EFFECT OF STAKEHOLDER ATTITUDES ON THE OPTIMIZATION OF WATERSHED CONSERVATION PRACTICES

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DEDICATION

To all of those who trust on me. Thank you

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I will start thanking God for this opportunity, embracing changes is not an easy task, but He had given me the strength, courage and patience to keep going.

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ABSTRACT

Adriana Debora Piemonti

EFFECT OF STAKEHOLDER ATTITUDES ON THE OPTIMIZATION OF WATERSHED CONSERVATION PRACTICES

Land use alterations have been major drivers for modifying hydrologic cycles in many watersheds nationwide. Imbalances in this cycle have led to unexpected or extreme changes in flood and drought patterns and intensities, severe impairment of rivers and streams due to pollutants, and extensive economic losses to affected communities. Eagle Creek Watershed (ECW) is a typical Midwestern agricultural watershed with a growing urban land-use that has been affected by these problems. Structural solutions, such as ditches and tiles, have helped in the past to reduce the flooding problem in the upland agricultural area. But these structures have led to extensive flooding and water quality problems downstream and loss of moisture storage in the soil upstream. It has been suggested that re-naturalization of watershed hydrology via a spatially-distributed implementation of non-structural and structural conservation practices, such as cover crops, wetlands, riparian buffers, grassed waterways, etc. will help to reduce these problems by improving the upland runoff (storing water temporally as moisture in the soil or in depression storages). However, spatial implementation of these upland storage practices poses hurdles not only due to the large number of possible alternatives offered by physical models, but also by the effect of tenure, social attitudes, and behaviors of landowners that could further add complexities on whether and how these practices are adopted and effectively implemented for benefits. This study investigates (a) how landowner tenure and attitudes can be used to identify promising conservation practices in an agricultural watershed, (b) how the different attitudes and preferences of stakeholders can modify the effectiveness of solutions obtained via classic optimization approaches that do not include the influence of social attitudes in a watershed, and (c) how spatial distribution of landowner tenure affects the spatial optimization of conservation practices on a watershed scale. Results showed two main preferred practices, one for an economic evaluation (filter strips) and one for an environmental perspective (wetlands). A land tenure comparison showed differences in spatial distribution of systems considering all the conservation practices. It also was observed that cash renters selected practices will provide a better cost-revenue relation than the selected optimal solution.

Meghna Babbar-Sebens, PhD., Chair

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LIST OF ABBREVIATIONS

BMP or BMPs:	Best management practice or Best management practices
CEES:	Center for Earth and Environmental Sciences
DEM:	Digital Elevation Model
DPLA:	Decentralized Pursuit Learning Algorithm
ECR:	Eagle Creek Reservoir
ECW:	Eagle Creek Watershed
FOTG:	Field Office Technical Guide
HRU:	Hydrologic Response Unit
HU:	Heat Units
HUC:	Hydrologic Unit Code
LOADEST:	Load Estimator
LULC:	Land Use Land Cover
NPV:	Net of present value
NSGA-II:	Non Sorting Genetic Algorithm version 2
NWI:	National Wetland Inventory
SB or SBs:	Subbasin or Subbasins
SPEA:	Strength Pareto Evolutionary Algorithm
SSURGO:	Soil Survey Geographic Database
SWAT:	Soil and Water Assessment Tool
USGS:	United State Geological Survey

1. INTRODUCTION

1.1. Motivation

Land alterations due to large-scale agriculture and urban developments have had adversarial impacts on the ability of watershed landscapes to intercept, store, and slow surface runoff. This has led to recurring incidences of increased flooding and/or droughts, worsening water quality and loss of biodiversity worldwide (Peterjohn and Correl (1984), Bronstert et al. (2002), Kim et al. (2002), Zedler (2003)). For example, in USA, 60% of historically existing wetlands have been drained to establish agriculture (Zedler (2003)). In Midwestern states alone the loss of wetlands has been even more significant, and up to as high as 87% in Indiana (Dahl (1990)).

In order to overcome the effects of land alterations, the use of non-structural flood control schemes via conservation practices, such as riparian forest and wetlands have been proposed by multiple researchers (e.g., Hey et al. (2004), Mitsch and Day (2006), Lemke and Richmond (2009)). These conservation practices also improve water quality, preserve the native flora, and create habitats for the fauna (Peterjohn and Correl (1984), D'Arcy and Frost (2001), Bekele and Nicklow (2005)). Recently, there has also been an increased interest in the restoration of degraded upland and downstream storage capacities of watershed landscapes via networks of distributed conservation practices that behave like water storage systems (Hey et al. (2009)). Hey et al. (2009) proposed that storage systems consisting of a combination of larger scale structural projects (such as levees, overflow and backflow structures) and restoration of the bottomlands could retain approximately 75% of all the water above the minor flood stage. The design of these storage systems is, however, extremely challenging and complex when sites and practices options have to be selected on the basis of not only physical and biogeochemical factors, but also on the basis of the socio-economic factors coexisting in the watershed.

A preliminary analysis of just the physical factors, such as soil type, land use and topography can yield 1000's of suitable potential sites for restoring or creating a conservation practice (Babbar-Sebens et al. (2010)). Additionally, watersheds are tightly coupled with socioeconomic drivers, such as land tenure type, land productivity, crop prices, environmental attitudes, municipality regulations, conservation programs, believes, general social norms, etc., which can be spatially and temporally distributed within the watershed system, thereby, affecting the spatial decision making and adoption of conservation practices across the watershed landscape.

In the field of watershed planning and management, multiple studies and approaches have been investigated for finding solutions to the complex spatial design problems in watersheds using optimization techniques and algorithms. For example, approaches for optimization of spatial distribution of conservation practices and best management practices in agricultural landscape have been investigated by multiple studies, such as, Newbold (2002; 2005), Kaini et al. (2007), Artita et al. (2008), Cutter et al. (2008), Maringanti et al. (2009), and Tilak et al. (2011a), etc.

Studies such as those by Kaini et al. (2007) and Tilak et al. (2011a) have investigated approaches for optimizing spatial distribution of ponds and wetlands in a watershed, based on physical factors. Both authors used a combination of different evolutionary algorithms and the Soil and Water Assessment Tool (SWAT), a hydrologic model from the United State Department of Agriculture (USDA) (Arnold et al. (2001; 2005)), in order to find the best possible combination of wetlands in different subbasins

(SBs) of watersheds in the Midwestern region. Kaini et al.'s study was based on the goal of minimizing the maximum daily peak flow, while constrain the maximum areas of ponds within an upper limit. They used a single-objective genetic algorithm (GA) to modify pond sizes in sub-basins across the watershed. They found that the optimal solution of distribution of ponds in their watershed site (Silver Creek watershed in Illinois) could lead to a reduction of maximum daily flows by 16.8%. Though their work demonstrates a useful watershed-scale approach to designing storage systems such as detention ponds, they did not incorporate any effect of landowners and socio-economic criteria on the design of these detention ponds.

Similar to Kaini et al. (2007), Tilak et al. (2011a) explored the design of structural water storage practices across the watershed landscape. Tilak et al. (2011a), however, investigated and compared two types of search/optimization algorithm Non-Sorting Genetic Algorithm (NSGA-II) (Deb et al. (2002)) and a Decentralized Pursuit Learning Algorithm (DPLA) (Tilak et al. (2011b)) for the spatial design of a distributed system of wetlands in a watershed. Their optimization formulation was based on two conflicting watershed-scale objectives: minimize the total area used by wetlands in the watershed, and minimize the difference (using a mean square error type of metric) between stream hydrographs at outlets of sub-basins when all wetlands of maximum areas are implemented and the stream hydrographs at the outlets of sub-basins when only a subset of wetlands proposed by the optimization algorithm are implemented. The results showed that for the entire watershed NSGA-II has a better performance than DPLA in finding solutions with better overall flow benefits for a specific total wetland area. The optimization was based on a binary decision variable scheme, where every SB either had or did not have wetlands. When a specific SB had wetlands, the maximum area of wetlands possible in that SB was used to estimate the performance of the wetlands in that sub-basin. This study also, similar to Kaini et al. (2007) used physical factors to determine the suitability of sub-basins for wetlands, even though they discussed the importance and need for inclusion of human constrains in the optimization algorithms for further evaluation of the wetlands designs from the perspective of the land-owners.

Other researchers have tried to include socio-economic criteria to represent landowner preferences for each conservation practice within the optimization. For example, Newbold (2005) proposed a landscape design model coupled with a hydrologic simulation model within an optimization framework for prioritizing potential wetlands restoration sites in Central Valley, California. The main objective of the study was to design the spatial distribution of wetlands that achieve maximum reduction of nitrogen from non-point sources for minimum restoration costs. Newbold's final results emphasize the importance of targeted site selection for the improvement of water quality. His work also shows that the reduction in restoration costs depends on the proximity of restoration sites to other existing water bodies and also demonstrated that incorporated only one benefit can yield limited reductions for the restoration. However, even though Newbold (2005) included economic drivers as part of the cost-benefit analysis, he did not consider the effect of landowner social conditions on the overall prioritization of wetland sites.

Similarly, other researchers such as, Bekele and Nicklow (2005), Artita et al. (2008), and Maringanti et al. (2009), have incorporated economic objectives and criteria along with environmental benefits as part of the optimization of conservation practices. For example, Bekele and Nicklow (2005) study the effect of different agricultural land uses (i.e. no tillage for row crops) that provide ecosystem services such as sediments, phosphorus and nitrogen reductions in the watershed. They used a combination of a strength Pareto evolutionary algorithm 2 (SPEA2) and the SWAT hydrologic model to identify the best scenarios under different changes on the landscape. The objectives used in their study were 4; sediments reduction, phosphorus reduction, nitrogen reduction and the negative value of the average net annual gross. This annual gross margin was calculated using a generic function ϕ (:) that depends on a policy withdraw from a poll of combination of land uses and tillage practices over a decision period in the watershed. Their results showed the importance of a tradeoff analysis between multiple objective, where the best selection can be made based on an overall assessment of all multiple objectives, instead of just one objective at a time. However, the evaluated economic function used in this study, similar to other studies, does not include the effect of landowner social conditions and preferences, etc.

On the other hand, Marangati et al. (2009) tried to incorporate landowner preferences in their optimization approach that used a combination of NSGA-II and the SWAT hydrologic model to optimize multiple best management practices in a watershed. This incorporation of landowner preferences was done by using the records from stakeholders and county agents to identify most popular and commonly adopted BMPs in their watershed sites and then use those BMPs within the optimization approach. However, their approach did not investigate the stakeholders or county agents reasons to select a particular BMP. There is a deficiency of information regarding attitudes and preferences not just of individual stakeholders, but also in the possible evaluations and scenarios that can be derive when a combination of decision makers is include in the optimization process of management plans for watershed. When a watershed plan is presented to the landowners in the watershed, some modifications of the original optimal solution could be made due to attitudes and preferences towards a specific target, such erosion control, or economics profits.

The trend to believe economics factors are the unique human constrain in the optimal solutions selection of conservation practices have to be reevaluated. Using information regarding conservation practice adoption we could be able to simulate scenarios were the attitudes of stakeholders become an important player in the selection of the objective functions necessaries to satisfy the requirements of different individuals. There exist some tendencies such as environmental attitudes and future planning of the land, which may influence in a decision of adoption, even when initial investment does not allow a favorable profit (Söderqvist (2003)).

Attitudes and behavior of agricultural stakeholders have been studied by several authors (Lynne et al. (1988), Weaver (1996), Luzar and Cosse (1998), Luzar and Diagne (1999), Soule et al. (2000), Söderqvist (2003)). Lynne et al. (1988) suggest the idea of a psychological environment where a negotiation among positive evaluation of the roles of conservation practices and negative evaluations, such as costs, occurred. This negotiation usually involves a weighing of importance or prioritizations of the individuals. The final behavior of adoption of practices is led by three main factors; first a social situational factor, that would involve, income, costs of practices and farm features; second the attitude of the farmers towards environment; and third the perception of others in the community, better known as a social norm. Crop and land prices, surveys, incentives, regulations and demographic characteristics are some of the features used to evaluate the socioeconomic drivers (i.e., land tenure, environmental attitudes, regulations, beliefs and available conservation programs), preferences of landowners, and the likelihood of adoption of conservation practices.

Then, preferences for optimal solutions can be based on not just the physical criteria, but also on these socio-economic drivers that would affect landowner attitudes and behaviors and motivate stakeholders to adopt only a sub-set of conservation practices (Luzar and Cosse (1998), Luzar and Diagne (1999), Soule et al. (2000), Söderqvist (2003), Oliver (2008), Ahnström (2009)).

In order to increase successful implementation of watershed management plans, and adoption of conservation practices by the stakeholders, it is important to create a bridge among the social effects and physical models, to present and evaluate the best optimal feasible solution considering interests and targeting trades that allow decision makers the maximum benefits.

1.2. Objectives

In this research, we investigate typical landowner (i.e. farmer) attitudes and preferences to conservation practices and propose a novel approach to investigate the effect of these attitudes on spatial optimization of best management practices (BMPs) in watersheds. The attitudes towards conservation practices are defined based on land-tenure, and a cost benefit analysis of an individual BMP-type in the watershed. We will also evaluate the effect of spatial distribution of the land-tenure on spatial optimization of conservation practices. The following sections describe the methodology containing the case study, the hydrologic and water quality model, the optimization formulation and the different experiments that were run. We then present and discuss results for these experiments, followed by a section on concluding remarks.

2. METHODOLOGY

2.1. Eagle Creek Watershed case study

Eagle Creek Watershed (ECW) is a HUC-11 watershed (05120201120) located in central Indiana, about 16 Km North West of Indianapolis city. It is part of the Upper White River Watershed (red delineation in Figure 1). Its drainage area is approximately 419.26 Km^2. It drains into Eagle Creek Reservoir (ECR), one of the major recreational and water drinking supply for Indianapolis. This reservoir has been impaired mainly by sediments, pesticides, herbicides and fertilizer from the agricultural land in the upstream areas (Tedesco et al. (2005)). Pollutants are transported by ditches and streams drained directly from agricultural areas.

The eight tributaries that join Eagle Creek above the reservoir include Dixon Branch, Finley Creek, Kreager Ditch, Mounts Run, Jackson Run, Woodruff Branch, Little Eagle Branch, and Long Branch. There are also 2 tributaries that contribute to the reservoir: School Branch and Fishback Creek. The watershed topography is relatively flat to undulating, with some dissection near Eagle Creek reservoir (Figure 2).

The watershed is located among 4 different counties (Figure 3) Marion, Hamilton, Hendricks and Boone and can be divided in 130 subbasins (or SBs) that varies in size from $41.01m^2$ to $767.92m^2$. Agriculture is the dominant land-use in the north area of the watershed (approximately 60%), with a predominant crop rotation of corn and soy-beans (Census of Agriculture (2007)). While in the downstream region there is an increasing high and low density urban development due to the increasing in the Indianapolis population (Figure 4).

The 4 counties are consistent in the decrease of total land assigned to farms, with the ranges of loss varying from 27% in Marion County to 1% in Boone. Among these factors is common to observe that race, age, principal operator’s sex and top crop are similar in each county. The agriculture community population consists of mainly Caucasian males in their mid-fifties. The community mostly produces corn and soybeans row crops (Purdue extension suggestion). Because of shortage data within the boundaries of the watershed, we are assuming that this feature, applied to the county’s portion, is contained within the watershed.

The dominant soils association in the area consists of the Crosby-Treaty-Miami association in the headwaters. These soils are generally deep, poorly drained, and nearly level to gently sloping soils formed in a thin silty layer overlying glacial till. Whereas downstream areas are dominated by and Miami-Crosby-Treaty association, generally deep well drained to somewhat poorly drained, and nearly level to moderately steep soils formed in a thin silty layer and the underlying glacial till.

The Eagle Creek valley has a minor soils association that consists of Sawmill-Lawson-Genesee. In the northwestern boundary are found 2 minor associations: Fincastle-Brookston-Miamian association and Mahalasville-Starks-Camden association. The minor soils also vary in their drainage characteristics based on the composition. Soils are described in Figure 5.

The climate in this area is predominantly temperate continental and humid, with an average annual temperature of approximately 11˚ C. The average annual precipitation varies from 97 to 102 cm, with late spring being the wettest seasonal period and February being the driest. Most of this average annual precipitation occurs during the 5-6 months frost-free growing season.

In previous works (Babbar-Sebens et al. (2010)), 2953 sites were identified in Eagle Creek where wetlands could be restored for runoff and water quality benefits. Existence of such large number of alternatives can lead to challenges in identification of most optimal design of alternatives when search space could be as large as 2^{2953} (in the case when one practice is either installed or not installed at a site).

2.2. Hydrologic and Water Quality model

The hydrology and water quality were simulated using the Soil and Water Assessment Tool 2005 (SWAT 2005) model; developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (Arnold et al. (1998), Neitsch et al. (2005)). This is a physically based, time continuous model that can be operated from ArcGIS interface. SWAT model was developed to simulate and predict management practices impact in a watershed level. The spatial factors such as topography, land use, soil type, and climate are necessary inputs for the development of the model.

The Eagle Creek Watershed SWAT model was built on a daily time step for a period of five years (i.e. 2004-2008). A pre-defined watershed with sub-basins and stream network prepared by the United State Environmental Protection Agency (USEPA, 2009) was used.

