by Kletke and Sestak.
- The source for crop prices was obtained from Oklahoma Agricultural Statistics

S: Sub-basin, h: HRU, i: crop, K: BMP
$P_i$: Price of pasture and Crop$_i$
$Y_{shik}$: Yield of pasture and Crop$_i$ with BMP$_k$ on one hectare in HRU$_h$ in subbasin$_s$
$C_{shik}$: Total Cost to produce pasture and Crop$_i$ with BMP$_k$ on one hectare in HRU$_h$ in subbasin$_s$
$X_{ik}$: The number of hectares of pasture and Crop$_i$ with BMP$_k$
$Ta_{sh}$: Total hectares in HRU$_h$
$SED_{shik}$: Sediment runoff from HRU$_h$ under pasture and Crop$_i$ with BMP$_k$ in subbasin$_s$
$SED_{limit}$: A parametric limit on the total amount of sediment from the watershed allowed
$Ph_{shik}$: Phosphorus runoff from HRU$_h$ under pasture and Crop$_i$ with BMP$_k$ in subbasin$_s$
$PHS_{limit}$: A parametric limit on the total amount of phosphorous from the watershed allowed

# Results

Baseline: Total sediment loss (tons/ha)



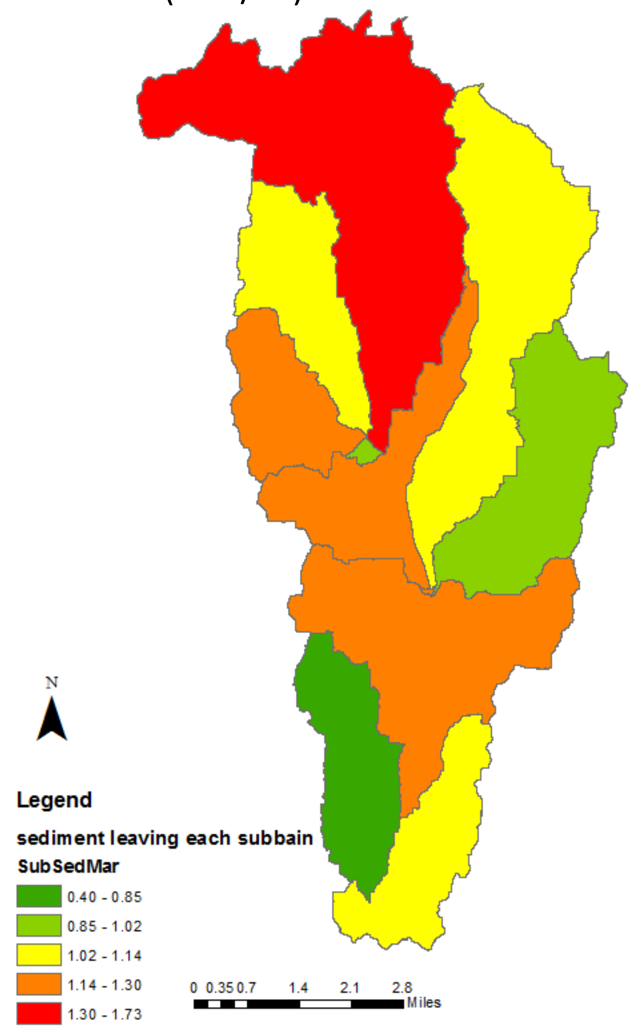




Net return and sediment loss per hectare by BMP/crops in the Five-Mile Creek watershed

# Results

- ❑ Scenarios
  - Linear Programing (market solution): Total sediment loss (tons/ha)