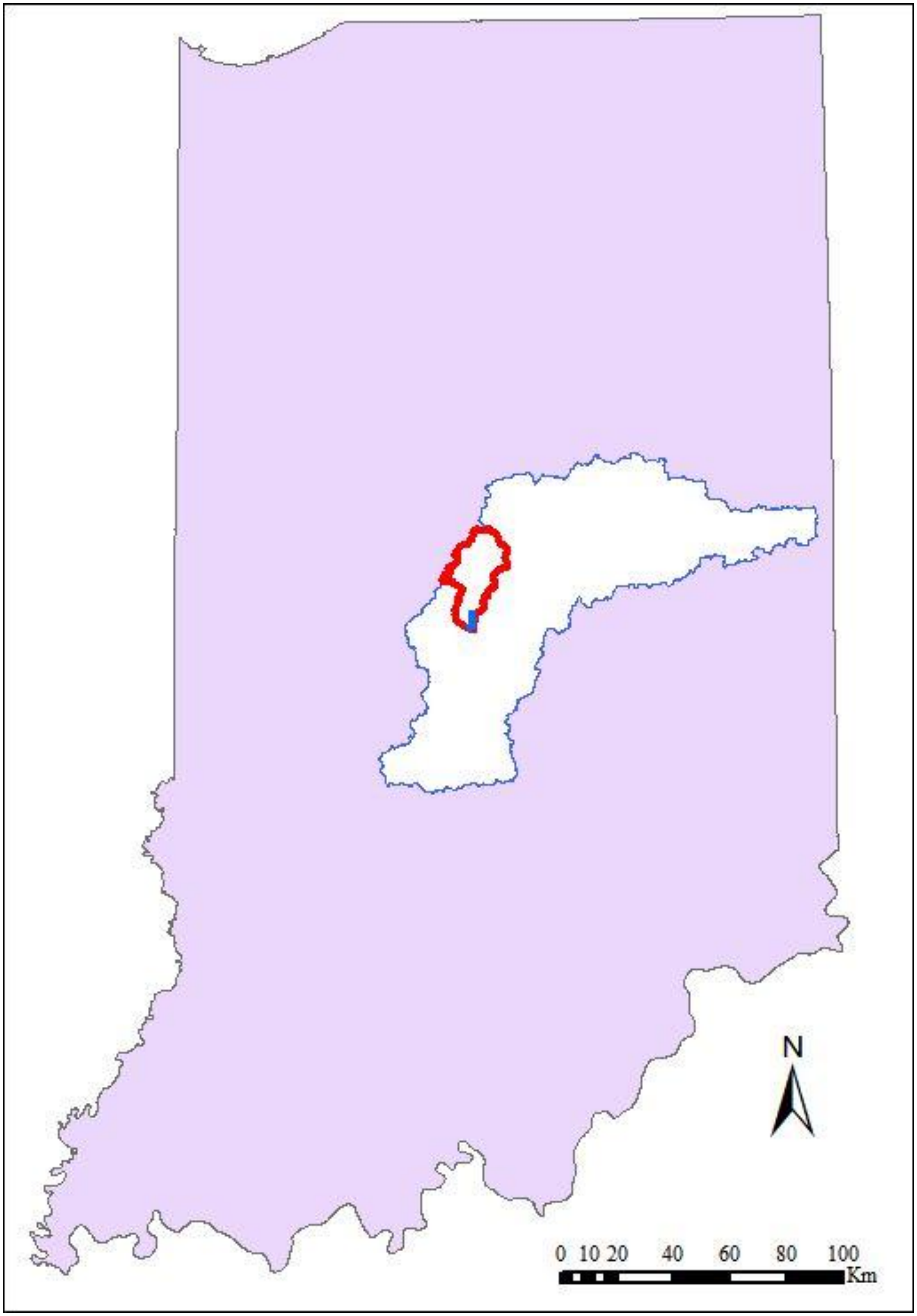


Figure 1. Location of Eagle Creek Watershed in the Upper White River Watershed

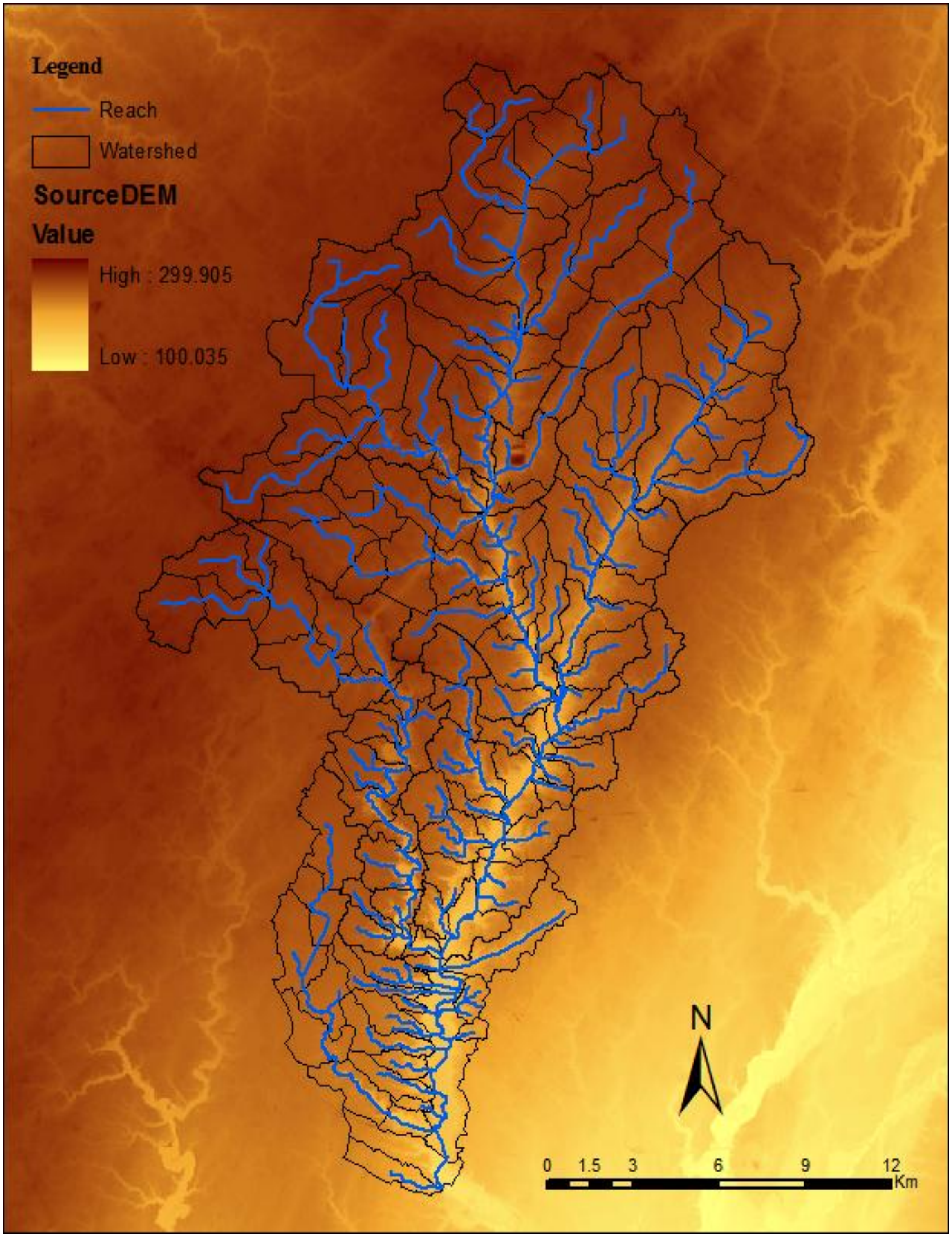


Figure 2. DEM layer for the Eagle Creek Watershed from United States Geological Survey (USGS)

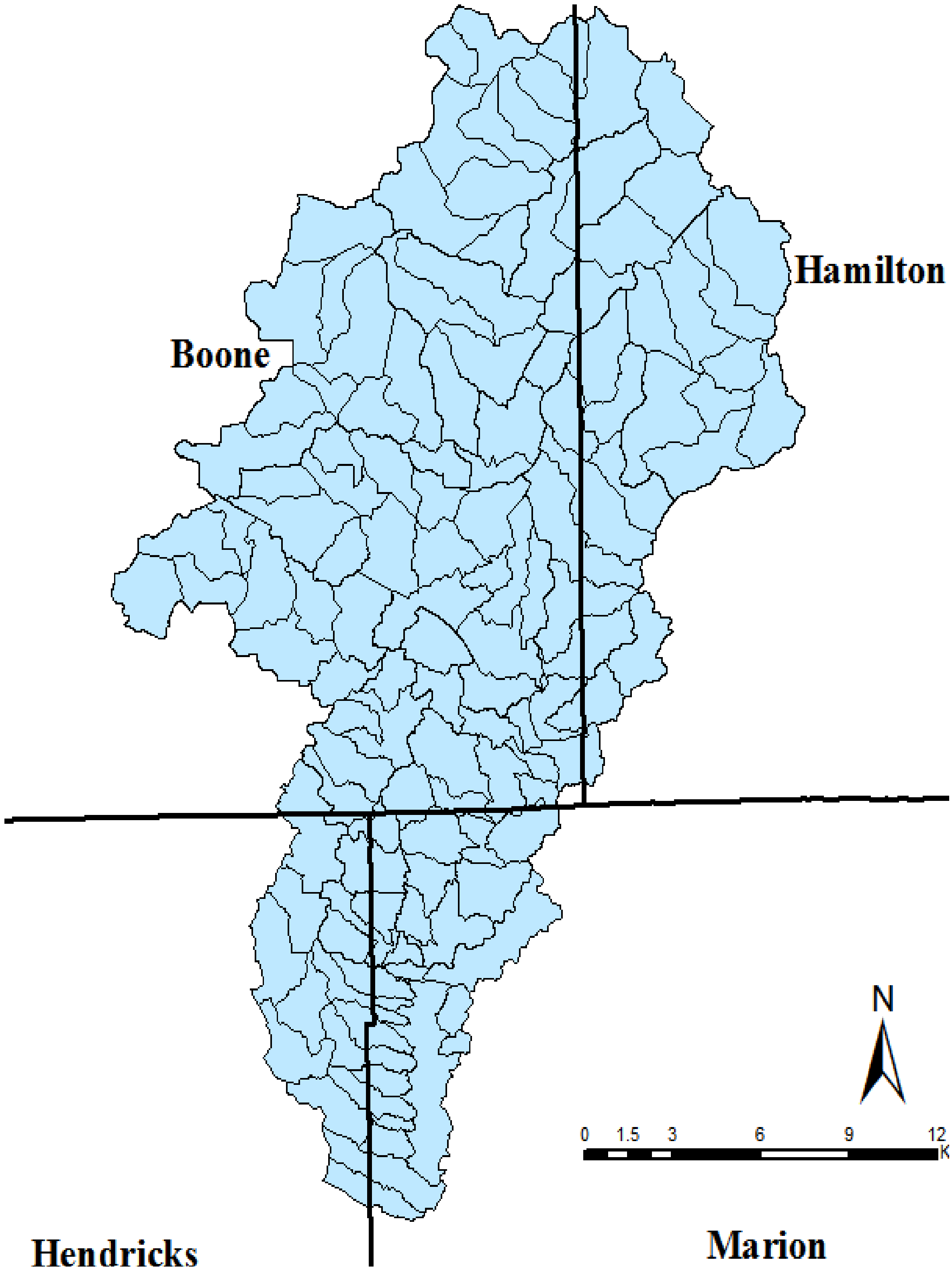


Figure 3. Subbasin divisions and county identification of Eagle Creek Watershed

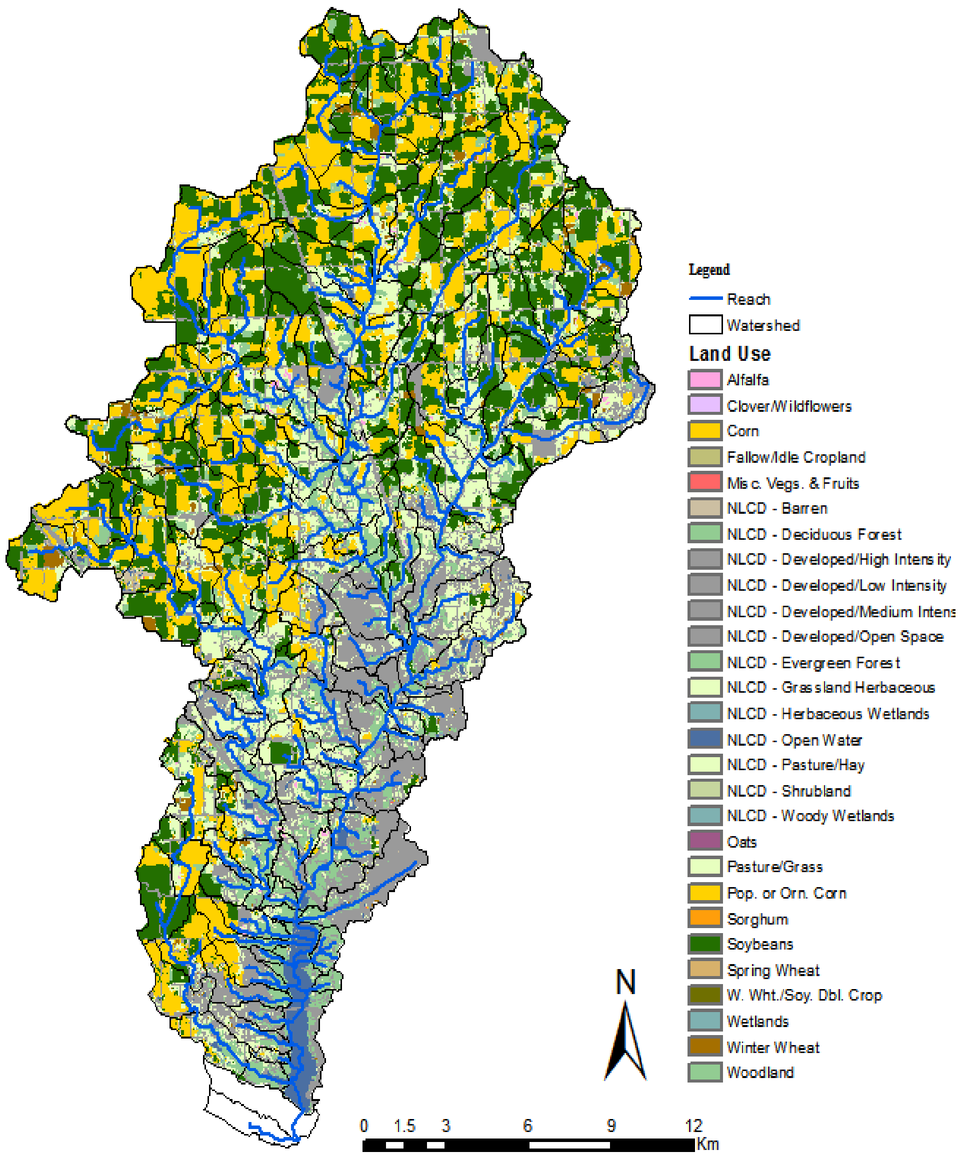


Figure 4. LULC layer for the Eagle Creek Watershed from United States Department of Agriculture (USDA)

For each sub-basin, the program calculated their outlet based on the stream network, DEM (USGS 10 meter) and pre-define boundaries. Once outlets are fixed to the exit of each sub-basin, the point sources (National Pollutant Discharge Elimination System (NPDES) located in sub-basins: 16, 42, 54, 59, 61, 71, 72, 74, 81, 87, and 128) and the reservoir (located in sub-basin 128) were added (Figure 6).

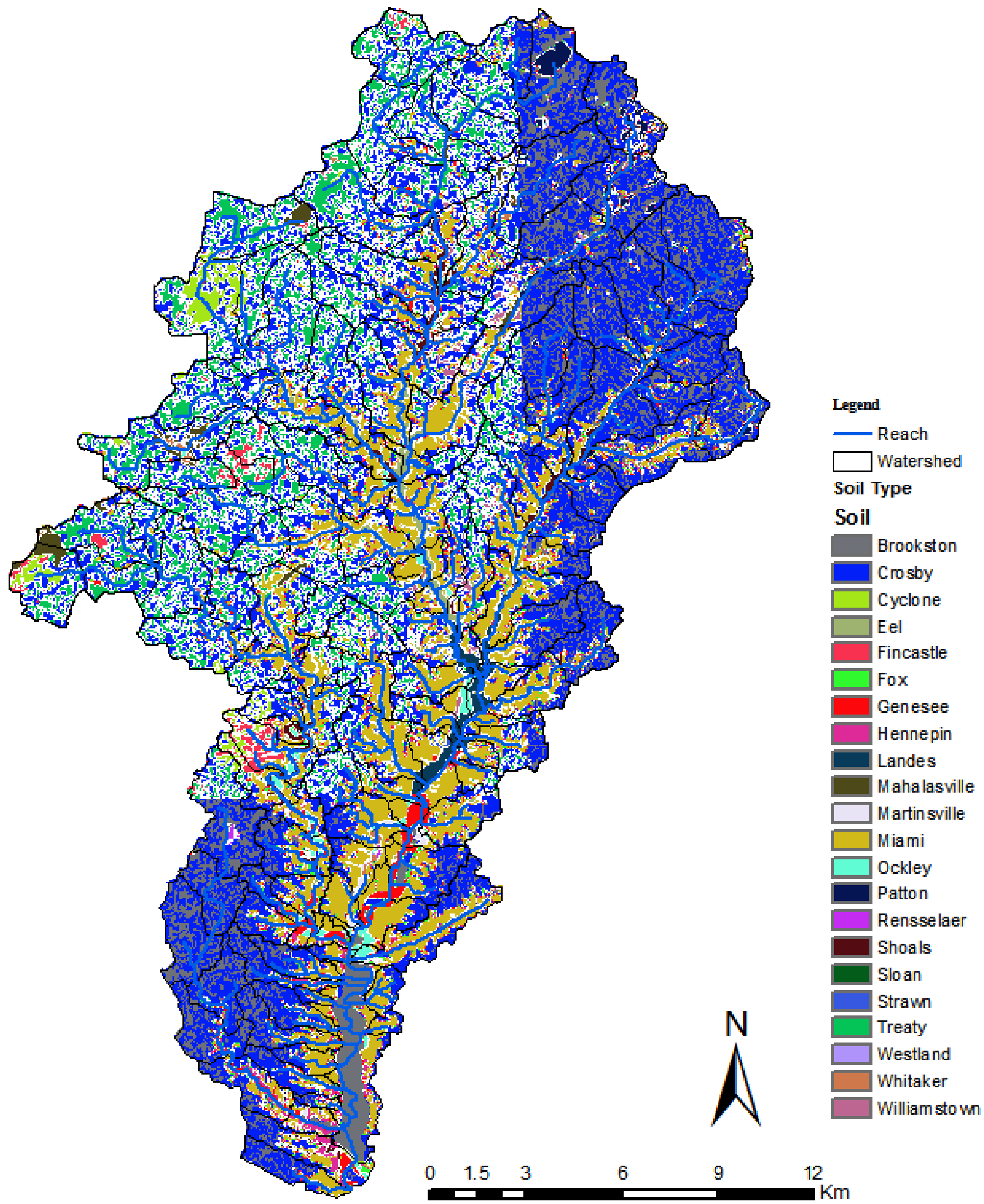


Figure 5. Distribution of various soils based on their drainage characteristics in the watershed, from Soil Survey Geographic Data Base (SSURGO)

The next step is to load the land use (USDA 2008) and soil type (USDA SSURGO) maps. These parameters used with the land slope will divide the sub-basins into hydrologic response units (HRUs). The HRUs are unique combinations of land use, soil type and slope used as a basic spatial unit for the mass balance in the watershed processes. In this case a the slope was classified into three classes (0-1%, 1-2%, and 2-999%). Finally a 10% threshold was applied for land use, soil class, and slope class in order to eliminate all land use, soil class and slope class combinations with less than 10% of area coverage.

Following this a climate input is necessary to represent the complete hydrologic cycle. The daily climate data for precipitation and temperature was obtained from the National Oceanic and Atmospheric Administration (NOAA) stations at Whitestown, IN (Station ID GHCND: USC00129557, latitude 39.996°, longitude -86.354°) and Indianapolis Eagle Creek, IN (Station ID GHCND: USC00124249, latitude 39.920°, longitude -86.313°).

Daily flow measurements at the USGS station at Clermont (# 03353460) were used to represent dam releases. This USGS station at Clermont was used because complete recordings of daily flow measurements at the USGS station # 03353451 just below the reservoir were not available. Based on the proximity of the two stations and similarity in their runoff area, the assumption of using Clermont station to represent dam releases was considered appropriate. Clermont station is only 1.13km downstream of USGS station # 03353451. In addition, Clermont station # 03353460 receives runoff from only 1.4% additional sub-basin land area compared to the USGS station # 03353451 below the reservoir.

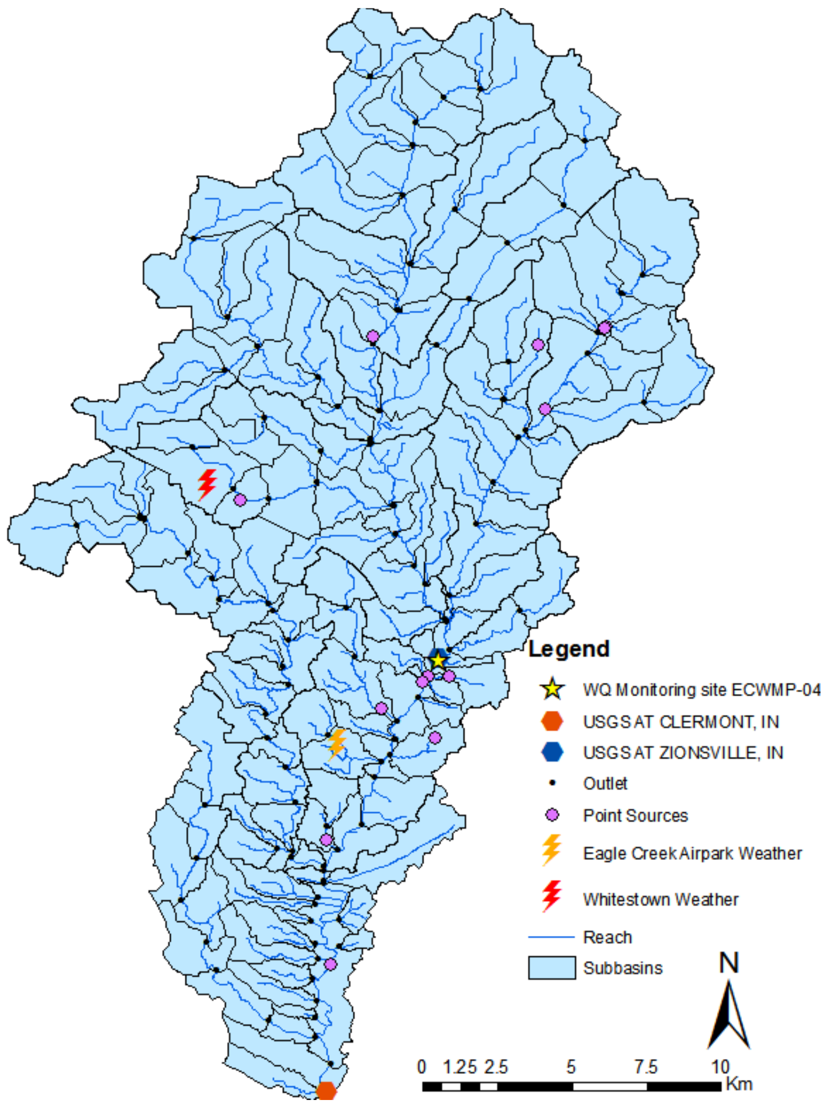


Figure 6. Distribution of outlets, point sources, weather stations, reservoir and water quality monitoring station in Eagle Creek Watershed

The input tables were written and modified using specific values for the Eagle Creek Watershed current management plan. For tile drain parameters Table 1 shoes the ones that were modified to match with those typical for Central Indiana. For estimating the runoff routing, the curve number method was chosen. While the Muskingum routing method was chosen for channel routing.

Table 1. Typical values in Central Indiana for tile parameters used in the SWAT model for Eagle Creek Watershed

Parameter	Files	Value
DEIMP (depth to impermeable layer)	.hru, .bsn	2500 mm
DDRAIN (depth to tile drains)	.mgt	1000 mm
TDRAIN (time to drain soil to field capacity)	.mgt	24 hrs
GDRAIN (drain tile lag time)	.mgt	96 hrs

Table 2 shows a typical operation schedule for 1 year used in corn and soybeans land use. This schedule was extended for 5 years in the same land use for all the HRUs.

Table 2. Operation schedule used for Corn and Soybeans land use

	Operation	Type	Amount Kg/Ha	Heat Units	Heat Units to Maturity
Corn	Pesticide application	Atrazine	1.12	0.1	
	Plant/begin growing season	Corn		0.15	1308.35
	Fertilizer application	Elemental Nitrogen	170	0.16	
	Tillage operation	GFPO*		1.2	
	Harvest and kill operation			1.2	
Soybeans	Pesticide application	Atrazine	1.12	0.1	
	Plant/begin growing season	SoyBean		0.15	1308.35
	Tillage operation	GFPO*		1.2	
	Harvest and kill operation			1.2	

*Generic Fall Plowing Operation

For the flow model calibration daily data from 2005-2008 of the USGS gage stations Zionsville gage station and Clermont gage station (Figure 6) was compared with the outflows of SBs 70 and 128 respectively for the same years (2004 year was let as a warming period for the model). To estimate the efficiency of the model a Nash-Sutcliffe efficiency (E_{NS}) (Nash and Sutcliffe (1970)) given by Equation (1) was used.

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} (O_i - M_i)^2}{\sum_{i=1}^{n} (O_i - O_{avg})^2} \qquad (1)$$

Where O_i is the observed data in day i, M_i is the model data in day I and O_{avg} is the average value of the observed data. Also a Pearson's product-moment correlation coefficient (R^2) (Legates and McCabe, (1999)) given by Equation (2) was used

$$R^2 = \left\{ \frac{\sum_{i=1}^{n} (M_i - M_{avg})(O_i - O_{avg})}{\left[\sum_{i=1}^{n} (M_i - M_{avg})^2 \right]^{0.5} \left[\sum_{i=1}^{n} (O_i - O_{avg})^2 \right]^{0.5}} \right\}^2 \qquad (2)$$

Where M_{avg} is the model data average. For both efficiency estimations equations, the close the value to 1 better is the performance of the model. Table 3 presents the parameters that were adjusted in order to improve the efficiency of the flow model.

Water quality observed data was registered by the Center of Environmental and Earth Sciences (CEES) of IUPUI (Station ID: ECWMP-04, latitude 39.946°, longitude -86.260°). Monthly data from March 2007 to December 2008 was available for sediments and nitrates. To calibrate we expand the observed data for sediments and nitrates using LOADEST (Runkel et al. (2004)) and compare with the data obtain from the SWAT model. Table 4 shows the variables that were modified for the sediments and nitrates.

2.3. Conservation Practices

Arabi et al. (2007) give a detail proceed to model different BMPs in a watershed using SWAT model. A set of 7 different practices commonly use and promoted by NRCS in the area were selected from this work.

Table 3. Flow calibration parameters, ranges of parameter values, and final calibrated values

Flow	Parameter	File	Parameter range	Calibrated value
	ALPHA_BF	.gw	0-1	0.048
	CH_K2	.rte	0-150	10
	CH_N2	.rte	0-1	0.01
	CN_FROZ	.bsn	0 or 1	1 (Active)
	CN2	.mgt	Specific to land use	AGRR, CORN, SOYB: 0.8075 * $CN2_{default}$ HAY: 1.045 * $CN2_{default}$ Other land-use: 0.95 * $CN2_{default}$
	ESCO	.hru, .bsn	0-1	0.95
	GW_DELAY	.gw	0-50	31
	GW_REVAP	.gw	0.02-0.2	0.02
	GWQMN	.gw	0-5000	0
	HRU_SLP	.hru	Specific to HRU	2* $HRU\_SLP_{default}$
	LAT_TTIME	.hru		4
	SLSUBBSN	.hru	10-150 (Specific to HRU)	2 * $SLSUBBSN_{default}$
	SMFMN	.bsn	0-10	1.4
	SMFMX	.bsn	0-10	6.9
	SOL_AWC	.sol	0-1 (Specific to HRU)	1.5* $SOL\_AWC_{default}$
	SURLAG	.bsn	0-10	6

Detail technical information regarding the practices can be found in the Field Office Technical Guide (FOTG). This is an electronic county level document nationwide developed by NRCS, as a database for basic scientific references that contain information of costs, laws, maps, flood profiles, management plans, typical installation and all those technical features need to promote an apply conservation practices.

Table 4. Water quality calibration parameters, ranges of parameter values, and final calibrated values

Sediments	Parameter	File	Parameter range	Calibrated value
	SPCON	.bsn	0.0001-0.1	0.001
	SPEXP	.bsn	0.0-2.0	0.65
	PRF	.bsn	0.0-2.0	0.01
	CH_COV	.rte	0.001-1.0	0.12
	CH_EROD	.rte	0.05-0.08	0.08
	ADJ_PKR	.bsn		0.01
Nitrates				
	NPERCO	.bsn	0.0-1.0	0.7
	SDNCO	.bsn		0.8
	CDN	.bsn	0.0-3.0	0.7
	RSDCO	.bsn	0.02-0.2	0.2
	IPND1	.pnd	0-12	1
	IPND2	.pnd	0-12	12
	RCN	.bsn	0.0-15.0	3
	RS4	.swq	0.001-0.1	0.001
	RS3	.swq	0-1	1
	N_UPDIS	.bsn		15
	SOL_NO3	.chm	0.0-100.0	100
	AI1	.wwq	0.07-0.09	0.071
	RHOQ	.wwq	0.05-0.5	0.5
	NSETLW1	.pnd	0.0-20.0	0.8
	NSETLW2	.pnd	0.0-20.0	0.8

1. Strip Cropping: This practice will increase the surface roughness, reduce surface runoff and reduce the sheet and rill erosion (Arabi et al. (2007)). Modifications on the CN (curve number), USLE_P (Practice factor in the Universal Soil Loss Equation), and OV_N (Manning's roughness coefficient) are required to model this practice.
2. Crop Rotation: According to the NRCS this practice will improve soil quality, manage the balance of plants nutrients, conserve water, and manage plant pest among others. SWAT is able to simulate crop rotation through the operation schedule management. The most common crop rotation use in Indiana is a Corn-Soybeans based.

3. Cover Crops: According to NRCS this practice will help in the soil moisture management, minimization and reduction of soil compaction, and also prevent erosion and increase soil organic matter. This practice is generally apply in the time when land is not use for production purposes (winter/spring). SWAT model allows scheduling more than one crop per year. Then the cover crops are simulated as a second crop in one year on the operation schedule management.
4. Filter Strips: This practice reduce solids and associated contaminants in the runoff. It is generally apply on the edges of channel segments. The variable simulating this conservation practice is the FILTERW (Filter width). According Arabi et al. (2007) it can range from 0 to 5 m.
5. Grassed Waterways: Reduce gully erosion, reduce flow velocity and increase sediment settlement (Arabi et al. (2007)). Because the main performance is to reduce the gully erosion, the simulation for this practice is model in those SB with stream order one. The CH_COV (Channel cover factor) is the variable modified on those SB with stream order 1.
6. No-Till: This practice will increase the amount of organic matter and water in the soil and also decrease erosion. Among the tillage operation in the operation schedule of the SWAT model we replace the generic fall tillage with a no till operation.
7. Wetlands: Wetlands will contribute with the reduction of sediments, reduction of peak flow, reduction of nutrients loads and also will provide some habitat for wild animals. Wetlands effects can be appreciated at the outlet of each SB. Then wet fraction (WET_FR) and area (WET_NSA) were modified for each SB according each SB wetland capability (Babbar-Sebens et al. (2010)).

Table 5 shows the necessary changes for each of the variables in a particular conservation practice.

2.4. Optimization Formulation

Although there are significant community's benefits for the implementation of conservation practices (Ribaudo et al. (1994), Aust et al. (1996), Yadav and Wall (1998), Coiner et al. (2001), Bryan and Kandulu (2009)), these systems have to be accepted and adopted by private stakeholders. Therefore it is most relevant to conduct not just public benefits, but also private incentives that would encourage the participation in conservation programs. Several are the factors to be considered by a decision maker when, not just the immediate economic revenue, but also the sustainable management of their land are being considered. According to Ahnström et al. (2009), some of the decisions on the farm stewardship are rooted in long term concerns about health of farms and soil. Soule et al. (2000) and Lambert et al. (2006) report that participation on conservation practices will depend in farm size, commodity mix and land tenure motivation. Valentin et al. (2004) test an empirical relation between adoption of conservation practices and farm profitability, developing the idea of a tight relation between economic costs in productions and decision of adoption.

In order to cover the different objectives report by these economic studies, 4 different objective functions were developed and used as constrains on a multi-objective optimization process that consider: cost-benefit analysis, peak flow reduction, sediments reductions and nitrates reduction. These functions represent stakeholder interests that play a key role in farm operations.

Table 5. Changes made on the SWAT model to simulate conservation practices

Practice	Modify	File	Range	Installation
Strip Cropping	CN USLE_P OV_N	.mgt .mgt .hru	-3 units 0.3 0.14	HRU level, where the LULC belongs to Corn or Soybeans
Conservation crop rotation	Operation Schedule	.mgt	Example of Corn-Soybean for2 years. This operation is change at a HRU level for Corn and Soybeans Year HU* Operation Kg/ha 1 0.1 Pesticide application 1.12 1 0.15 Plant Corn 1 0.16 Fertilizer application 170.00 1 1.2 Harvest and Killing 1 1.2 Generic Fall Tillage 2 0.1 Pesticide application 1.2 2 0.15 Plant Corn 2 1.2 Harvest and Killing 2 1.2 Generic Fall Tillage	
Cover Crops	Operation Schedule	.mgt	Example of Corn-Soybean for2 years. This operation is change at a HRU level for Corn and Soybeans Year HU* Operation Kg/ha 1 0.1 Pesticide application 1.12 1 0.15 Plant Corn 1 0.16 Fertilizer application 170.00 1 1.2 Harvest and Killing 1 1.2 Generic Fall Tillage 1 0.15 Plant Winter Wheat 1 0.6 Harvest and Killing	
Filter Strips	FILTERW	.mgt	0-5 meters	A typical installation requires a 19 ha field and a 37 m length
Grassed Waterways	CH_COV	.rte	0.001	Streams order 1
No Till	Operation Schedule	.mgt	Example of Corn-Soybean for2 years. This operation is change at a HRU level for Corn and Soybeans Year HU* Operation Kg/ha 1 0.1 Pesticide application 1.12 1 0.15 Plant Corn 1 0.16 Fertilizer application 170.00 1 1.2 Harvest and Killing 1 1.2 No Till	
Wetlands	WET_FR WET_NSA	.pnd	0-max wet fraction 0-max wetland area	All SB. Effects simulated at the outlet

*HU represents the Heat Units

2.4.1. Cost-revenue function

This objective function was develop considering the effect of the BMP in a period of 5 years (model time period), and represents a net of present values of cost-benefits relation that the conservation practice will offer to the stakeholder.

The landowner occurs to be the main actor in the adoption of BMPs. The cost-benefits function was developed to evaluate the cost on what the landowners have to incur and the economic benefits they will obtain with the adoption. Upon differences in land tenureship, cost-benefits function will have different variables. Typically we can find 3 types of land tenure on farm operations: landowners who farm their own land, cash-renters who pay a fix amount for renting the land and share-renters who have a share agreement with the landowner on the farm stewardship.

Table 6 shows a scheme of the factors considered on the cost-benefits function if the farm land management change land tenure types. CI is the cost of implementation for each conservation practice, OM is the operation and maintenance cost, Rin is the rent receive by the conservation program for those lands that are taken out of production, SP is the savings in productions (how much will be safe if there is not planting require in the area), PI represents the profits for increasing productivity, Rent is the amount of rent for the land in case it is cash-rented, and Fraction is the representation of the sharing costs in case the land is share-rented.

A cash flow was developed for each case on the 5 years period. One important consideration was to keep fix the land tenure during the whole time modeled. The landowners function is present by Equation (3).

$$NVP_i = \sum_{j=1}^{BMP} CI_j + \sum_{n=1}^{years} \sum_{j=1}^{BMP} \langle \left[\left(OM_j - Rin_j \right) * A_{i,j} \right] - PI_n - SP_n \rangle * PWF_n \qquad (3)$$

where i is the SB where the BMP is installed, *BMP* is the total number of BMPs, *A* is the area of the BMP per SB and *PWF* is the single payment present worth per year given by:

$$PWF_n = \frac{1}{(1+int)^n} \qquad (4)$$

where *int* is the estimate interest rate

Table 6. Variables considered in the cost-benefit function development by land tenure

Land tenure	CI	OM	Rin	SP	PI	Rent	Fraction
Landowner	X	X	X	X	X		
Cash-renter	X	X	X			X	
Share-renter	X	X	X*	X	X		50-50

*For Share-renters case Rent from the incentive programs is not considered as a share factor.

PI and *SP* are calculated based on the yield production and BMP adopted (see appendix A.4). For this two values, the first year is consider as a warming period, due to the under development of the system; then $PI_1 = SP_1 = 0$.

Equation (5) shows the final cost-benefits function when a landowner cash-rent the land.

$$NVP_i = \sum_{j=1}^{BMP} CI_j + \sum_{n=1}^{years} \sum_{j=1}^{BMP} \langle \left[\left(OM_j - Rin_j \right) * A_{i,j} \right] - RR_n \rangle * PWF_n \qquad (5)$$

where RR_n is the rent of the land, also calculated based on the yield production of the particular year (see appendix A.4). Again, the first year is considered as a warming period for the model and then all the variables dependents on yield are deliberated omitted, then $RR_1 = 0$.

Equation (6) shows the equation for the landowner who share-rent the land.

$$NVP_i = \sum_{j=1}^{BMP} CI_j * f + \sum_{n=1}^{years} \sum_{j=1}^{BMP} \langle \left[\left(OM_j * f - Rin_j \right) * A_{i,j} \right] - (PI_n - SP_n) * f \rangle * PWF_n \qquad (6)$$

where *f* represents the share fraction between the landowner and the share renter. In this case the fraction was selected as 0.5 for each part.

2.4.2. Peak flow reduction function

The peak flow reduction was calculated based on the maximum difference between the flow of the calibrated model and peak flow of the new alternative (system of conservation practices). Equation (7) presents the form of this objective function.

$$PFR = min\left(-\max_{i,n}\left(peakflow_{i,n,baseline} - peakflow_{i,n,alternative}\right)\right) \qquad (7)$$

where *PFR* is the peak flow reduction *i* is the day, *n* is the modeled year, $peakflow_{i,n,baseline}$ is the baseline flow and $peakflow_{i,n,alternative}$ is the conservation practice modeled flow. The peakflow in the equation is defined as:

$$peakflow_t = flow_t \text{ ,}$$

$$if\ flow_t > flow_{t-i}\ and\ flow_t > flow_{t+1}$$

else, $peakflow_t = 0$. Where t is a specific day.

2.4.3. Sediments reductions function

Sediments reduction (*SR*) calculation is showed in Equation (8). This function was planned to show the entire watershed reduction in sediments during the modeled period.

$$SR = \ min\left(-\sum_{i=1}^{\#\ of\ SB}\left(\sum_{t=367}^{1828}\left(Sedout_{i,t,baseline} - Sedout_{i,t,alternative}\right)\right)\right) \quad (8)$$

where *i* is the SB number, *t* is the day counting from the second to the fifth year (as mention previously the first year was used as warming up period), $Sedout_{i,t,baseline}$ is the sediment out taken from the baseline.rch file and is the calibrated model without calibration practices, and $Sedout_{i,t,alternative}$ is the sediment out taken from the output.rch file with a conservation practice implemented.

2.4.4. Nitrates reductions function

Nitrates reduction (*NR*) calculation is showed in Equation (9). This function was planned to show the entire watershed reduction in nitrates during the modeled period.

$$NR = min\left(-\sum_{i=1}^{\#\ of\ SB}\left(\sum_{t=367}^{1828}\left(Nitsout_{i,t,baseline} - Nitsout_{i,t,alternative}\right)\right)\right) \quad (9)$$

where *i* is the SB number, *t* is the day counting from the second to the fifth year (as mention previously the first year was used as warming up period), $Nitsout_{i,t,baseline}$ is the sediment out taken from the baseline.rch file and is the calibrated model without calibration practices, and $Nitsout_{i,t,alternative}$ is the sediment out taken from the output.rch file with a conservation practice implemented.

2.4.5. Analysis of attitudes

Information found in the literature regarding attitudes (Lynne et al. (1988), Weaver (1996), Luzar and Cosse (1998), Luzar and Diagne (1999), Soule et al. (2000), Söderqvist (2003), Lambert et al. (2006), Ahnström et al. (2009)) was the base to build a set of weights that rank the importance of a certain objective over others. The literature suggested there are also other concerns that cannot be diminished. An apprehension about healthy state of soils to maintaining high yields are related with economic benefits, but also shows the importance of environmental issues such as erosion. Then, even when there is an agreement regarding economic factors being one of the main drivers on a decision making process (Lynne et al. (1988), Soule et al. (2000), Söderqvist (2003), Lambert et al. (2006)), the presence of mixed interests can lead not just to the solution under constraints budget, but at the same time solve problems related with the environment.

As a research example the identification of 4 main objectives were classify based on the preferences of stakeholders. Table 7 shows this objective functions and the weight values used to distinguish among attitudes. The 4 main objectives are associated with 4 related attitudes regarding farming issues. Notice that for this experimental classification the decision was rank extreme attitudes with a fix range of weighting, then for a high preference (weight_high) we assume a rank that goes between 0.7 and 0.9; a medium preference will be the half value of the result from the difference of a unique preference (identified with number 1) and the high preference ((1-weight_high)*0.5); a low preferences will be a quarter value of the result from the difference of a unique preference and the high preference ((1-weight_high)*0.25). In this way the consideration of less important objective will also play a role in the decision making process.

In the case of economic profits oriented attitudes, stakeholders with interests in immediate revenues and business benefits are considered. Then the cost-revenue function will have a high weight, while peak flow reduction and sediments reduction will have a low consideration. For this particular case nitrates reduction was choose as a mid-level concern because it is associated with fertilizer loss, which is tightly related to a higher investment in fertilizer applications.

For flooding prevention, the idea is minimize the surface runoff to prevent any damage in the crops; then peak flow reduction will be consider as the most important objective, while cost-revenue preferences will occupy a second place, followed by the sediments reduction and nitrates reduction.

On the other hand, if the interest is to preserve the soils and enhance the productivity in the land, the Sediments reduction will play the main role, having the highest weight of interest, followed for a medium weight for the cost-revenue preferences, and leaving a low rank for peak flow and nitrates reduction.

In case that preference are oriented toward fertilizer loss reduction, then Nitrates reduction will play the most important role, followed by cost-revenue with a medium weight, and peak flow and Sediment reduction with low weights.

Notice that for the purpose of this research the selection of the weights was made in such a way that the sum of all the weights is equal to one in a specific set of ranges (unique preference identification).

It is known that modifications in these weights will result also in modifications of the solution space. The weights will determine systems preferences and location preferences among the different land tenureship. The analysis of extreme cases is required to have a starting point of evaluations for a possible variety of behaviors due to several selections of choices.

Table 7. Extreme weights for different attitudes preferences

Attitude	Objective Function	Weights
Economic Profit	Cost-Revenue	High (weight_high = 0.7-0.9)
	Peak Flow reduction	Low ([1-weight_high]*0.25)
	Sediments reduction	Low ([1-weight_high]*0.25)
	Nitrates reduction	Medium ([1-weight_high]*0.5)
Flooding prevention	Cost-Revenue	Medium ([1-weight_high]*0.5)
	Peak Flow reduction	High (weight_high = 0.7-0.9)
	Sediments reduction	Low ([1-weight_high]*0.25)
	Nitrates reduction	Low ([1-weight_high]*0.25)
Soil Conservation	Cost-Revenue	Medium ([1-weight_high]*0.5)
Productivity preservation	Peak Flow reduction	Low ([1-weight_high]*0.25)
	Sediments reduction	High (weight_high = 0.7-0.9)
	Nitrates reduction	Low ([1-weight_high]*0.25)
Fertilizer Loss	Cost-Revenue	Medium ([1-weight_high]*0.5)
	Peak Flow reduction	Low ([1-weight_high]*0.25)
	Sediments reduction	Low ([1-weight_high]*0.25)
	Nitrates reduction	High (weight_high = 0.7-0.9)

These weights help to develop a cost - benefits score system that based on the interest will allow joining all the objective functions and assigning a preference score over a specific practice. Equations (10) and (11) show the analysis of this cost-benefit score for the different objective functions

$$Score_{Econ,l} = \frac{NVP_l}{maxNVP} * \gamma_{costs} - \frac{PFR_l}{maxPRF} * \gamma_{Flood} - \frac{SR_l}{maxSR} * \gamma_{Seds} - \frac{NR_l}{maxNR} * \gamma_{fert} \quad (10)$$

$$Score_{K,l} = -\left(\frac{NVP_l}{maxNVP} * \gamma_{costs} - \frac{PFR_l}{maxPRF} * \gamma_{Flood} - \frac{SR_l}{maxSR} * \gamma_{Seds} - \frac{NR_l}{maxNR} * \gamma_{fert}\right) \quad (11)$$

where $Score_{Econ,l}$ is the economic score, NVP_l is given by Equation (12)

$$NVP_l = \sum_{i=1}^{all\ SB} NVP_{i,l} \quad (12)$$

maxNVP, *maxPRF*, *maxSR*, *maxNR* are the maximum values for each objective function among all the practices, γ_{costs}, γ_{Flood}, γ_{Seds} and γ_{fert} are the weights assign according attitudes, $Score_K$ is the score for the cost-benefits analysis on the set of physical objectives, where *K* represent the different objective function (peak flow, sediments, and nitrates) and *l* is the conservation practice.