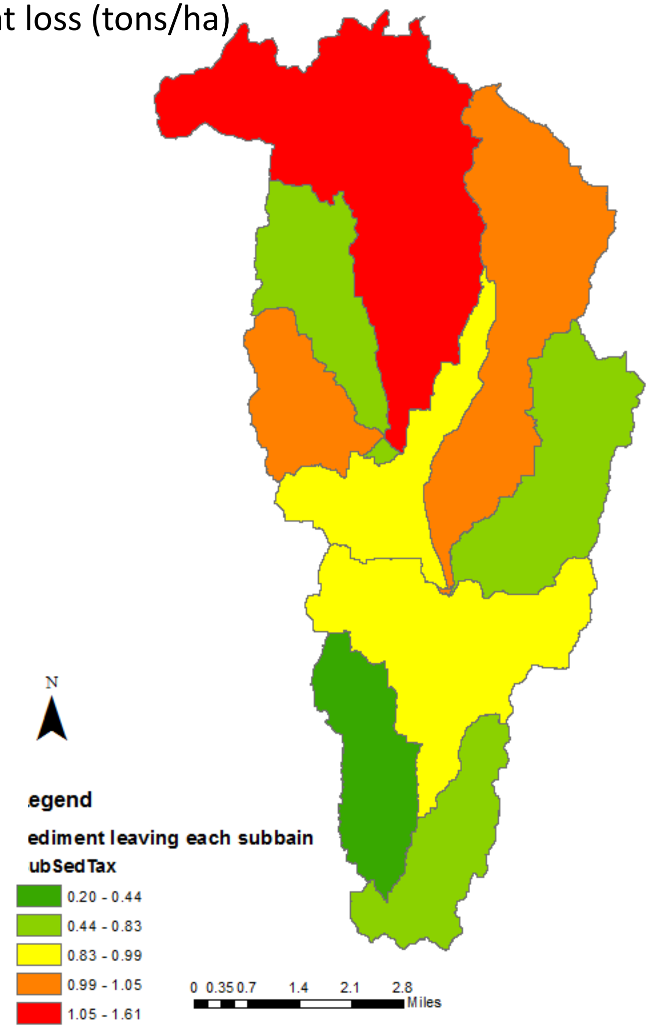
- 26% Increase in net revenue over the conventional crops in the baseline solution ($805,200 )
- 12% reduced total sediment at the outlet
- 26% reduced total phosphorous loads at the outlet
- 75.5% increase in the grain sorghum area from the baseline of which 98% was no-till
- 32% increase in wheat
- All wheat was planted with non-contour conservation tillage in the market solution.
- The area for all cotton (irrigated and dryland) declined 39.4% from the baseline.
- The areas of dryland cotton with conventional reduced tillage increased by 168.5% while the irrigated cotton area decreased by 99%.
- 86.7% of irrigated cotton was converted to wheat under a conservation (conventional or reduced) tillage system



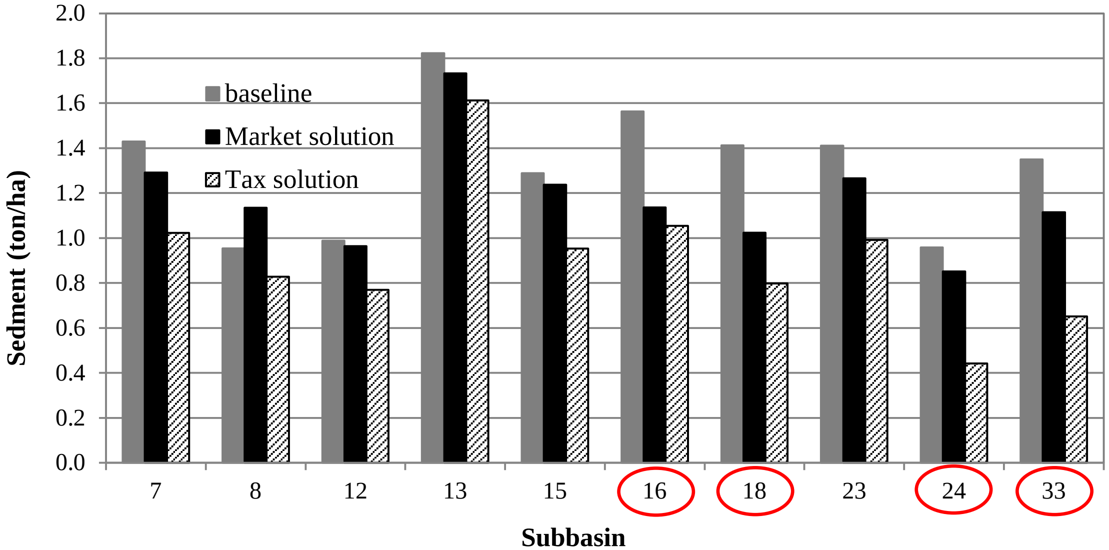
# Results

- Scenarios
  - Linear Programing (tax solution): Total sediment loss (tons/ha)