3. RESULTS

3.1. Flow Calibration

A total E_{NS} = 0.68, R^2 = 0.83 for Zionsville (Figure 7) and E_{NS} = 0.90, R^2 = 0.95 (Figure 8) for Clermont were found in each final flow calibration.

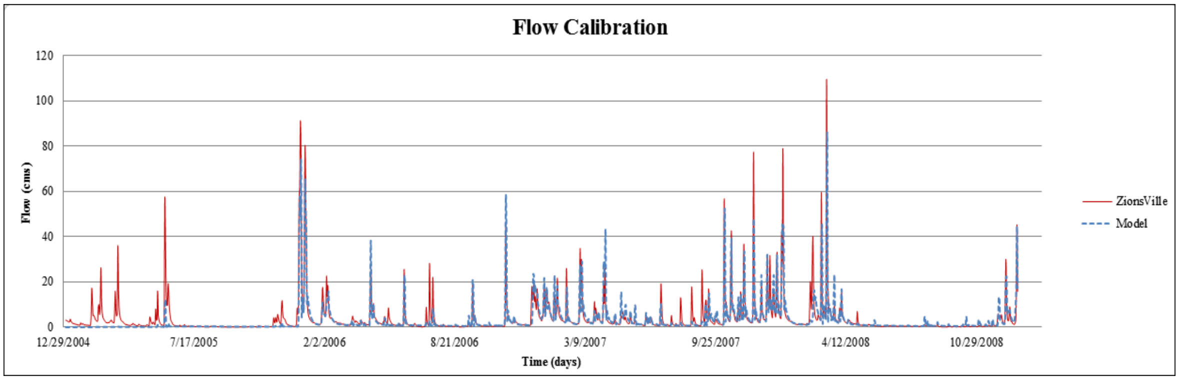


Figure 7. Flow calibration for the Zionsville Gage station in the 2005-2008 modeled period

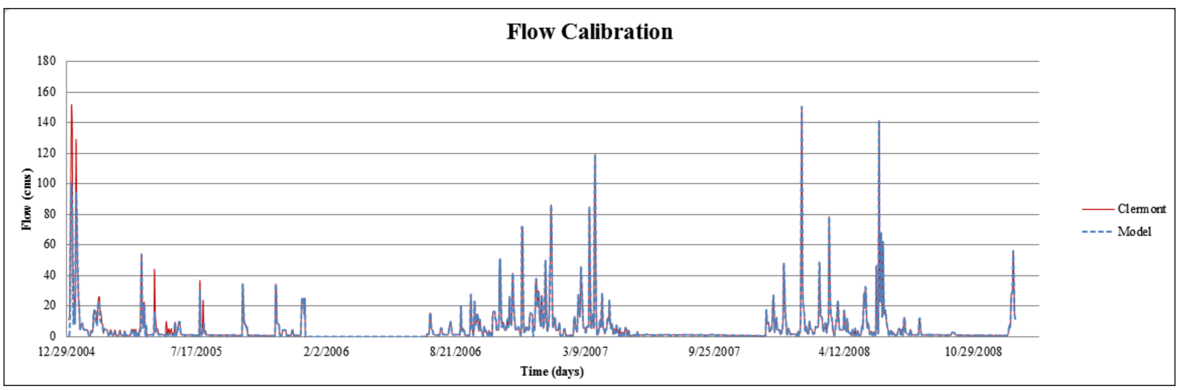


Figure 8. Flow calibration for the Clermont Gage station in the 2005-2008 modeled period

These values corresponded with other reports values for flows calibration (White et al. (2005), Gassman et al. (2007)) where the model efficiency for flow calibration range from 0.58 to 0.98 for E_{NS} and from 0.63 to 0.97 for R^2. Gassman et al. (2007), compile some reports for hydrologic calibration in SWAT, and for Indiana a monthly calibration give a range from 0.73 to 0.84 for E_{NS} and a range of 0.86 to 0.92 for R^2. For a daily calibration (also in Indiana) an E_{NS} range from -0.23 to 0.28 was reported. Limitations in observed data, and different considerations involved in each watershed can lead to these discrepancies in reports. Nevertheless the values obtain are consider as a valid range for accuracy of the model.

3.2. Water Quality Calibration

As it was mention in the methodology section, the limited data for sediments and nitrates was expanded using the LOADEST (Runkel et al. (2004)). The results for sediments are showed in Figure 9. With a E_{NS} = 0.70 and a R^2 = 0.90, the calibration for sediments is considered to be acceptable (White et al. (2005)).

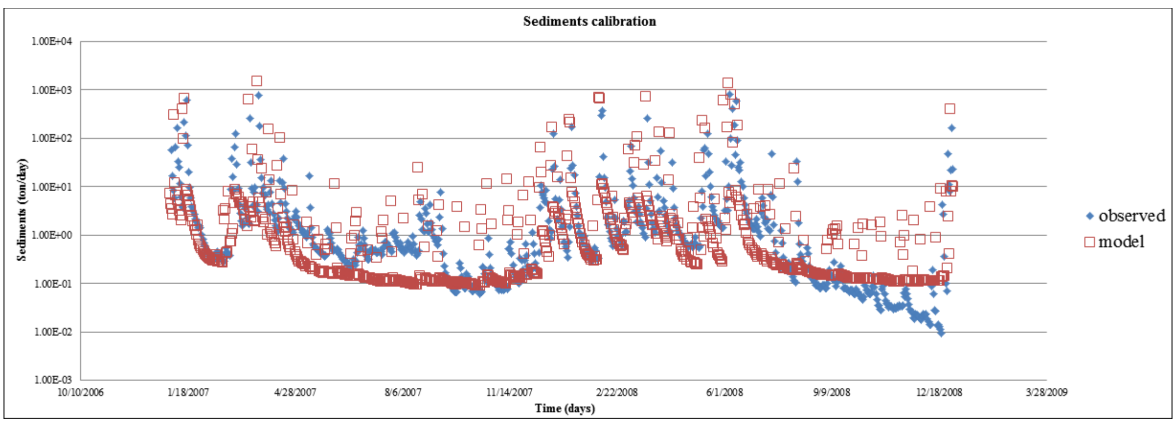


Figure 9. Water Quality Calibration for the ECWMP-04 station in the 2007-2008 modeled period for sediments

On the other hand, the results for nitrates are shown in Figure 10. For this case, E_{NS} = 0.34 and R^2 = 0.71. Although these values do not represent a high accuracy, we can observe in Figure 10 that this is due to a poor correspondence of the model with the peak of the observed data. But the baseflow follows a pretty accurate tendency with the observed data.

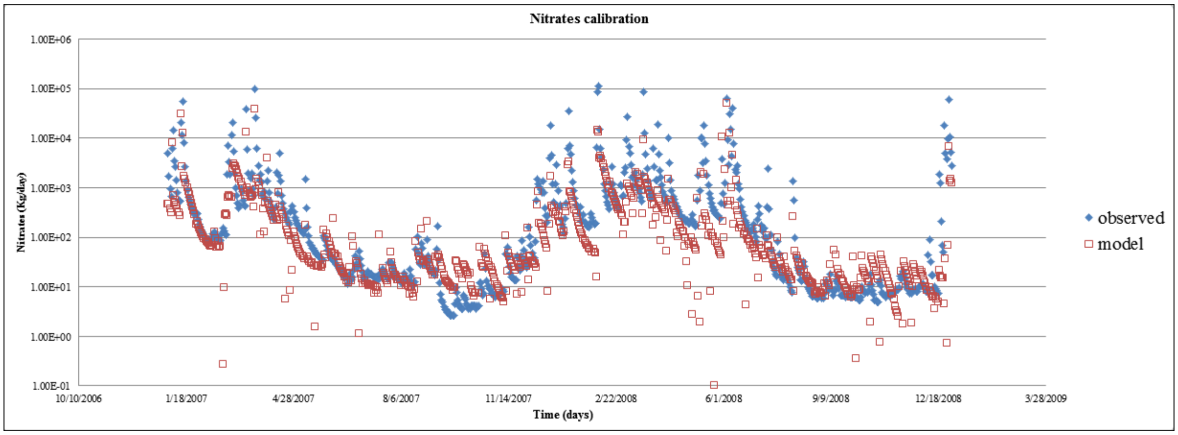


Figure 10. Water Quality Calibration for the ECWMP-04 station in the 2007-2008 modeled period for nitrates

3.3. Experiments

Three different experiments were performed to evaluate the changes on optimize solutions due to attitudes influences.

The first run involved a sensitivity analysis. In this experiment the intention was to present the behavior of each single practice over the entire watershed, and determine which one by itself has the best and worst contribution in each of the main objectives (cost-revenue, peak flow reduction, sediments reduction and nitrates reduction).

The second trial intent to find the optimize solution when the entire watershed has the same land tenure type. It is intended to show how attitudes will affect the optimal solutions when a specific threshold in the reduction of effectiveness of the system is selected. Comparisons of spatial distribution among a restricted budget is also presented

The third and last experiment is a trial of multiple random tenure type and multiple practice systems. Information regarding land tenure for a specific SB is not available. Then a random distribution with an approximate percentage of land tenure type

(Duffy et al. (2008)) was used to compare with the optimal solutions of just one tenure type over the entire watershed.

3.3.1. Sensitivity Analysis

First a comparison between each practice was performed. Scaling the practices in a range from 0 to 1 allowed comparing the 7 different practices under 6 different scenarios. The SWAT model was run assuming that in the entire watershed just one practice was install. Figure 11 shows the results for the cost-revenue function with the 3 different land tenureship, peak flow reduction, sediment reduction and nitrate reduction.

For the cost-revenue function, 2 distinguish trend are found. First landowner and share renters have almost an exact distribution, with perhaps some differences in the ranges for the wetlands practices. The minimum value for this two tenures is associated with filter strips, showing that in the entire watershed, this will be the most economic prefer practices, because is the one that have more revenues. The lowest performance is for the grassed waterways. This fact could be related to the choice of the simulation just in the SB with order one streams instead of the overall entire watershed.

On the other hand, cash renters have a completely different trend. This could be attributing to the rent calculation that is based on yield production. The model is under estimating the yield productions, if we compare with the real data, then it will be necessary perform a calibration also for the yield production. If any practice changes the yield, it will modify the total cost-revenue relation. Notice that in this case cover crops are the less favorable. Even when is not clearly appreciated in the graph, filter strips has a well performance among the overall practices for the cash-renters. This is the only value with a negative net for the cost-revenue function.

Notice also, that even when filter strips perform well for cost-revenue objective, it does not contribute with the peak flow reduction, and it is not the best choice for sediment reduction.

For peak flow reduction, sediment reduction and nitrates reduction there is a very interesting result. The three objectives show wetlands as the most effective practice, while cost-revenue relations rank it as one of the less favorable for landowners and share renters. The worst performance for peak flow is the one associated with filter strips. The results show there is no peak flow reduction. For sediments reduction and nitrates reduction the less favorable practices is the No-Till option.

It is important to remember here that the evaluation of the results is for a 4 years period (2005-2008) and some of these practices will need more time in order to reach the summit of their performance in nature.

Also a sensitivity analysis using the weights define in Table 7 for the attitudes preferences was performed. Figure 12 shows the effects over the practices when the economic profits are preferred. Notice how filter strips are still the prefer selection for a landowner and a share renter, but the cash renters change their tendencies having as more effective the wetlands. Also notice that for the three cases the less prefer practice will be the No-Till.

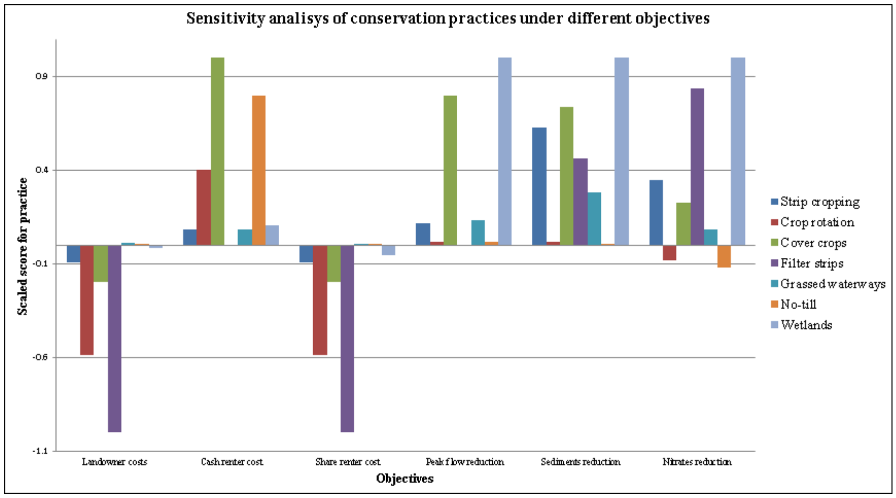


Figure 11. Sensitivity analysis of the different practices for under individual objectives

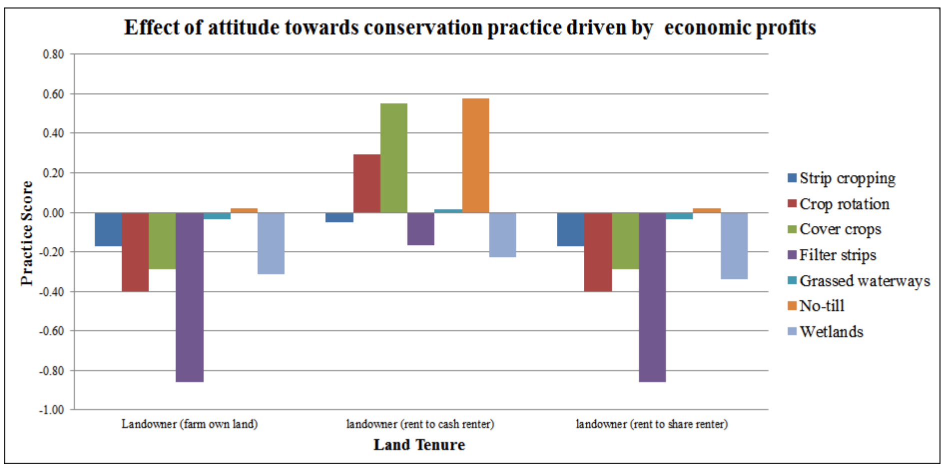


Figure 12. Sensitivity analysis of the practices under economics preferences

Figure 13 shows the results for the peak flow reduction when the prefer attitude is the flood control. In this case the wetland option is still dominating over other options. This effect is also present for Sediments reduction when the preference is erosion control (Figure 14) and Nitrates reduction when preference is fertilizer loss control (Figure 15). The behavior of the graph in these 3 cases is very similar. All of them list as a less prefer the No-Till conservation practice. Nevertheless some distinctions can be clear identify as the choice of a filter strips to control the fertilizer loss (linked with the nitrates reduction) over a cover crop to control upland flooding and erosion (linked with peak flow reduction and sediments reduction).

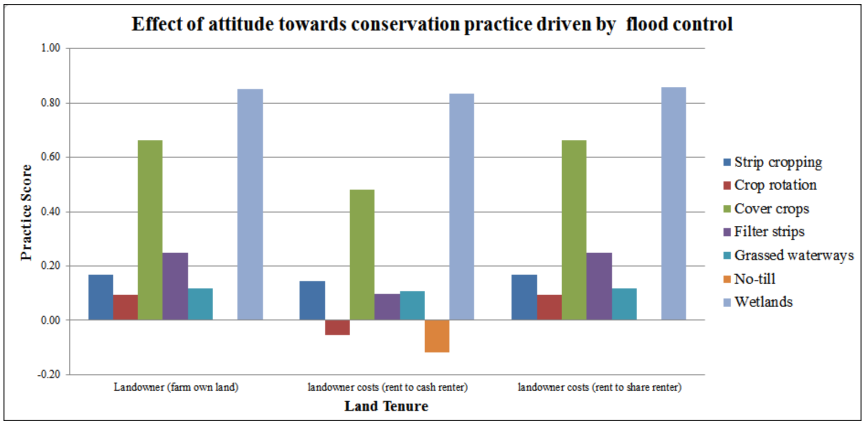


Figure 13. Sensitivity analysis of the practices under flood control preferences

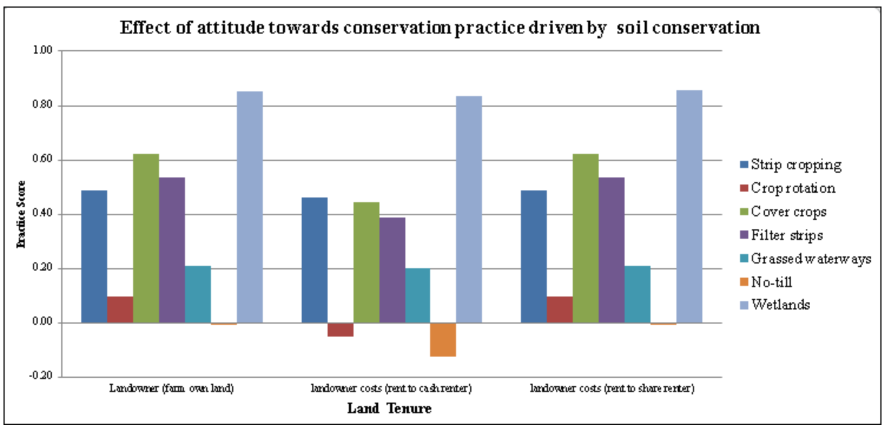


Figure 14. Sensitivity analysis of the practices under sediments control preferences

3.3.2. Attitudes, effects over multiple practices

This experiment shows the differences among the same land tenure type and the attitudes of stakeholders. Using the weights in Table 7, a random selection of 100 realizations was performed to identify the changes on practices preferences when they are subject to changes. As the changes with establish ranges were not significant, an average of the 100 scores was selected to determine the total effectiveness score. Effectiveness score ($EScore_m$) is given by Equation (13):

$$EScore_m = \sum_{l=1}^{num\ Practices}(Score_{Econ,l} + Score_{K,l}) \qquad (13)$$

where *m* represents each land tenure type.

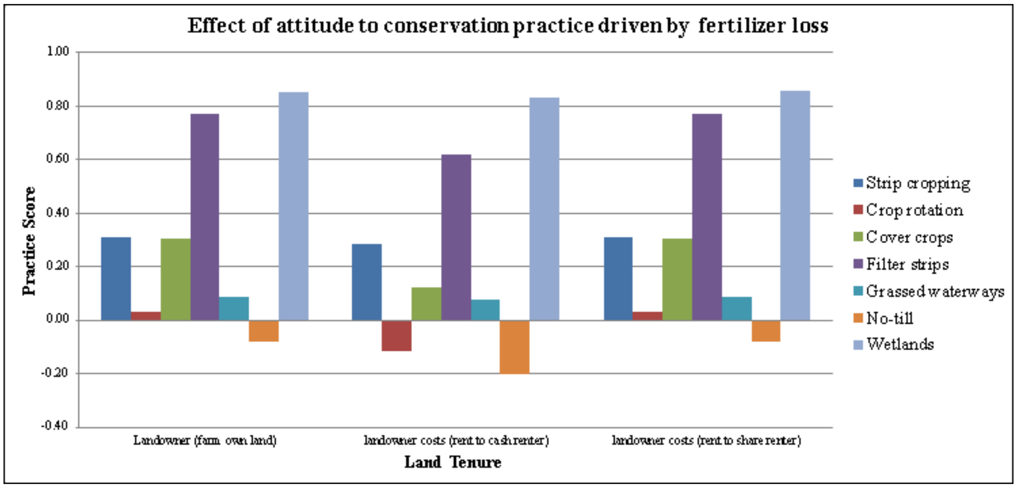


Figure 15. Sensitivity analysis of the practices under nitrates control preferences

As an implementation of all the desire practices in the watershed is fairly difficult, two different thresholds where selected to observe the differences among a set of practice selection influence by a determine attitude. The first threshold will reduce the $EScore_m$ up to 15% (total effectiveness will be greater or equal to 85%). While the second threshold will reduce it up to 55% (total effectiveness will be greater or equal to 45%). The selection of practices for the 4 objective functions is showed in Figure 16 to Figure 19. The practice percentage is calculated based on the contribution to the effectiveness score.