- Wheat was the dominant crop with 48% of the area while only 2% remained in cotton.
- The net revenue was $2,611,627, 14% and 32% less than the baseline and market solution, respectively.
- The sediment and phosphorous load in the outlet of watershed was respectively 27% and 28% lower than in the baseline scenario.
- $1.2 million compensation to producers to adopt BMPs would result in 28% sediment (4,507 tons) and 27% phosphorous (17 tons) reduction over the baseline.
- Wheat area increased by 60.2% from the baseline of which, 11% were planted on contours.
- The cotton area decreased by 87.9% from the baseline; dry cotton with conservation (reduced) tillage decreased by 46.5% and irrigated cotton decreased by 99%.
- 90.6% of irrigated cotton was converted to wheat with non-contour conservation (reduced) tillage system.



# Results



2.0
1.8
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1.0
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Sedment (ton/ha)
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Tax solution
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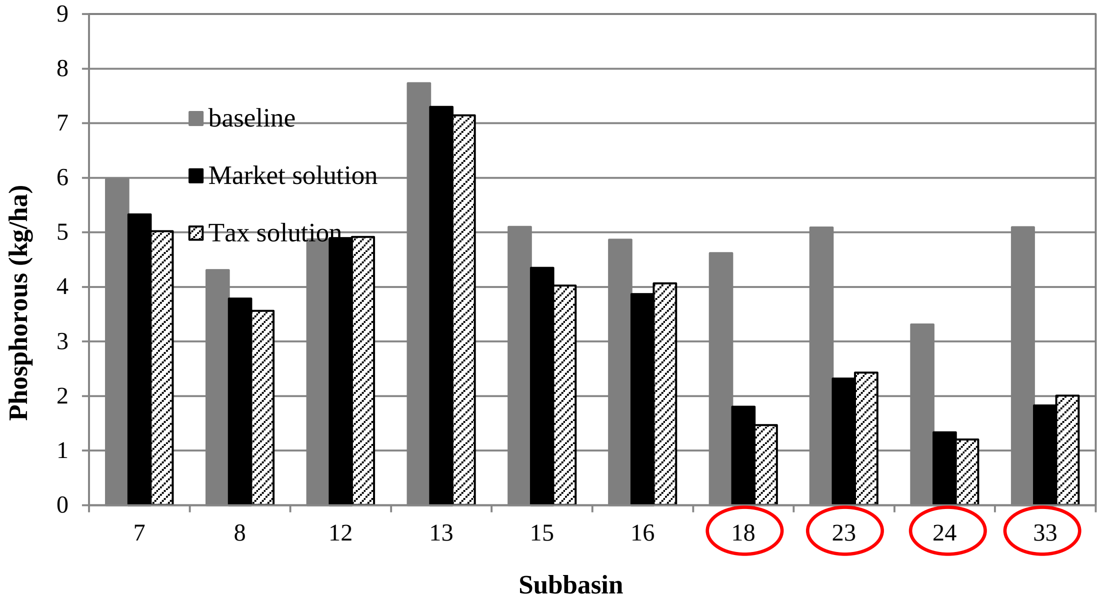

9
8
7
6
5
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Phosphorous (kg/ha)
baseline
Market solution
Tax solution
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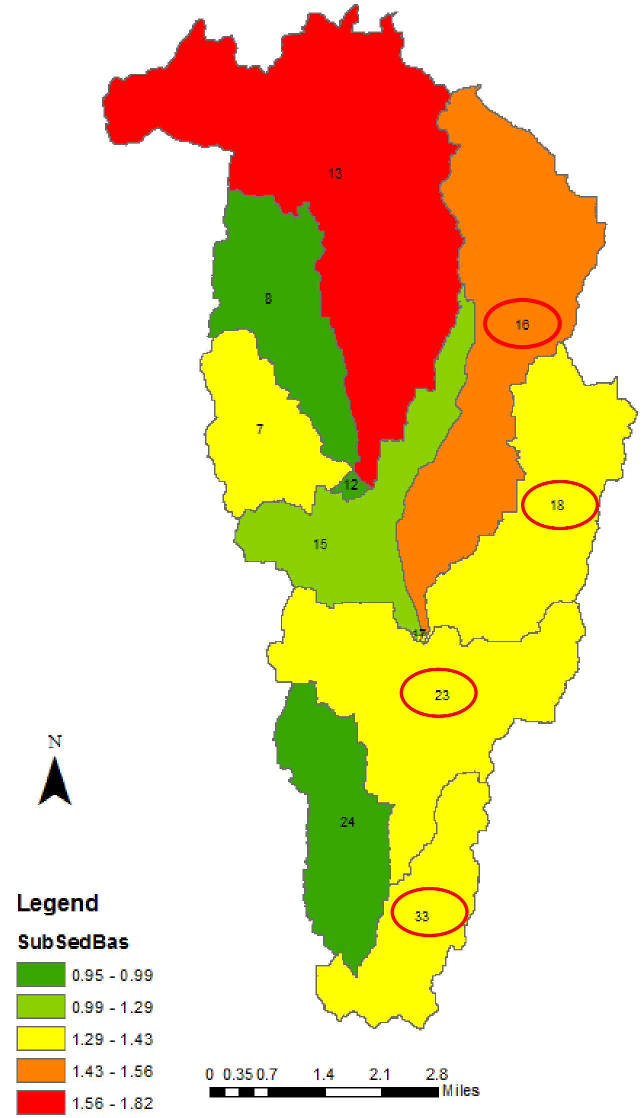

13
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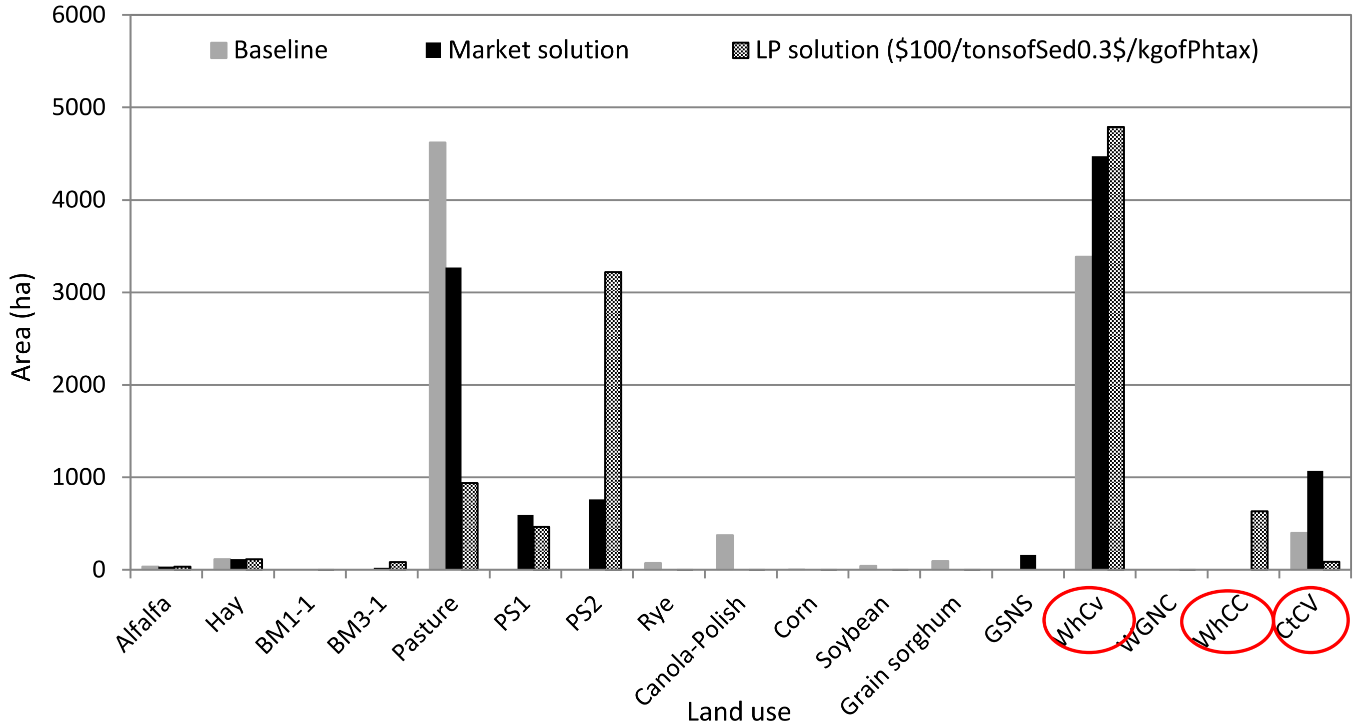
0.95 - 0.99
0.99 - 1.29
1.29 - 1.43
1.43 - 1.56
1.56 - 1.82
0 0.35 0.7 1.4 2.1 2.8
Miles