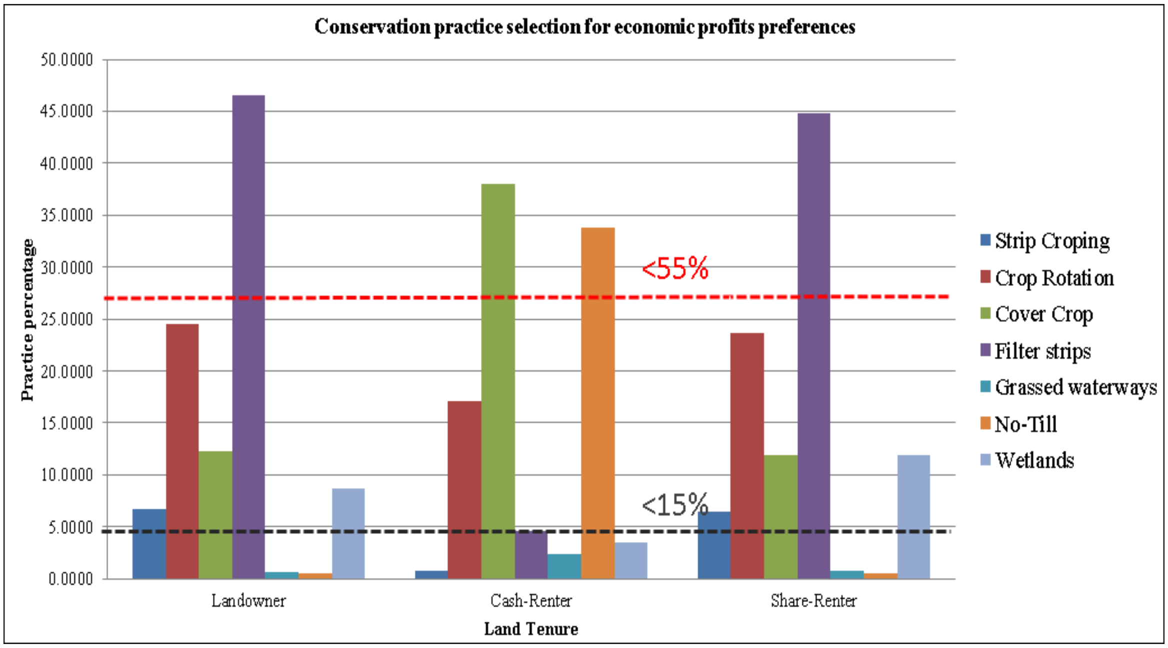


Figure 16. Practices selection for an Economic profits preferences

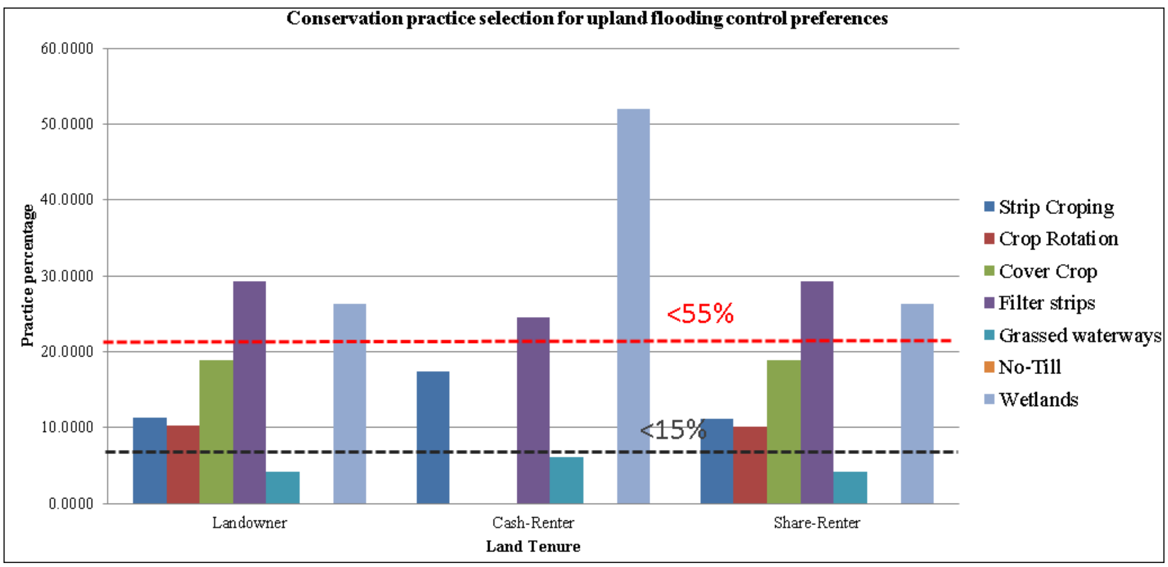


Figure 17. Practices selection for upland flooding control preferences

For all the practices that are environmental oriented (flood control, sediments control, nitrates control) a wetland practice prevail no matter the threshold selected. On the other hand, Filter strip has a good performance not just in the economic function but also among the environmental ones. Although in the case of erosion control, cover crops seems to have a better performance.

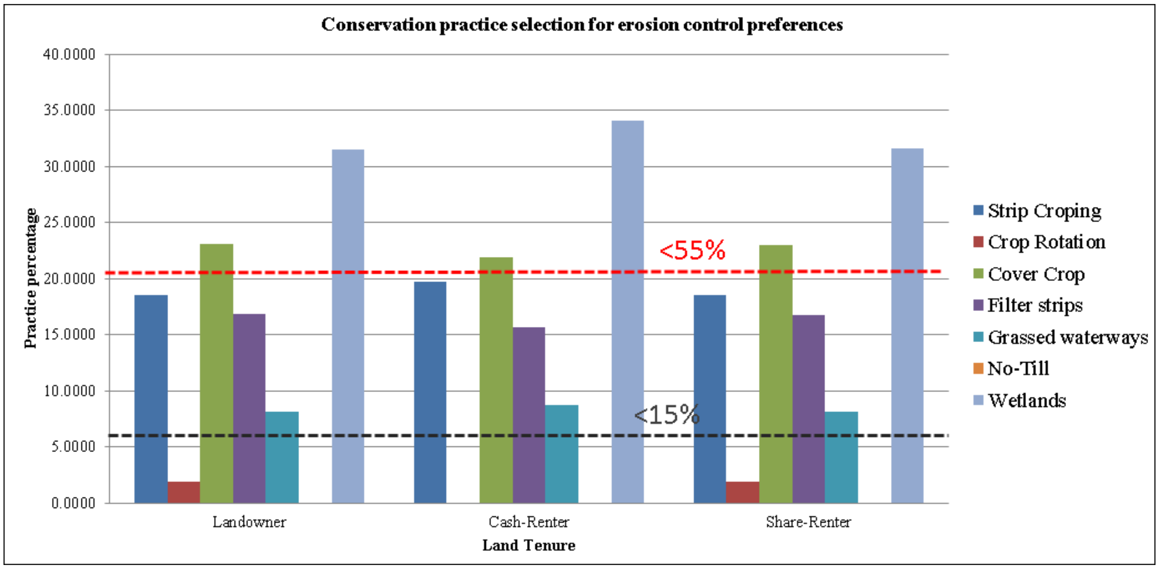


Figure 18. Practices selection for erosion control preferences

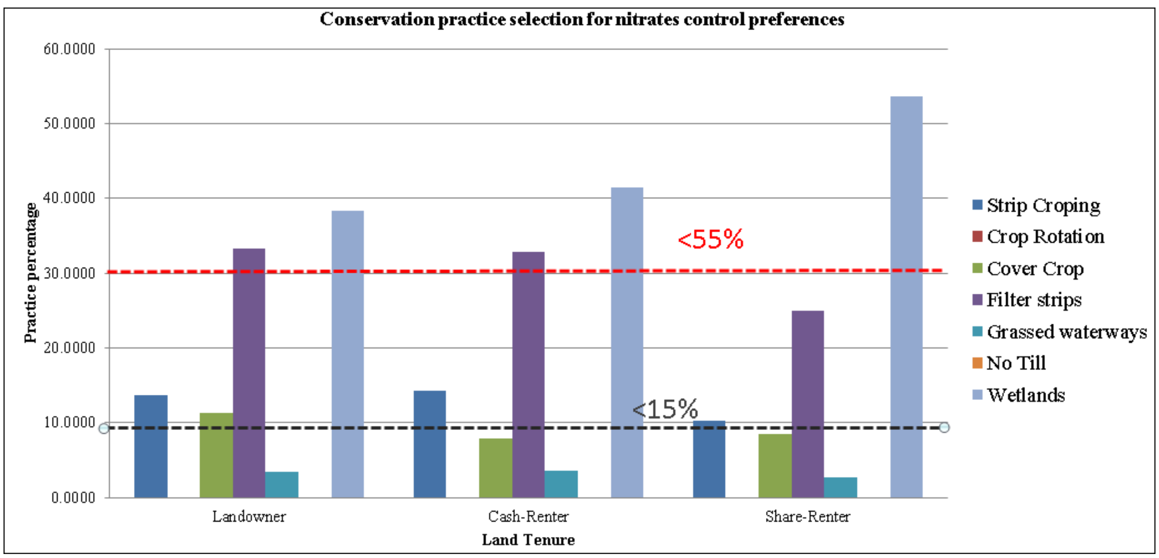


Figure 19. Practices selection for nitrates control preferences

These results will provide the bases for the comparison with optimal solutions. Optimal solutions per land tenure for the watershed system of practices were found using a NSGA-II algorithm. The code was run with a maximum population of 100 individuals in a limit of 75 generations. These optimal alternatives were found using all the practices per land tenure, i.e. we assume the stakeholder is managing the entire watershed and does not have any bias towards any particular solution.

An example of spatial distribution of practices in the watershed under different levels of effectiveness for a peak flow reduction preference by landowners is shown in Figure 20.

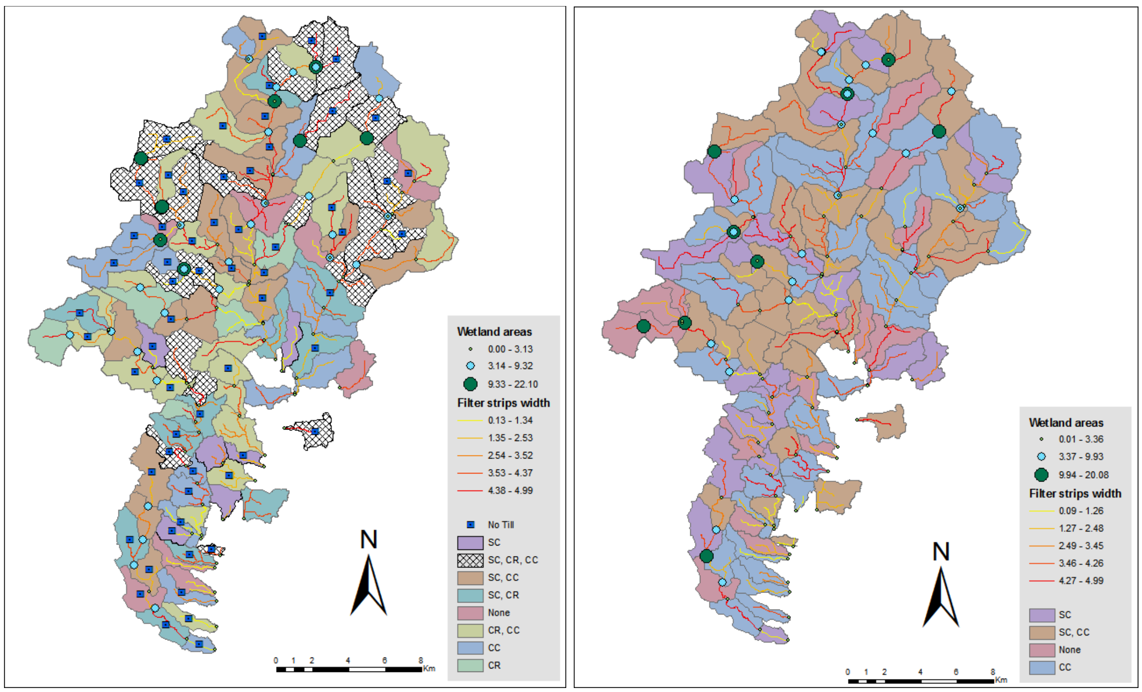


Figure 20. Spatial distribution for a landowner and a effectiveness of 100% (left) and with a preference of peak flow reduction and an effectiveness of 85% (right). In the legend: SC = Strip Cropping, CR = Crop Rotation and CC = Cover Crops

The decision of showing just the one with 85% is mainly due to visualization purposes. But this option was carefully selected after the similarities in peak flow reduction for the alternative with all the practices install and the one with 85% (see Figure 21, bottom left).

Then using the practices selected with the attitudes towards a specific objective function, the optimal alternatives were modified in order to exclude those practices that are not preferred. Two different examples are shown if Figure 21; the left side represent a landowners set of solutions, while the right side represents a cash-renter set of solutions.

Each plot shows a comparison between optimal, 15% and 55% effectiveness reduction on the systems. This example shows in the left hand side the landowner results, while in the right hand side are the cash renter results. For landowner the practices selected for the 85% effectiveness were strip cropping, cover crops, filter strips and wetlands. For the cash renter the same practices were selected. In the case of 45% effectiveness just cover crops and wetlands were selected for both cases. The landowners plots show a common tendency of increasing in costs-revenue relations while the effectiveness is reduce. It seems in this case that a system with all the practices will perform better and will provide more revenues to the stakeholder. Also reductions of peak flow, sediments and nitrates are proportionally related to effectiveness percentage, i.e. if the effectiveness decreases, the total reduction will also decrease. It can be also shown that there is not overlapping among solutions, in the case of the cost-revenue range, and it is evident the variability among the spreading of the solutions; a less effective set of practices will have a narrow range of cost-revenue options.

Looking carefully to the bottom left Pareto fronts (Economic costs vs. nitrates reduction) it is evident that with the 85% set of solution we can get a similar reduction, nevertheless the cost-revenue relation is greater, what means it will incur in more costs than revenues.

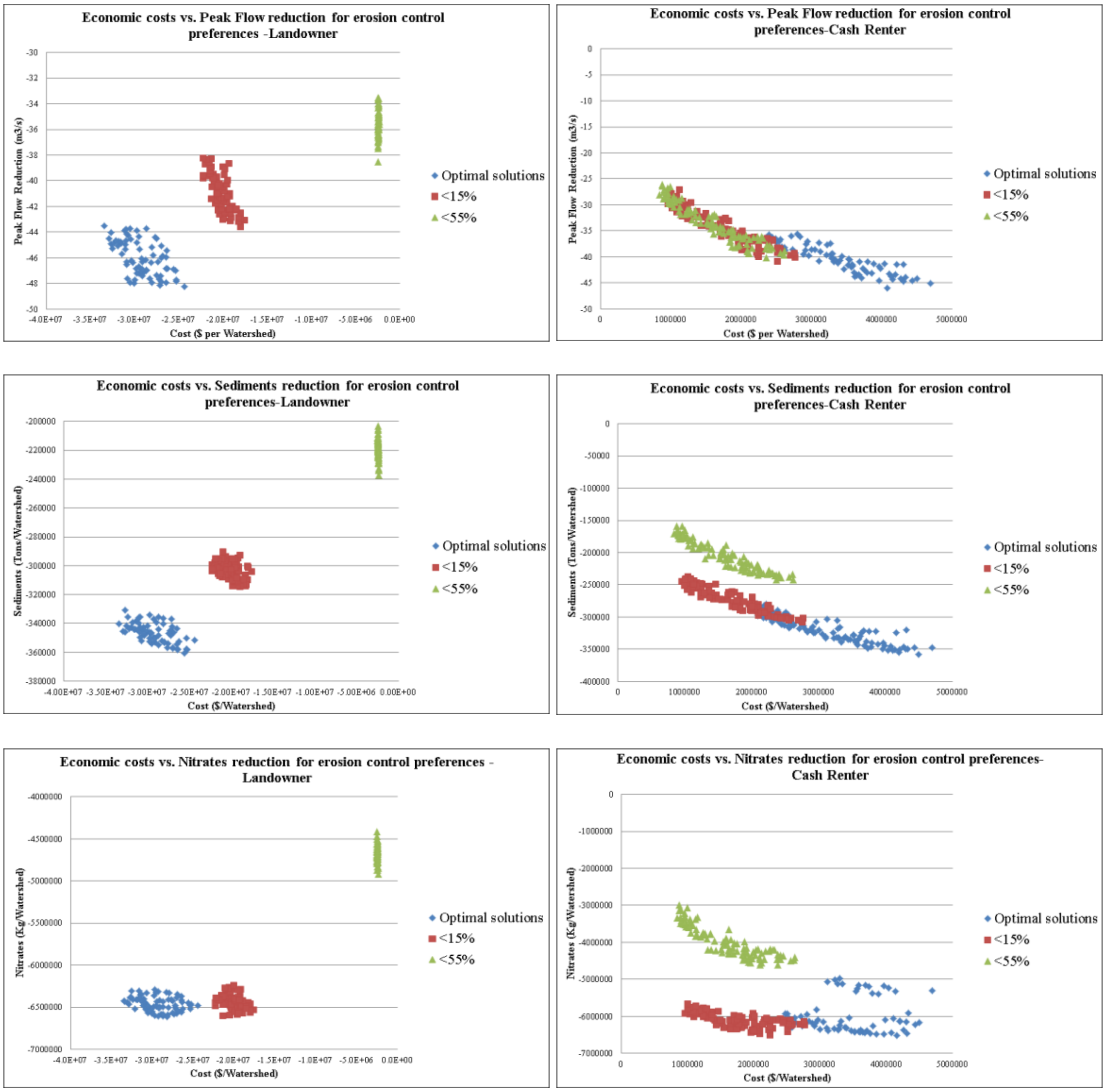


Figure 21. Modifications in optimal solutions for a landowner (left side) and a cash renter (right side) with an attitude towards erosion control preferences

These graphics were expected among all the tenures; nevertheless cash renter tendency is different. There is a consistency that for a less effective system, the cost-revenue relation is lower. This particular feature in the cash renter trends could be a product of the variation of the rents. As mention in the methodology, the rents are calculated using the yield production.

Also there is a complete overlapping on the economic costs vs. peak flow (top left) between the two reduce systems. This could be interpreted as that there are just 2 systems that really affect the peak flow reduction but also with an interest in erosion control, these are filter strips and wetlands. The overlapping of the optimal solutions with the reductions could also demonstrate the statement.

3.3.3. Multiple tenure, multiple practices

After the evaluation of a uniform stakeholder management and interests over the entire watershed, the decision of try a variation of land tenures to simulate a more realistic scenario was made. Figure 22 shows the random spatial distribution considered in this work. This random distribution agrees with the land tenure proportions presented by Duffy et al. (2008). A random distribution was selected due to the lack of information regarding tenure in each SB.

Figure 23 shows a comparison among the Pareto fronts of the objective uniform and variable tenure types. Plots have similar distribution for each objective function. Notice a clear distinction in cost-revenues values among the 3 land tenure type. For the period of time it has being modeled (2005-2008), this pareto fronts suggest that a landowner will have higher revenues if he implement conservation practices in the land that is produced by him, than in a land that is being cash-rented to someone else. This could increase business risks, but those are hurdles that are not intended to develop in this study.

As an example of the spatial distribution of the practices and its modifications due to land tenure, Figure 24 shows 4 scenarios for ECW. Notice in this example we used all the available practices, just to shows spatial distribution.

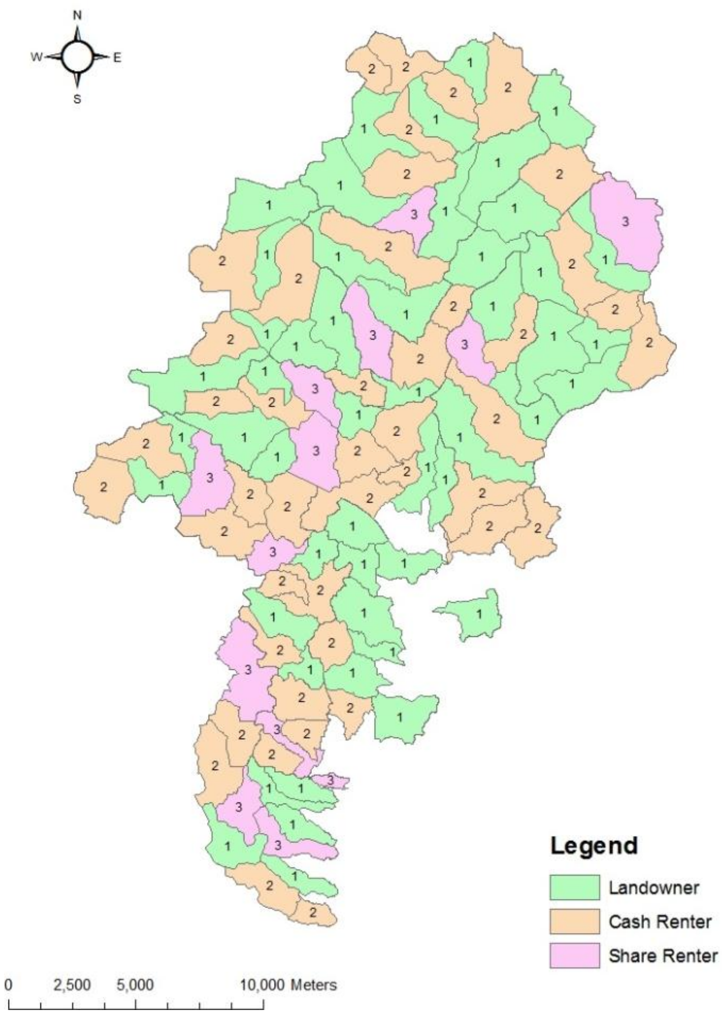


Figure 22. Random distribution of land tenure type in the watershed

All 4 maps were built based on a nitrate reduction of approximately 6500000 Kg/watershed. It was intended to find a common point were all; uniform and variable land tenure presents solutions. Although all the plots present this feature, Nitrates reduction shows a more compact set of solutions for landowners, share renters and random distributions.