# Results

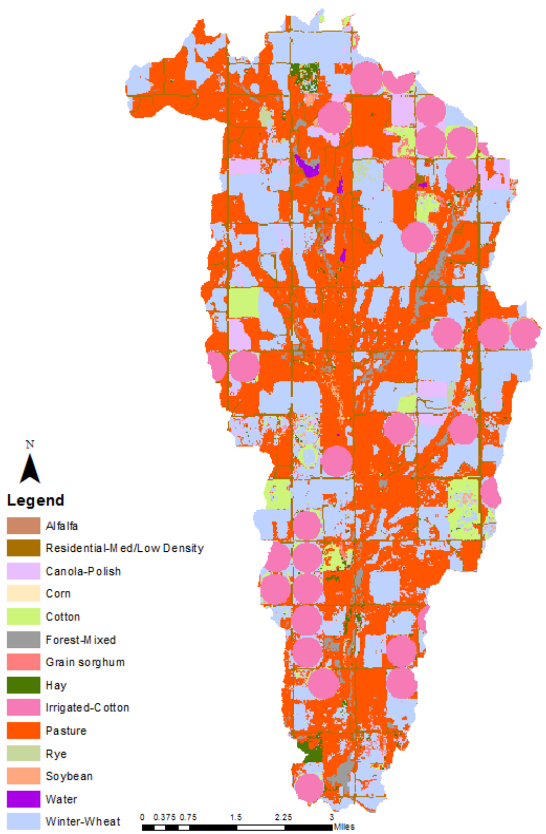
| Scenarios | Net revenue (uncompensated income) ($) | Tax cost (producer's compensation subsidy) ($) | Producer's income (compensated income) ($) | Sediment (ton) | Phosphorous (kg) |
|---|---|---|---|---|---|
| **Baseline** | 3,026,795 | _ | _ | 16,512.8 | 62,571.7 |
| **Market solution** | 3,831,996 | _ | _ | 14,546.8 | 46,275.7 |
| **Tax solution** | 2,611,628 | 1,214,134 | 3,825,762 | 12,005.4 | 45,321.3 |



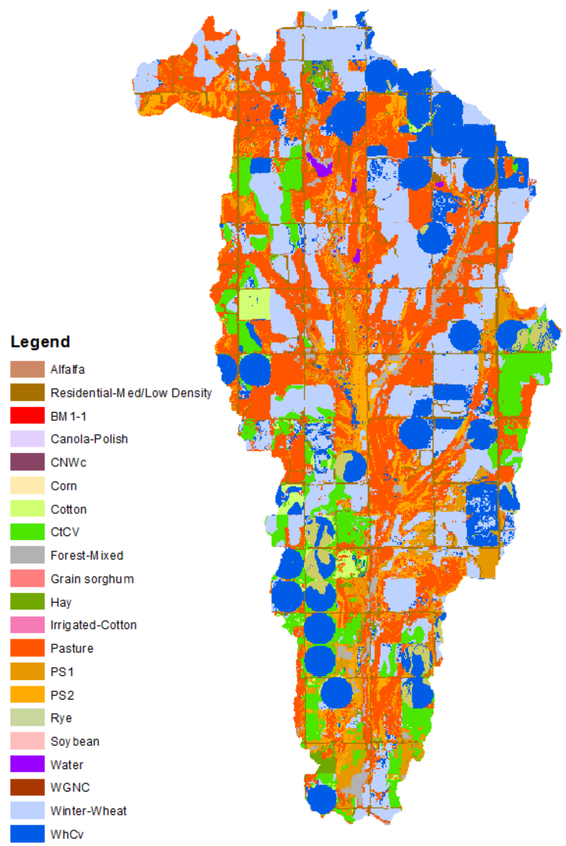

- In the market solution scenario, 41% of the area is native pasture, 40% is wheat, and 10% is cotton, as the most dominate crops in the study area.
- In the tax scenario, wheat was the dominant crop with 48% of the area while only 2% remained in cotton.