It is evident the different distribution in each case, nevertheless, the effectiveness in the nitrates reductions is similar in all the cases.

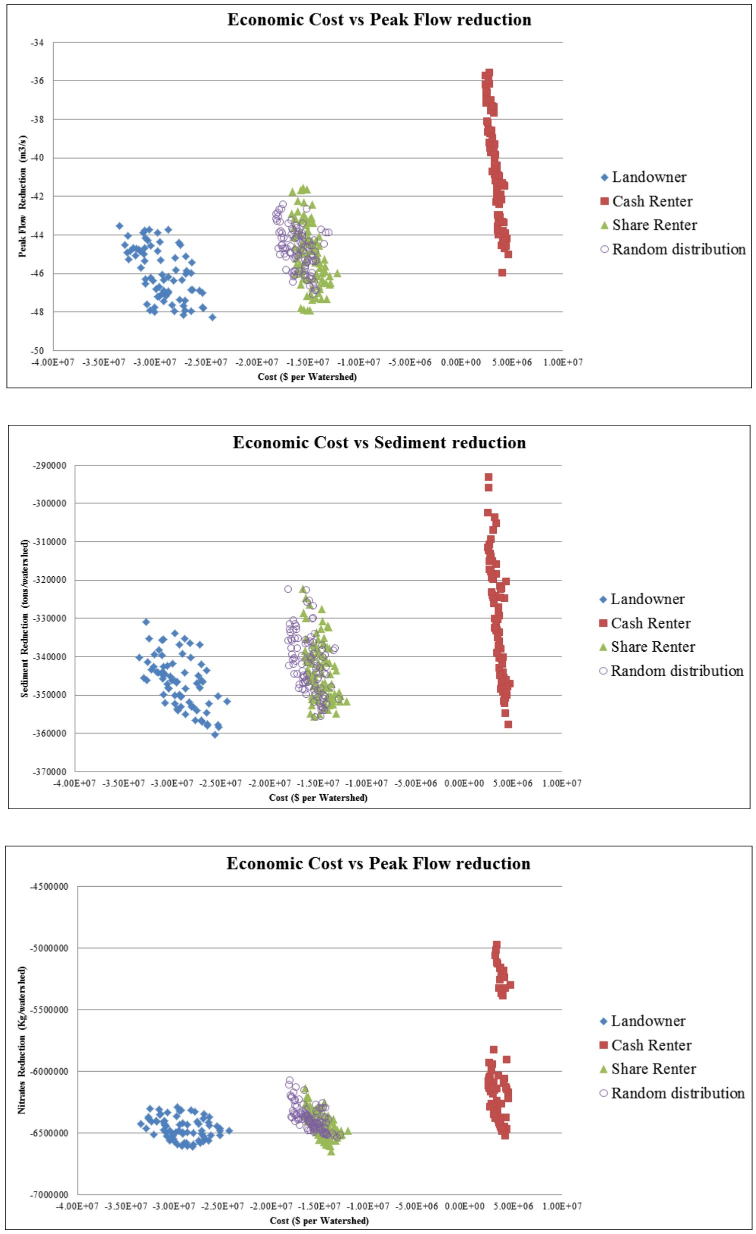


Figure 23. Pareto fronts for the objective functions considering the different land tenure types, using all available practices.

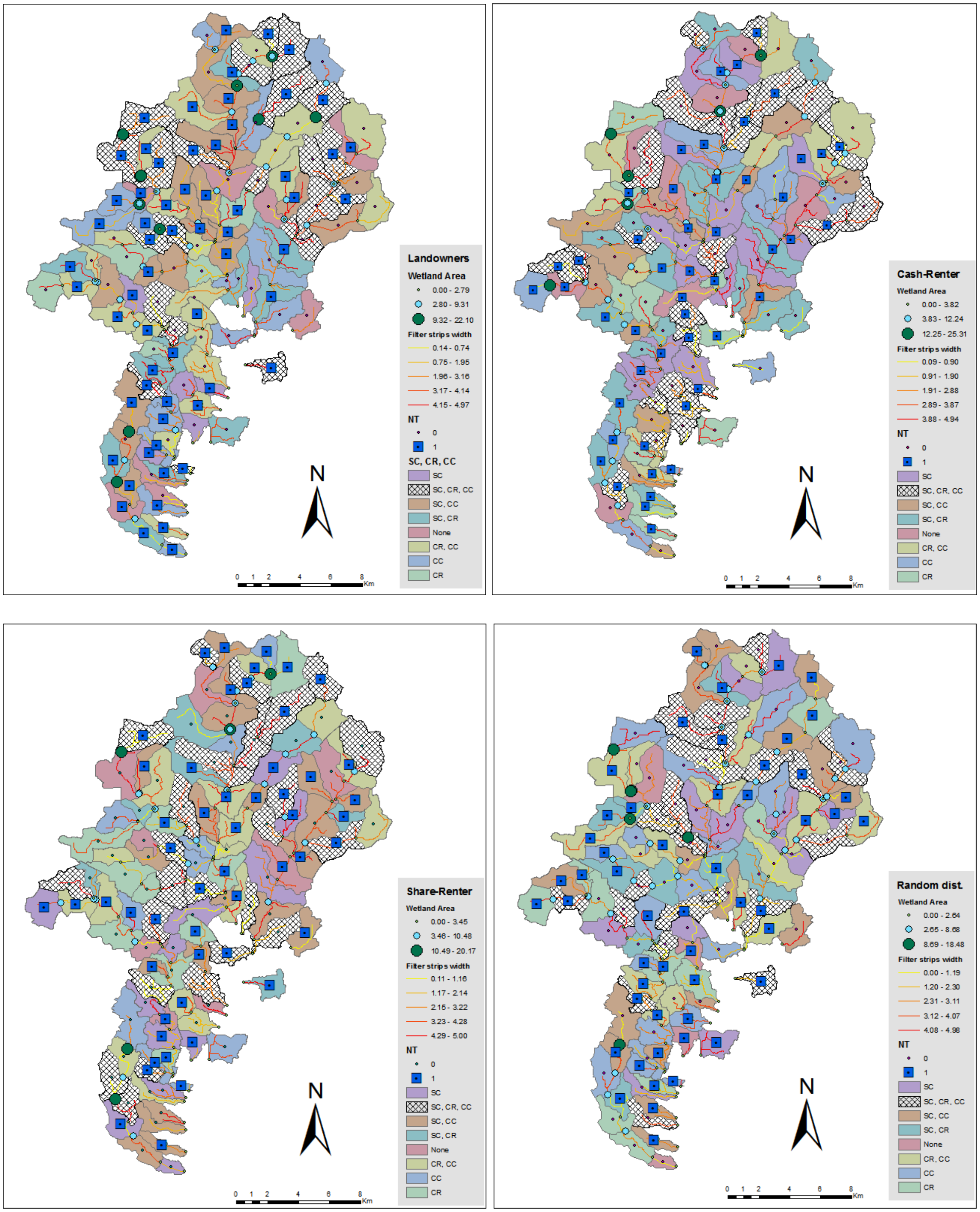


Figure 24. Distribution of practices depending on land tenure type with the restriction of nitrates reductions of approximately 6500000. NT = No Till, SC = Strip Cropping, CR = Crop Rotation, CC = Cover Crop

For example, the combination of Strip Cropping, Crop Rotation and Cover Crops, have a higher density and a better distribution on the entire watershed for the cases of share renter and cash renters. This consists with the Pareto fronts results, were the trade off in this too cases overlap.

Observations also suggest that filter strips varies along the 4 cases, and that wetlands of bigger size tend to be located in the North West area of the watershed. Nevertheless evaluation and analysis of the solutions in individual maps give a better observation of the different distributions. However, we need to consider that all the practices most be implemented in order to accomplish the target reduction goal.

4. DISCUSSION AND CONCLUSIONS

Watershed management plans are very powerful tools in the creation of sustainable environments. The goal is to find equilibrium between the human needs and the capability of nature to restore and replenish those products used by societies.

It is a challenging task to find a perfect center for this equilibrium. For the past few years, computational tools have helped in the modeling of nature response under modifications of its physical features. This has provided excellent insightful perspective of consequences due to nature's alterations, and has allow to test different ways to restore natural services while agree with the limitations and conditions of communities development. However, studies have been focus just in physical features and economic consequences, without finding a clear response on the low rate of adoption of watershed management plans.

This study was oriented towards analysis of systems that will help in spatial location of conservation practices in order to optimize their functions while considering the stakeholder preferences. Seven different common practices were studied as a connected system to enhance the health of Eagle Creek Watershed in Indiana. Using a NSGA-II algorithm we were able to select the best alternatives, for 3 different land tenure; landowner, cash renter and share renter.

Preferences of practices were tested based on attitudes towards 4 main objectives; economic profits, peak flow reduction, sediment reduction and nitrate reductions. It was found that depending on the attitude towards one of these objectives, stakeholder could modify the effectiveness of a total developed plan. In the provide example it is evident the decrease of effectiveness of an optimal set of solutions when practices are removed from the system. However, this is not a unique rule, and it was also found that some isolated practices could have the same effect at a lower cost-revenue relation.

Also, considering the best optimal solutions for each land tenure type, evaluations of spatial distribution of the different systems was made. The results suggest that even whit a common target, distribution of practices will vary depending on the land tenure. A random distribution was tested to see the effect on optimization and spatial location. It was found that for the random distribution and for share-renters, the optimal solutions overlap for the three Pareto fronts and that range of cost-revenue relation for cash renters is very stretch in comparison with the other cases.

The work does not intend to provide final decisions, but help in the selection and understand the effects, and cost-benefits relation under a different combination of alternatives, driven by a selected stakeholder attitude. This works intents to be part of that bridge linking only physical model and its interactions with decision makers.

Assumptions such as random distributions, market prices and motivation of adoptions should be studied by integrating real agents in the process. Watersheds are unique not just in its physical features, but also at a socio-economical level. The incorporation of assumptions will increase the uncertainty level in the model; however it is necessary build an initial framework that would be used in the future research in order to validate and include missing points of the process.

APPENDIX

A.1 Background Literature

Attitudes and behavior of agricultural stakeholders have been studied by several authors (Weaver (1996), Luzar and Cosse (1998), Luzar and Diagne (1999), Soule et al (2000), Söderqvist (2003)). Weaver (1996) described two types of attitudes expected from farmers, when they are involved in efforts related to increasing or preserving the supply of a public resource, e.g., water quality. The first type of farmer (also called the "selfish hedonist") is motivated only by the determinants of profit-maximization. However, with increased education and improved knowledge about the effects of their decisions on the environment they can be influenced to participate in a conservation program oriented to the adoption for environmental solutions in agricultural land. The second type of farmer (also called the "egoistic hedonist") is motivated by their own preferences (such as private goods and factors of production) but adopt a better environmental attitude because of an individual perspective on a private contribution for environmental public goods; even when the investment have a negative effect on the net of revenue. This behavior will provide with a private incentive in order to support public goods; i.e. the implementation of conservation practices will not require a conservation program. Among other variables this behavior will be determined by socio-demographic features, values and beliefs According to Luzar and Cosse (1998), attitudes are defined as the level of acceptance of a result multiplied by the outcome of the result. They pointed out that attitude influences the behavior and the degree of acceptance will vary depending on factors such as multiple contradictory attitudes, prior information, or contemplation. Although these factors are not complete predictors of behavior, the tendency of individuals to take an action is highly correlated with them. Links between attitudes, values and beliefs play an important role in defining individual behavior. There exists a reciprocal correlation between beliefs and attitudes as well as a positive correlation between values and attitudes. For example, a person who values the environment and believes in the effectiveness of conservation practices is more likely to have a positive attitude in the restoration of natural systems via conservation practices.

Luzar and Cosse (1998) suggest the hypothesis that socio-economic characteristics of farmers would explain the variation in willingness to pay due to their document association with environmental concerns. According to their work, features such as age, presence of young children, gender and higher education level have a positive influence in the likelihood of adoption, while lower levels of education and lower income levels represent a negative influence. Also, employment status (farmers) and awareness of water quality problems will increase willingness to pay, considering these factors as positive influences. Their survey results showed that individuals are willing to increase the payments for change in water quality, but at a individual level.

Another study by Luzar and Diagne (1999) considers the different factors affecting the behavioral conducts. The relation between attitudes and behaviors is founded in the theory of reasoned actions, where the individual's intentions are the behavior's trigger, but these intentions are defined by the attitude toward a subject. Luzar and Diagne (1999) presented a behavioral model toward the participation of stakeholders in an incentive-based mechanism such as the Wetland Reserve Program (WRP). Using probit analysis, they were able to identify variables that influenced in a negative or positive way the voluntary participation of these programs. Acreage of wetlands owned, information about the program, ownership of farmed wetlands, involvement in environmental organizations, and higher income levels represented some of the features that lead a positive attitude about the voluntary participation. Education level (lower degrees) and number of people living in the household (big families) affected the enrollment in a negative perspective.

Due to the non-rival characteristics of public goods there is a tendency that motivates cooperation on the conservation of the product; in this case it is the concern for water quality and flooding problems. Söderqvist (2003) studied the voluntary participation of stakeholders in programs designed for environmental protection. Two questions were developed in this study: 1) How significant is the financial motives in the participation of farmers in environmental programs? And 2) is prosocial behavior encouraged by non-financial incentive?

According to the results of surveys answers and in a later statistical model that related the probability of willingness to participate in conservation programs the results led to a believe where this probability is not only related to the financial benefits obtained by the program. Stakeholders tend to also consider the design of the conservation practice that provides private environmental benefits and their perception of those benefits, before they participate in conservation programs and practices.

One limitation that these types of studies face is the sample population. Although in all the cases surveys are sent via postal mail, usually only less than 60% of the population responds to them. Table A1 shows an example of the percentage and total population that participated in surveys for several stakeholder attitudes studies. This includes Söderqvist (2003), Luzar and Cosse (1998) and a survey applied by the Natural

Resource Social Science Lab of Purdue University. The lack of enough data on stakeholder preferences and enough sample size of surveys makes it challenging to accurately and comprehensively model attitudes and behaviors of stakeholder communities. These surveys, however, can only be used to provide some general feedback on how likely the stakeholders are in participating in the different incentive and cost-sharing programs oriented towards the implementation of conservation practices.

Table A1. List of percentages of answered surveys

Study	Total survey release	Total answered	Percentage
Söderqvist (2003)	200	119	55%
Luzar and Cosse (1998)	1938	664	34%
ECWA (2010) Rural	219	77	35%
ECWA (2010) Urban	399	176	44%

Other studies, such as the one accomplished by Soule et al. (2000), used national data, provided by the USDA (United State Department of Agriculture) through the ARMS (Agricultural Resource Management Study). In this study Soule et al. (2000) researched the land tenure and the adoption of the conservation practice.

It is believed then that land tenure will affect the decision making process over a property. This could be influenced by several factors such as landowner-renter arrangement, future land plan, crop prices, risk attitudes towards markets, land productivity, savings in productions, flooding concerns, among some of the relevant agents that will lead to a decision making process regarding the adoption of a conservation practice. With this information we can generate some scenarios that involved attitudes and characteristics of different stakeholders.

Although there are significant community's benefits for the implementation of BMPs (Ribaudo et al. (1994), Aust et al. (1996), Yadav and Wall (1998), Coiner et al. (2001), Brian and Kandulu (2009)); we need to consider the available benefits that will support the decision makers to consider the implementation in a private property. Economic and social criteria such as the value of the land, current zoning of the site decided by the zoning board, stakeholder environmental attitude, and cost of implementation/maintenance (Soule et al. (2000), Ahnstrom et al. (2009)) will affect the decision for private stakeholders. These factors add complexity to the design problem.

According a survey report prepared by the Iowa State University Extension (Duffy et al. (2008)) the farm lands tenure is controlled in the following way: 46% by landowners and 54% is rented out to cash-renters (42%) and share-renters (12%).

Table A2. Percentage of land tenure type find in the Iowa. Taken from Duffy et al. (2008)

STATE OF IOWA 2007		
Owner Controlled:		46%
Owner operated	37%	
Custom farmed	2%	
Government conservation programs and other uses	7%	
Leased:		54%
Cash rent	42%	
Crop share	12%	
Other type of agricultural lease	<1%	
Total:		100%

A2. Extra data in SWAT model

Also, we add the information of wetlands and ponds in the region collected form the National Wetland Inventory (NWI). This information is available at <http://www.fws.gov/wetlands/index.html> in a shape file format that was clipped to the ECW boundaries. Then wetland areas and volume was extract and add to the baseline as pre-existing wetlands.

A3. LOADEST estimation for water quality calibration

LOAD ESTimator (LOADEST) is a program built in FORTRAN that help with the estimation of constituent load (calibration) through regression models. This program assists the user in calibration process, estimating missing points using a regression model.

Estimation calculations in LOADEST is based in 3 statistical estimation methods: Adjusted Maximum Likelihood Estimation (AMLE), Maximum Likelihood Estimation (MLE) and Least Absolute Deviation (LAD).

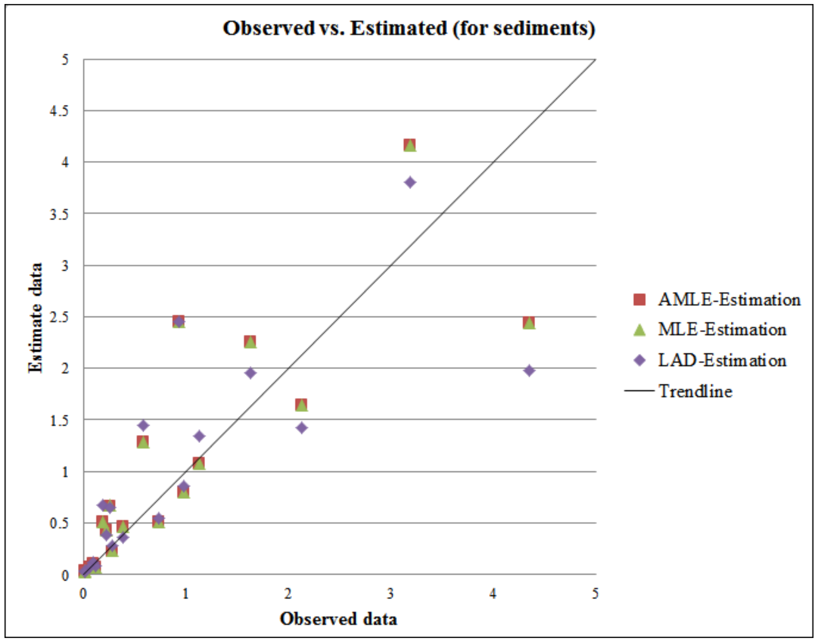
In this research the need for an extended version of the water quality observed parameters led to the use of LOADEST. With the observed data, a test was made to evaluate the accuracy of the model on those days. The require inputs for the model is the discharge (in cfs), the concentrations (ppm or mg/L, it can be specify) of observed variables and the desire output units. For each statistical method the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970) and the Pearson's product-moment correlation coefficient (R^2) (Legates and McCabe, 1999) was calculated. Table A3 present the results. Also, a plot of the 3 estimations and the observed data was generated to compare differences between estimation and observed data (Figure A1).

The estimations have an effective coefficient with the observed data that goes from 0.59 - 0.73 for the E_{NS} and 0.77-0.86 for R^2. As these results were consider as acceptable match, the extended version of the observed data for the years 2007-2008 was generated and used as observed data to be used as a calibration base for the SWAT model. As we do not know the shape of the residuals, we do not assume a normal distribution and just used the values from the LDA estimation. To keep consistency, this values were used in sediments and nitrates calculations.

Table A3. Nash-Sutcliffe efficiency for the different statistical methods in

Variable	E_{NS} AMLE	E_{NS} MLE	E_{NS} LDA	Pearson AMLE	Pearson MLE	Pearson LDA
Sediments	0.66	0.66	0.59	0.82	0.82	0.77
Nitrates	0.65	0.65	0.73	0.86	0.86	0.86

The savings in production costs as well as the rent was calculated depending on the crop involved. Purdue Extension-Agriculture Economics has recorded data from the last 10 years on production prices associated with yields of corn, soybeans and wheat. The data is collected based in productivities. Then they classify the data in poor, medium or high land productivity. Each of these ranges has a particular price that will vary from year to year depending on the market trends. The average of each classification was used to build a trend line that has being used in the calculation of all yield related costs, rents and production increase.

(a)


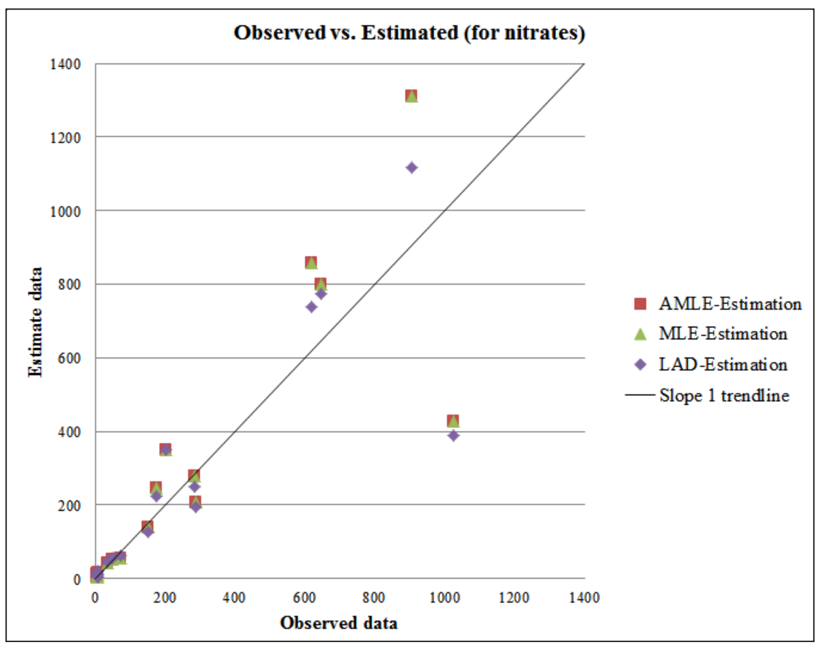
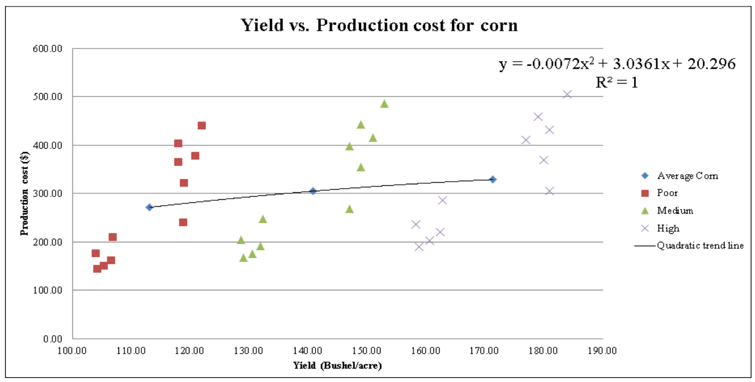
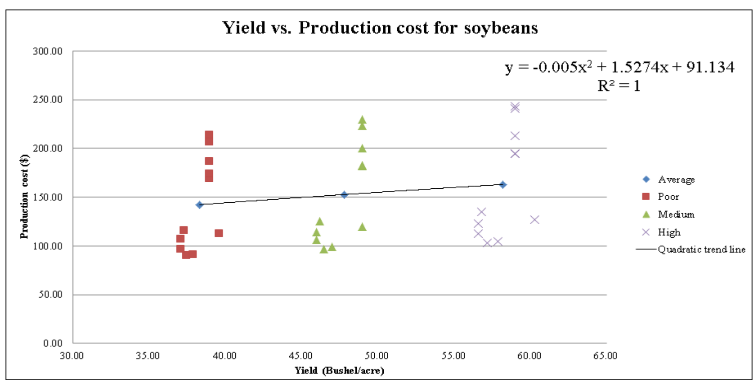
(b)


Figure A1. Observed vs. estimated data for sediments (a) and nitrates (b)

A4. Calculations of costs of production and rent based on yields

Figure A2 shows the three trend lines for an average of 10 years of corn, soybeans and winter wheat prices based on land productivity yields. This data was used to estimate the revenues such as increase in land productivity, rent and savings in production for each crop. The data found a perfect fit for a quadratic trend line.

a) 

b) 

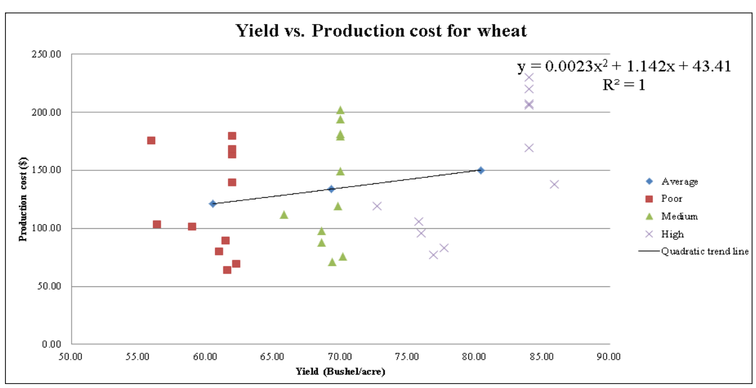
c) 

Figure A2. a) Trend line for the production cost of corn, b) trend line for the production cost of soybeans and c) trend line for production cost of winter wheat

In the same way, an average of 10 years data collection of average rent for 3 different kinds of land productivity was used to build a trend line in order to calculate the rent based on the yield productivity. This trend line, show in figure A3, also present a perfect match with a quadratic function.

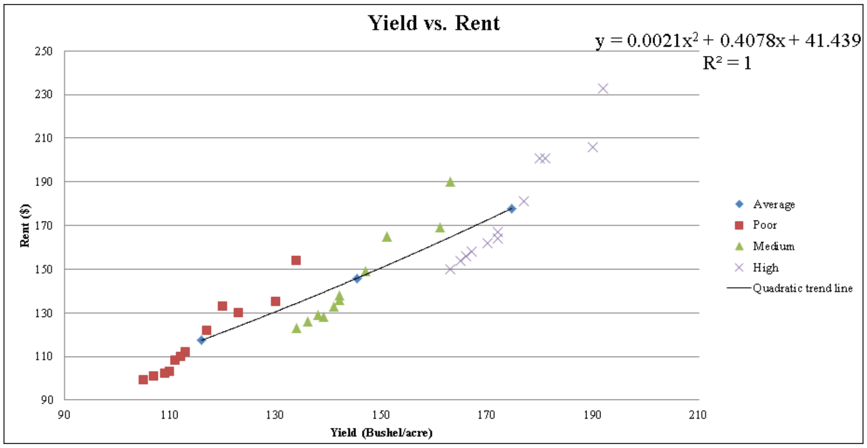


Figure A3. Trend line for rent land calculation. This rent land is use for the cash renter land tenure type.

A5. Land tenureship percentages

Accurate information about percentages of Landowner, cash renter and share renter are not available in detail for the study area. However, the census of agriculture shows a similar trend among all the Corn Belt states. Therefore, Iowa state publication regarding percentages of tenure was used as the percentages relation in Eagle Creek watershed to build the random distribution of tenure used in the experiment: 'Multiple tenure, multiple practices'. Table A2, under the background literature shows these percentages.

A6. Preferences Graphs

Preferences Graphs show all those possible solutions that were explore during the research. Figures A4 to A12 represents the differences among optimal solutions and the two thresholds for the effectiveness lost due to stakeholder preferences. These graphs also show the effect of the percentages and optimal solutions over the objectives.

Observations for Cash-Renters show that optimal solutions raises the cost for the entire watershed (Figures A7-A9). This can be a consequence of the rent calculation due to under prediction of the yield by the SWAT model.

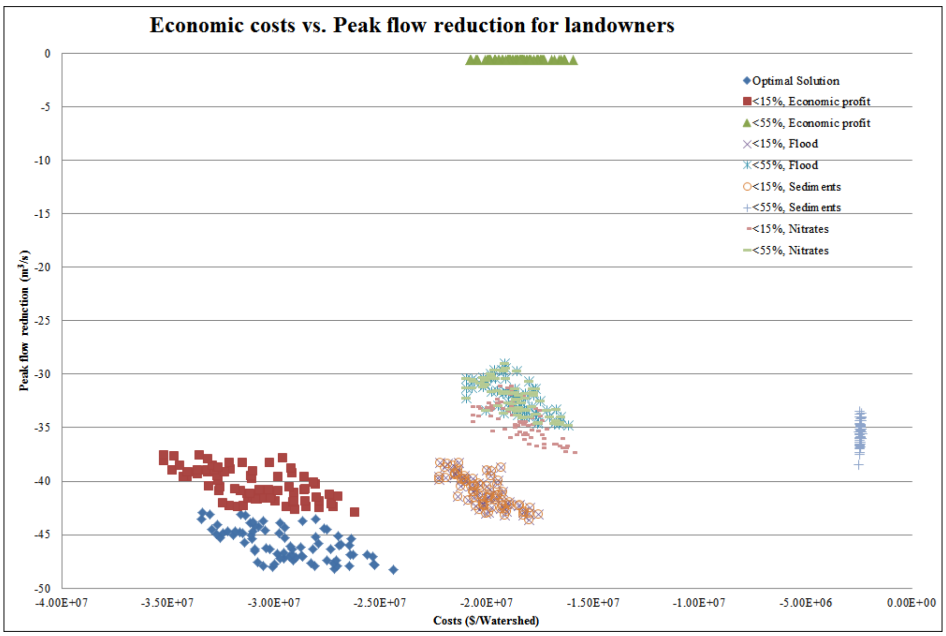


Figure A4. Landowner effects over peak flow reduction optimal solutions under different attitudes.

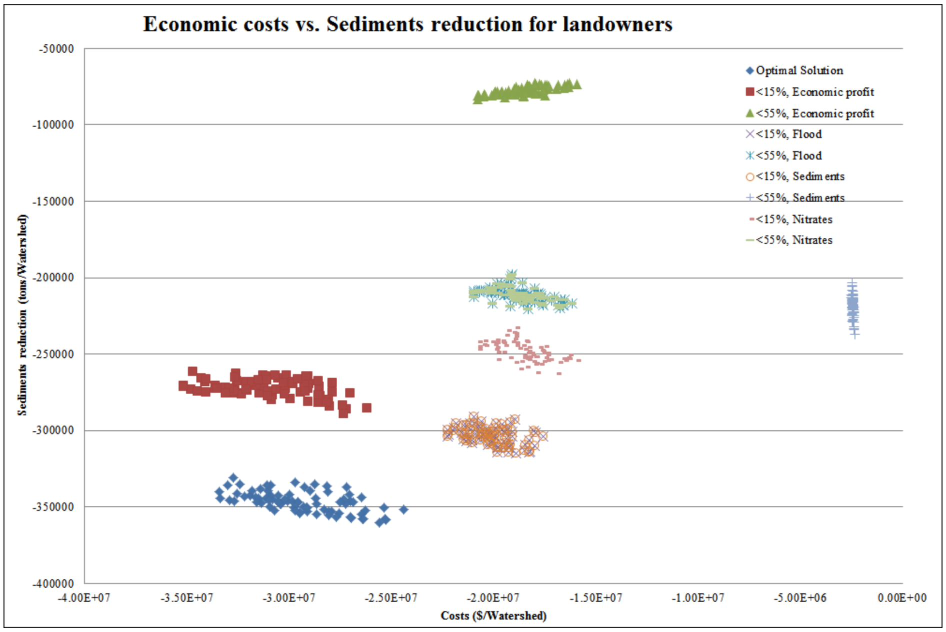


Figure A5. Landowner effects over Sediments reduction optimal solutions under different attitudes.

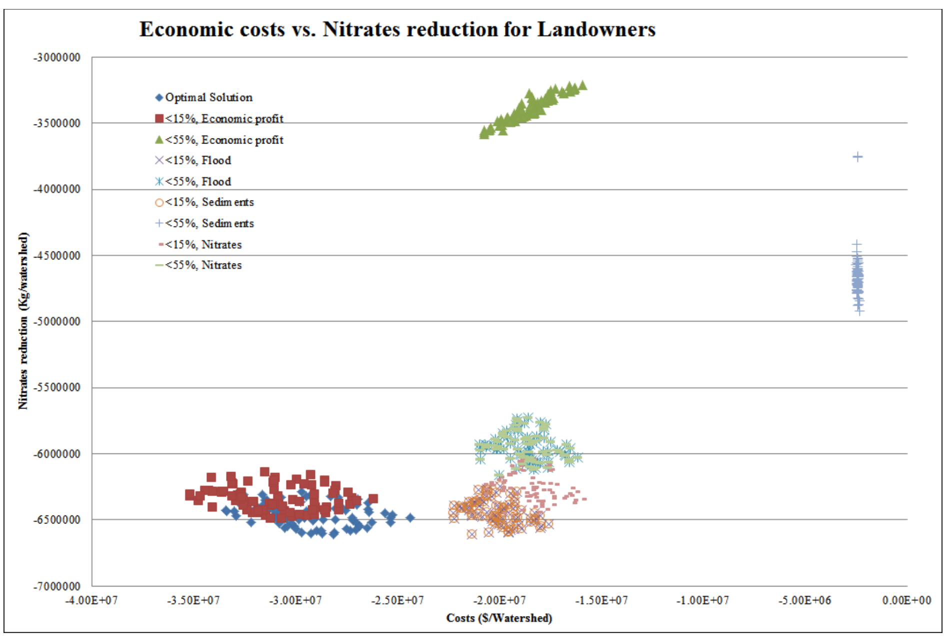


Figure A6. Landowner effects over Nitrates reduction optimal solutions under different attitudes.

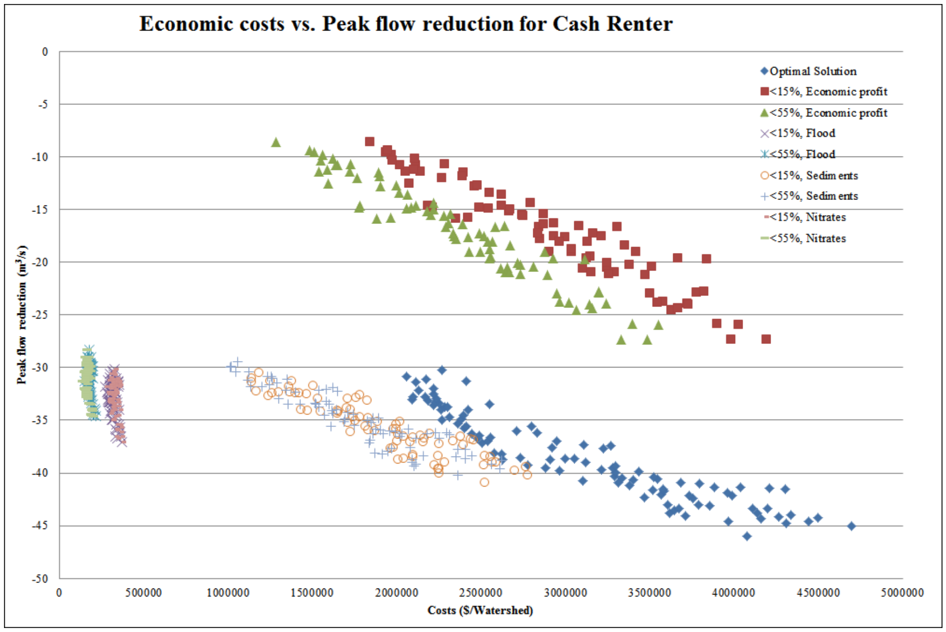


Figure A7. Cash-Renter effects over peak flow reduction optimal solutions under different attitudes.

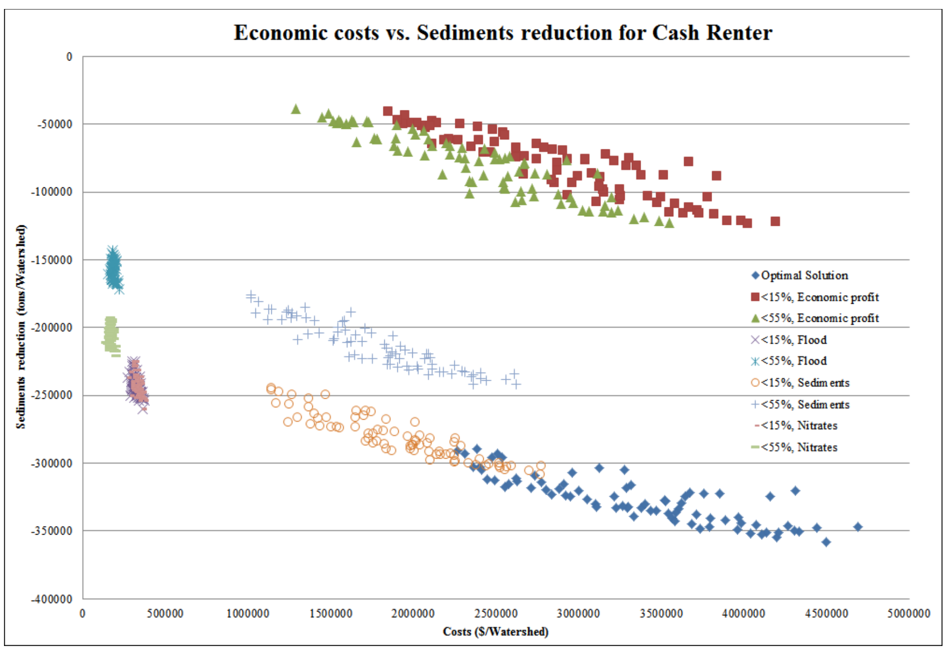


Figure A8. Cash-Renter effects over Sediments reduction optimal solutions under different attitudes.

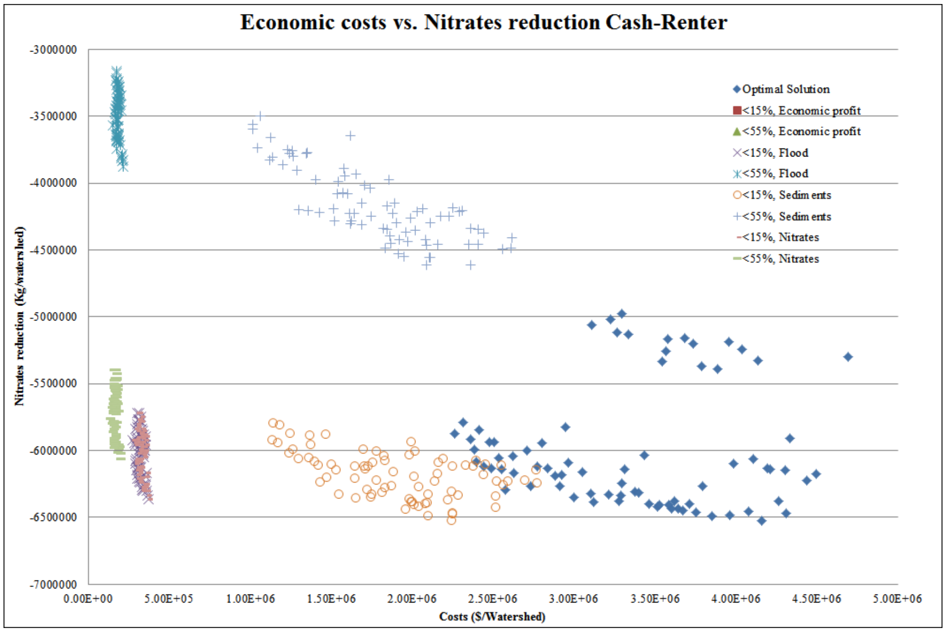


Figure A9. Cash-Renter effects over Nitrates reduction optimal solutions under different attitudes.

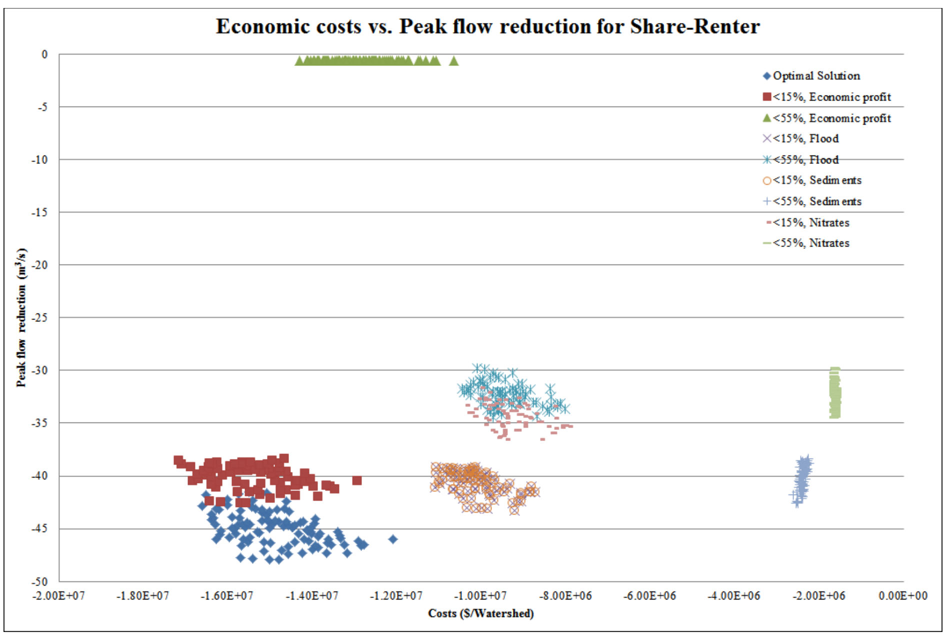


Figure A10. Share-Renter effects over peak flow reduction optimal solutions under different attitudes.