# Results

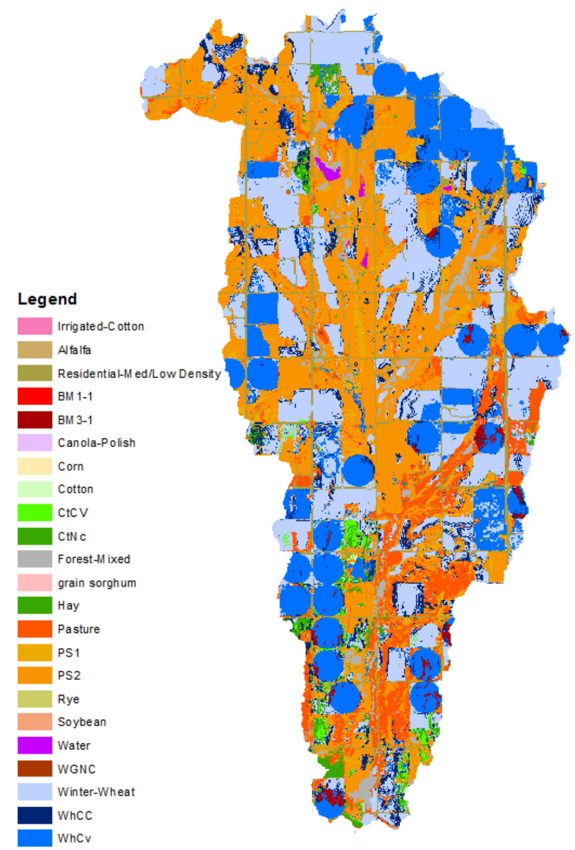
Spatial allocation of FMC BMP/crop in different sediment and phosphorous abatement scenarios




Baseline




Market solution




Tax solution

# Estimated Sediment (tons) Loss occurring after tax Solutions

| Soil texture | Slope | Tax solution | | | | | | | Baseline | | | Sediment reduction (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cotton | | | Wheat | | | | | | | |
| | | Conventional tillage | Conservation tillage | Contour+ No-till | Contour+ Conservation tillage | Conservation tillage | Conventional tillage | Total | Cotton | Wheat | Total | |
| Clay loam | Total | | | | 0.16 | 1.59 | 1.51 | 3.26 | 1.42 | 1.54 | 2.96 | -10.0 |
| | 0-2 | | | | | 0.87 | 1.21 | 2.08 | 0.88 | 1.21 | 2.09 | 0.5 |
| | 2-4 | | | | | 0.62 | 0.21 | 0.83 | 0.41 | 0.21 | 0.62 | -33.4 |
| | 4-6 | | | | | 0.10 | 0.09 | 0.19 | 0.13 | 0.10 | 0.23 | 15.6 |
| | 6-9999 | | | | 0.16 | | | 0.16 | | 0.03 | 0.03 | -492.9 |
| Sandy loam | Total | 2.80 | 4.96 | 28.50 | 47.26 | 90.73 | 6.28 | 180.54 | 67.53 | 220.99 | 288.52 | **37.4** |
| | 0-2 | 2.80 | 4.93 | | | 2.04 | 0.01 | 9.78 | 2.75 | 6.60 | 9.35 | -4.6 |
| | 2-4 | | 0.03 | 14.12 | | 8.15 | 0.72 | 23.02 | 11.36 | 30.00 | 41.36 | 44.3 |
| | 4-6 | | | 13.19 | 4.76 | 45.67 | 5.44 | 69.06 | 11.22 | 45.15 | 56.37 | -22.5 |
| | 6-9999 | | | 1.19 | 42.51 | 34.87 | 0.11 | 78.68 | 42.21 | 139.24 | 181.45 | 56.6 |
| Fine sandy loam | Total | 0.15 | 2.39 | | 579.65 | 213.95 | 510.37 | 1306.50 | 234.02 | 1189.91 | 1423.94 | 8.2 |
| | 0-2 | 0.15 | 2.39 | | | 25.00 | 29.68 | 57.22 | 11.13 | 54.66 | 65.79 | 13.0 |
| | 2-4 | | | | | 61.83 | 131.03 | 192.87 | 46.13 | 142.66 | 188.78 | -2.2 |
| | 4-6 | | | | 26.19 | 107.20 | 270.49 | 403.88 | 72.36 | 229.74 | 302.11 | -33.7 |
| | 6-9999 | | | | 553.46 | 19.91 | 79.17 | 652.54 | 104.40 | 762.85 | 867.25 | 24.8 |
| Loamy fine sand | Total | | 4.11 | | 37.65 | 36.48 | 23.41 | 101.66 | 21.37 | 30.24 | 51.60 | -97.0 |
| | 0-2 | | 4.11 | | | 2.12 | 1.80 | 8.04 | 2.34 | 1.70 | 4.04 | -98.8 |
| | 2-4 | | | | | 3.29 | 6.59 | 9.88 | 9.68 | 6.53 | 16.21 | 39.1 |
| | 4-6 | | | | 2.29 | 30.25 | 14.31 | 46.85 | 7.26 | 7.45 | 14.70 | -218.7 |
| | 6-9999 | | | | 35.36 | 0.82 | 0.71 | 36.89 | 2.09 | 14.57 | 16.65 | -121.5 |
| Silty clay loam | Total | | 3.82 | 1.40 | 48.95 | 175.14 | 227.85 | 457.16 | 115.47 | 277.67 | 393.15 | -16.3 |
| | 0-2 | | 3.82 | 0.38 | | 73.63 | 91.43 | 169.26 | 46.33 | 102.78 | 149.11 | -13.5 |
| | 2-4 | | | 1.02 | | 59.75 | 89.39 | 150.16 | 38.41 | 94.84 | 133.25 | -12.7 |
| | 4-6 | | | | 0.27 | 32.74 | 42.68 | 75.70 | 19.96 | 42.28 | 62.24 | -21.6 |
| | 6-9999 | | | | 48.68 | 9.01 | 4.34 | 62.03 | 10.78 | 37.77 | 48.55 | -27.8 |
| Silt | Total | | | | 181.12 | 121.91 | 177.04 | 480.07 | 162.00 | 443.46 | 605.46 | 20.7 |
| | 0-2 | | | | | 10.24 | 20.63 | 30.87 | 15.87 | 32.96 | 48.83 | 36.8 |
| | 2-4 | | | | | 41.09 | 63.42 | 104.51 | 41.77 | 90.20 | 131.97 | 20.8 |
| | 4-6 | | | | 38.56 | 61.68 | 76.78 | 177.03 | 56.16 | 115.84 | 171.99 | -2.9 |
| | 6-9999 | | | | 142.56 | 8.90 | 16.20 | 167.66 | 48.20 | 204.47 | 252.67 | 33.6 |
| Very fine sandy loam | Total | | | | 173.51 | 33.62 | 31.67 | 238.79 | 5.80 | 206.72 | 212.52 | -12.4 |
| | 0-2 | | | | | 2.94 | 1.67 | 4.61 | 0.78 | 2.14 | 2.92 | -57.9 |
| | 2-4 | | | | 0.08 | 9.60 | 29.69 | 39.37 | 1.51 | 19.19 | 20.71 | -90.1 |
| | 4-6 | | | | 48.12 | 2.03 | 0.31 | 50.45 | 2.40 | 52.08 | 54.48 | 7.4 |
| | 6-9999 | | | | 125.31 | 19.05 | | 144.36 | 1.11 | 133.31 | 134.41 | -7.4 |

# Conversion of baseline crops to different BMP/crops based on soil texture and land slope in tax solution scenario

| *Soil texture | Slope (%) | Conversion of baseline irrigated cotton to | | | Conversion of baseline dryland cotton to | | | Conversion of baseline grain sorghum to | | | | | Conversion of baseline minimum till wheat to | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BM31 | WhCC | WhCv | CtNc | WhCC | WhCv | CtCV | CtNc | WGNC | WhCC | WhCv | CtCV | CtNc | WGNC | WhCC |
| Clay loam | Total | | | | | | 2.5 | | | | | 0.1 | | | | |
| | 0-2 | | | | | | 2.1 | | | | | 0.1 | | | | |
| | 2-4 | | | | | | 0.4 | | | | | | | | | |
| | 4-6 | | | | | | | | | | | | | | | |
| | >6 | | | | | | | | | | | | | | | |
| Sandy loam | Total | 25.0 | | 237.0 | 7.7 | 5.9 | 12.0 | 3.5 | 4.4 | | 3.8 | 5.9 | 57.7 | 94.8 | | 72.5 |
| | 0-2 | | | 97.9 | | | 2.4 | 3.5 | | | | 0.9 | 57.7 | | | |
| | 2-4 | | | 95.3 | 7.1 | | 4.6 | 0.1 | 3.7 | | | 1.3 | | 79.1 | | |
| | 4-6 | | | 40.8 | 0.6 | | 4.7 | | 0.4 | | | 3.3 | | 15.7 | | |
| | >6 | 25.0 | | 3.0 | | 5.9 | 0.3 | | 0.2 | | 3.8 | 0.4 | | | | 72.5 |
| Fine sandy loam | Total | 48.7 | 14.0 | 341.1 | | 10.9 | 77.2 | | | | 10.9 | 21.9 | 9.0 | | | 241.3 |
| | 0-2 | 0.3 | | 184.7 | | | 24.9 | | | | | 5.5 | 9.0 | | | |
| | 2-4 | 5.8 | | 106.5 | | | 30.0 | | | | | 8.1 | | | | |
| | 4-6 | 10.4 | | 43.3 | | | 20.3 | | | | | 8.3 | | | | 30.4 |
| | >6 | 32.1 | 14.0 | 6.7 | | 10.9 | 2.0 | | | | 10.9 | | | | | 210.9 |
| Loamy fine sand | Total | 7.4 | 0.6 | 49.0 | | 0.3 | 12.0 | | | | 0.2 | 0.9 | 0.5 | | | 5.9 |
| | 0-2 | | | 28.4 | | | 4.1 | | | | | 0.6 | 0.5 | | | |
| | 2-4 | | | 16.7 | | | 5.8 | | | | | 0.3 | | | | |
| | 4-6 | 3.4 | | 3.9 | | | 2.1 | | | | | 0.1 | | | | |
| | >6 | 3.9 | 0.6 | | | 0.3 | | | | | 0.2 | | | | | 5.9 |
| Silty clay loam | Total | | 5.1 | 466.2 | 0.3 | 1.3 | 162.0 | | | | 0.2 | 22.3 | | 6.0 | | 18.2 |
| | 0-2 | | | 371.0 | 0.3 | | 118.6 | | | | | 13.4 | | 5.2 | | |
| | 2-4 | | | 80.3 | | | 34.4 | | | | | 6.1 | | 0.8 | | |
| | 4-6 | | | 14.7 | | | 7.8 | | | | | 2.2 | | | | |
| | >6 | | 5.1 | 0.2 | | 1.3 | 1.2 | | | | 0.2 | 0.6 | | | | 18.2 |
| Silt | Total | | 19.5 | 134.9 | | 3.5 | 89.2 | | | | 3.3 | 11.3 | | | | 93.4 |
| | 0-2 | | | 61.4 | | | 38.0 | | | | | 3.1 | | | | |
| | 2-4 | | | 49.8 | | | 30.2 | | | | | 3.7 | | | | |
| | 4-6 | | | 23.7 | | | 17.0 | | | | | 3.9 | | | | 4.1 |
| | >6 | | 19.5 | | | 3.5 | 4.0 | | | | 3.3 | 0.5 | | | | 89.4 |
| Very fine sandy loam | Total | 3.7 | 4.4 | 10.2 | | 0.3 | 3.8 | | | | 0.3 | 0.7 | | | | 58.2 |
| | 0-2 | | | 4.4 | | | 1.9 | | | | | 0.2 | | | | |
| | 2-4 | | | 5.9 | | | 1.2 | | | | | 0.4 | | | | |
| | 4-6 | | 3.4 | | | 0.2 | 0.6 | | | | 0.1 | 0.1 | | | | 26.7 |
| | >6 | 3.7 | 1.0 | | | 0.1 | 0.1 | | | | 0.2 | | | | | 31.5 |

# Conclusion

- Continuous minimum till wheat remains the dominant crop  in the FMC area (until problems with continuous no-till wheat can be solved ).
- Simulations with winter wheat as a cover crop or double crop in rotation with cotton or grain sorghum gave lower economic returns and some increase in erosion.
- $1.2 million compensation to producers to adopt crop/BMPs would result in 28% sediment (4,507 tons) and 27% phosphorous (17 tons) reduction over the baseline.
- Tax scenario would also result in reduction of sediment (15%) and phosphorous (2%) over the market solution.
- In tax solution scenario the wheat area increased by 60.2% and 21.3% from the baseline and market solution respectively
- In tax solution scenario the cotton area decreased by 87.8% and 80% from the baseline and market solution respectively.

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Thank you for your attention