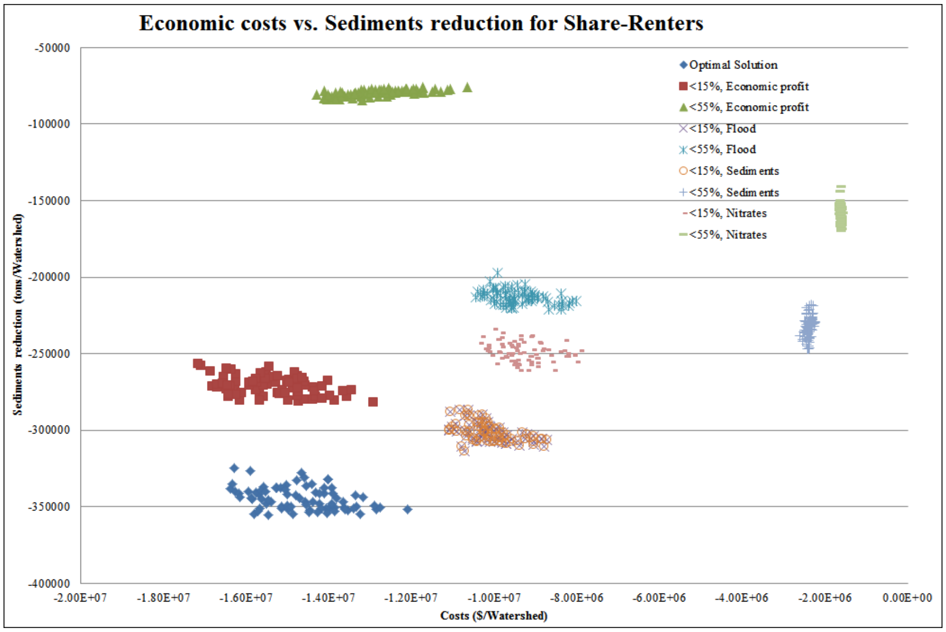


Figure A11. Share-Renter effects over Sediments reduction optimal solutions under different attitudes.

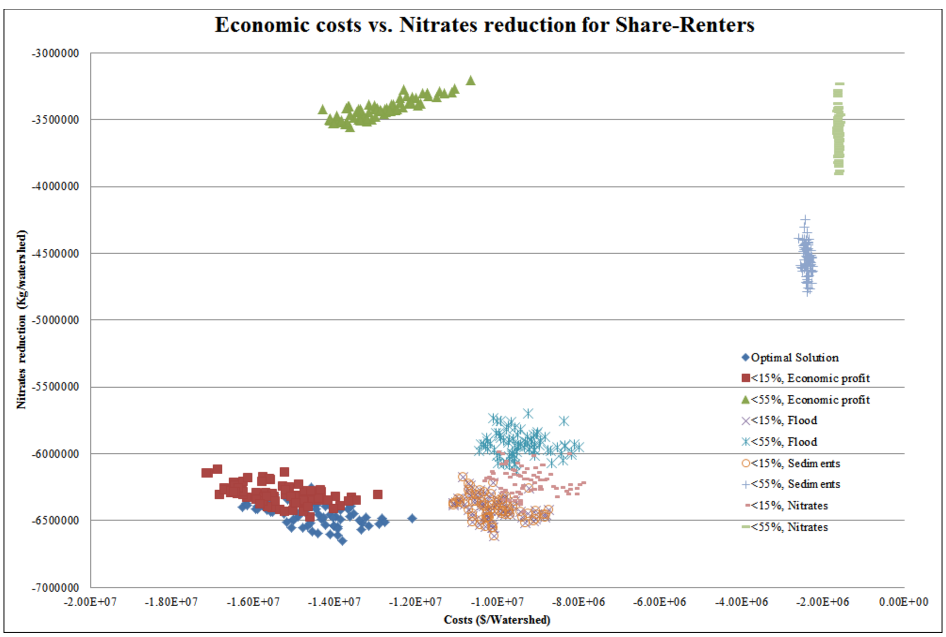


Figure A12. Cash-Renter effects over Nitrates reduction optimal solutions under different attitude

A7. FORTRAN algorithm for the Economic function objective

```
! Cost_function_v1.f90

!
!  FUNCTIONS:
!  Cost_function_v1. by Adriana D. Piemonti, 2012
!****************************************************************************
!
!  PROGRAM: Cost_function_v1
!
!  PURPOSE:  - Calculate the net of present values for different BMPs
! in a watershed, based in the output files of SWAT model and in the typical
! values for BMP (best management practice) implementation.
!
!****************************************************************************
   program Cost_function_v1

   implicit none

   integer :: i, j, k, n, p, q,  num_hru, allBMPs, num_subbasins, allSB, modyears, aux_m,
aux_i , hru_aux
   integer :: SB_aux, num_LandUse, aux_p, Rotation_year, biomass
   real :: int, fraction, corn_value, soy_value, wheat_value, factor, TotalWatershed
   character :: BMP_aux*14, crop_aux*4, dummy1*5, dummy2*3
   integer, allocatable, dimension(:) :: act, SB, tenure, LandUse, num_hruSB
   integer, allocatable, dimension(:,:) :: hruSB_crop
   real, allocatable, dimension(:) :: Rin, CI, OM, cost0, hru_area, NPVcost
   real, allocatable, dimension(:) :: net_Uniformtot, TotalPI_cc, TotalPI, TotalSP,
TotalRR
   real, allocatable, dimension(:,:) :: gene, BMParea, CropHRU_area, Croparea_validSB,
net_Uniform, yield1base, yield2base
   real, allocatable, dimension(:,:) :: yield3base, yield1, yield2, yield3, PI, PI_cc, SP_fs
   real, allocatable, dimension(:,:) :: SP_bw, SP_vaw, RR, SP, avg_produc_price,
produc_price
   character, allocatable, dimension(:) :: BMP*25, crop*4

   num_hru = 2744
   allBMPs = 10
   num_subbasins = 108
   allSB = 130
   modyears = 5
   int = 0.05
   fraction = 0.5
   corn_value = 5.5
   soy_value = 13.12
```

```
wheat_value = 8.21
aux_i = 1
aux_m = 1
num_LandUse = 3


allocate(BMP(allBMPs), act(allBMPs), SB(num_subbasins), tenure(num_subbasins), Rin(allBMPS), CI(allBMPS))
allocate(OM(allBMPS), cost0(num_subbasins), num_hruSB(allSB), LandUse(num_LandUse), hru_area(num_hru), crop(num_hru))
allocate(net_Uniformtot(num_subbasins), TotalPI_cc(num_subbasins), TotalPI(num_subbasins), produc_price(modyears, num_subbasins))
allocate(SP_fs(modyears, num_subbasins), RR(modyears, num_subbasins), SP(modyears, num_subbasins),TotalSP(num_subbasins))
allocate(net_Uniform(num_subbasins, modyears), yield1base(modyears,num_hru*5), yield2base(modyears,num_hru*5))
allocate(yield1(modyears,num_hru*5), yield2(modyears, num_hru*5), yield3(modyears, num_hru*5), yield3base(modyears,num_hru*5))
allocate(gene(allBMPs, num_subbasins), BMParea(num_subbasins, allBMPs), CropHRU_area(num_landUse, allSB))
allocate(hruSB_crop(num_LandUse, allSB), Croparea_validSB(num_LandUse, num_subbasins), TotalRR(num_subbasins))
allocate(PI(modyears, num_subbasins), PI_cc(modyears, num_subbasins), avg_produc_price(modyears, num_subbasins))
allocate(SP_bw(modyears, num_subbasins), SP_vaw(modyears, num_subbasins))
allocate(NPVcost(num_subbasins))

gene = 0
num_hruSB = 0
cropHRU_area = 0
hruSB_crop = 0
cost0 = 0
net_Uniform = 0
net_Uniformtot = 0
yield1base = 0
yield2base = 0
yield3base = 0
yield1 = 0
yield2 = 0
yield3 = 0
PI = 0
PI_cc = 0
TotalPI = 0
TotalPI_cc = 0
SP = 0
SP_fs = 0
```

```
   SP_bw = 0
   SP_vaw = 0
   RR = 0
   TotalSP = 0
   TotalRR = 0
   Rin = 0
   CI = 0
   OM = 0
   Croparea_validSB = 0
   avg_produc_price = 0
   produc_price = 0
   NPVcost = 0

   open(1, file = 'indiv.dat', status = 'old')       !Read file with individuals information
   read(1,*) (BMP(i), i = 1, allBMPs)
   read(1,*) (act(i), i = 1, allBMPs)
   read(1,*) (SB(i), i = 1, num_subbasins)
   read(1,*) (tenure(i), i = 1, num_subbasins)
   do j = 1, allBMPs
      if(act(j) .eq. 1)then
         read(1,*)(gene(j,i), i = 1, num_subbasins)
      endif
   enddo
   close (1)

   open(2, file = 'values.txt', status = 'old')          !Read database with the BMP costs
information
   read(2,*)
   do j = 1, (allBMPs - 2)
      read(2,*) BMP_aux, Rin(j), CI(j), OM(j)
   enddo
   close(2)

   open(3, file = 'BMPs_areas.txt', status = 'old')      !Read database with BMP area from
total cropland and Total Maximum Areas
   read(3,*)
   do i = 1, num_subbasins
      read(3,*)SB_aux,(BMParea(i,j),j = 1,(allBMPs-1))
   enddo
   close(3)

   open(4,file = 'SBandHRU.txt', status = 'old')         !Read file with HRU information on
SB and area
   read(4,*)
   ! Here we identify number of corn, soyb, and other HRUs in every sub-basin
   do p = 1, (num_hru + allSB)
```

```
        read(4,*) SB_aux, hru_aux, crop(aux_m), hru_area(aux_m)
        if(SB_aux .eq. 9999)then
           aux_i = aux_i + 1
        else
           num_hruSB(aux_i) = num_hruSB(aux_i) + 1             !Count number of HRU per
subbasin
           if(crop(aux_m) .eq. 'CORN')then
              hruSB_crop(1, aux_i) = hruSB_crop(1, aux_i) + 1 !Count the number of CORN
HRU per SB
           else if (crop(aux_m) .eq. 'SOYB')then
              hruSB_crop(2, aux_i) = hruSB_crop(2, aux_i) + 1   !Count the number of
SOYB HRU per SB
           else if (crop(aux_m) .ne. 'CORN' .or. crop(aux_m) .ne. 'SOYB')then
              hruSB_crop(3, aux_i) = hruSB_crop(3, aux_i) + 1    !Count all the non Crop
land of HRU per SB
           endif
           aux_m = aux_m + 1
           if(aux_m .gt. 2744)then
              go to 100
           endif
        endif
     enddo
     close(4)

100 aux_p = 1
     ! Here, we calculate the total crop-specific HRU area, in every sub-basin. This will be
used to identify average savings in production per acre for wetlands later.
     do i = 1, allSB
        do k = 1, num_LandUse
           if(hruSB_crop(k,i) .ne. 0)then
              do q = 1, hruSB_crop(k,i)
                 if (crop(aux_p) .eq. 'CORN' .and. k .eq. 1)then
                    CropHRU_area(1,i)    =    CropHRU_area(1,i)    +    hru_area(aux_p)
!Calculating area of CORN per SB
                    aux_p = aux_p + 1
                 else if(crop(aux_p) .eq. 'SOYB' .and. k .eq. 2)then
                    CropHRU_area(2,i)    =    CropHRU_area(2,i)    +    hru_area(aux_p)
!Calculate area of SOYBEANS per SB
                    aux_p = aux_p + 1
                 else if(crop(aux_p) .ne. 'CORN' .and. crop(aux_p) .ne. 'SOYB' .and. k .eq. 3)
then
                    CropHRU_area(3,i) = 0
                    aux_p = aux_p + 1
                 endif
              enddo
           endif
```

```
      enddo
    enddo

    ! Filter out crop specific total HRU areas for only those sub-basins that are modeled for
cost function.
    do k = 1, num_LandUse
      do i = 1, num_subbasins
        do p = 1, allSB
          if(SB(i) .eq. p)then
            Croparea_validSB(k,i) = CropHRU_area(k,p)          !Subbasins with valid
BMPs installation
          endif
        enddo
      enddo
    enddo

    ! Calculate BMP areas for filter strips and wetlands, in acres.
    do i = 1, num_subbasins
        ! Check if filter strip is modeled as a BMP and is used in this sub-basins (i.e. if the
gene value is more than 0)
        if (act(4) .eq. 1 .and. gene(4,i) .gt. 0)then
          do k = 1, num_LandUse
            BMParea(i,4) = BMParea(i,4) + (gene(4,i) * 1452 * 0.0254 * 2.47E-4 *
Croparea_validSB(k,i))/48  !Calculate area in acres for Filter Strips
          enddo
        endif
        if (act(8) .eq. 1 .and. gene(8,i) .gt. 0)then
          BMParea(i,8) = (gene(8,i)*2.47)  !Calculate area in acres for VAW (Variable
Area Wetlands)
        endif
        if (act(9) .eq. 1) then
          BMParea(i,9) = 0                    !This value will represent a wet_fraction, not a
area. We make it zero to prevent any misscalculation
        endif
    enddo


    !Year 0:
    do i = 1, num_subbasins
      do j = 1, allBMPs-2
        if(act(j) .eq. 1 .and. (tenure(i) .eq. 1 .or. tenure(i) .eq. 2) .and. (gene(j,i) .gt.
0))then ! Check for practice, tenure, and if the sub-basin is supporting the practice
          cost0(i) = cost0(i) + (CI(j)*BMParea(i,j))
        else if(act(j) .eq. 1 .and. tenure(i) .eq. 3 .and. (gene(j,i) .gt. 0))then
          cost0(i) = cost0(i) + (CI(j)*fraction*BMParea(i,j))
        endif
```

```
    enddo
  enddo

  !Uniform net present values: Operation and Maintenance and Rent from incentive program
  do i = 1, num_subbasins
    do n = 1, modyears
      factor = 1/((1+int)**n)
      do j = 1, (allBMPs - 2)
        if(act(j) .eq. 1 .and. (tenure(i) .eq. 1 .or. tenure(i) .eq. 2) .and. (gene(j,i) .gt. 0))then
          net_Uniform(i,n) = net_Uniform(i,n) + ((OM(j) - Rin(j))*BMParea(i,j))
        else if(act(j) .eq. 1 .and. tenure(i) .eq. 3 .and. (gene(j,i) .gt. 0))then
          net_Uniform(i,n) = net_Uniform(i,n) + (((OM(j)*fraction) - Rin(j))*BMParea(i,j))
        endif
      enddo
      net_Uniform(i,n) = net_Uniform(i,n)*factor
      net_Uniformtot(i) = net_Uniformtot(i) + net_Uniform(i,n)
    enddo
  enddo

  !Variable net present values: Savings in production costs, profit for increasing productivity and Cash-renter rent

  open(5, file = 'outstdbaseline.std', status = 'old')
  do i = 1,1979
    read(5,*)
  enddo
  !Read baseline of output.std
  do p = 1, num_hru
    read(5,*) crop_aux, dummy1, hru_aux, dummy2, Rotation_year, yield1base(1,p), biomass, yield2base(1,p), biomass, yield3base(1,p)
    if(crop_aux .eq. 'CORN' .or. crop_aux .eq. 'SOYB')then
      do n = 2, modyears
        read(5,*) crop_aux, dummy1, hru_aux, dummy2, Rotation_year, yield1base(n,p), biomass,  yield2base(n,p), biomass, yield3base(n,p)
      enddo
    endif
  enddo
  close(5)

  !Read new output.std
  open(6, file = 'output.std', status = 'old')
  do i = 1,1979
    read(6,*)
```

```
   enddo
   do p = 1, num_hru
      read(6,*) crop_aux, dummy1, hru_aux, dummy2, Rotation_year, yield1(1,p),
biomass, yield2(1,p), biomass, yield3(1,p)
      if(crop_aux .eq. 'CORN' .or. crop_aux .eq. 'SOYB' .or. crop_aux .eq. 'WWHT' .or.
crop_aux .eq. 'CSCP'.or. crop_aux .eq. 'SSCP')then
         do n = 2, modyears
            read(6,*) crop_aux, dummy1, hru_aux, dummy2, Rotation_year, yield1(n,p),
biomass,  yield2(n,p), biomass, yield3(n,p)
         enddo
      endif
   enddo
   close(6)

   do p = 1, num_hru
      do n = 1, modyears
         !convert Kg/Ha to Bushel/acre
         yield1base(n,p) = 0.016*yield1base(n,p)
         yield2base(n,p) = 0.016*yield2base(n,p)
         yield3base(n,p) = 0.016*yield3base(n,p)
         yield1(n,p) = 0.016*yield1(n,p)
         yield2(n,p) = 0.016*yield2(n,p)
         yield3(n,p) = 0.016*yield3(n,p)

      enddo
   enddo

   !Calculate Profits for increase in productivity

   do n = 2, modyears
      aux_p = 1
      factor = 1/((1+int)**n)
      do aux_i = 1, num_subbasins
         do p = aux_p, (aux_p + num_hruSB(SB(aux_i))-1)
            if(act(3) .eq. 1 ) then
               if (crop(p) .eq. 'CORN') then
                  PI(n,aux_i)      =      PI(n,aux_i)      +      ((yield2(n,p)-
yield2base(n,p))*hru_area(p)*corn_value)
                  PI_cc(n,aux_i)      =      PI_cc(n,aux_i)      +      ((yield1(n,p)-
yield1base(n,p))+(yield3(n,p)-yield3base(n,p))*hru_area(p)*wheat_value)
               else if(crop(p) .eq. 'SOYB') then
                  PI(n,aux_i)      =      PI(n,aux_i)      +      ((yield2(n,p)-
yield2base(n,p))*hru_area(p)*soy_value)
                  PI_cc(n,aux_i)      =      PI_cc(n,aux_i)      +      ((yield1(n,p)-
yield1base(n,p))+(yield3(n,p)-yield3base(n,p))*hru_area(p)*wheat_value)
               endif
```

```
            else
               if (crop(p) .eq. 'CORN') then
                  PI(n,aux_i) = PI(n,aux_i) + ((yield2(n,p)-
yield2base(n,p))*hru_area(p)*corn_value)
               else if(crop(p) .eq. 'SOYB') then
                  PI(n,aux_i) = PI(n,aux_i) + ((yield2(n,p)-
yield2base(n,p))*hru_area(p)*soy_value)
               endif
            endif
         enddo
         aux_p = aux_p + num_hruSB(SB(aux_i))
         if (aux_i .lt. num_subbasins) then
            if ((SB(aux_i + 1) - 1) .gt. SB(aux_i)) Then
               do p = SB(aux_i) + 1,SB(aux_i + 1) - 1
                  aux_p = aux_p + num_hruSB(p)
               enddo
            endif
         endif
         if(act(3) .eq. 1) then
            PI_cc(n,aux_i) = PI_cc(n,aux_i) * factor
            TotalPI_cc(aux_i) = TotalPI_cc(aux_i) + PI_cc(n, aux_i)
         endif
         PI(n,aux_i) = PI(n,aux_i) * factor
         TotalPI(aux_i) = TotalPI(aux_i) + PI(n,aux_i)
      enddo
   enddo


   !Calculate average savings to be use for wetlands
   do n = 1, modyears
      aux_p = 1
      do aux_i = 1, num_subbasins
         do p = aux_p, (aux_p + num_hruSB(SB(aux_i))-1)
            if(crop(p) .eq. 'CORN')then
               produc_price(n, aux_i) = produc_price(n, aux_i) + ((-
0.0072*(yield2base(n,p)**2)) + 3.036*(yield2base(n,p)) + 20.296)*hru_area(p)
            else if(crop(p) .eq. 'SOYB')then
               produc_price(n, aux_i) = produc_price(n, aux_i) + ((-
0.005*(yield2base(n,p)**2)) + 1.5274*(yield2base(n,p)) + 91.134)*hru_area(p)
            endif
         enddo
         aux_p = aux_p + num_hruSB(SB(aux_i))
         if (aux_i .lt. num_subbasins) then
            if ((SB(aux_i + 1) - 1) .gt. SB(aux_i)) Then
               do p = SB(aux_i) + 1,SB(aux_i + 1) - 1
                  aux_p = aux_p + num_hruSB(p)
```

```
            enddo
          endif
        endif
        if (BMParea(aux_i, 1) .gt. 0)then
          avg_produc_price(n, aux_i) = avg_produc_price(n, aux_i) + (produc_price(n,
aux_i)/BMParea(aux_i,1))
        endif
      enddo
    enddo

    do n = 2, modyears
      aux_p = 1
      factor = 1/((1+int)**n)
      do i = 1, num_subbasins
        do j = 1, allBMPs-2
          if(act(j) .eq. 1 .and. (j .eq. 4 .or. j .eq. 7 .or. j .eq. 8) .and. gene(j,i) .gt. 0) then
            if(j .eq. 4) then
              SP_fs(n,i) = SP_fs(n,i) + (BMParea(i, 4)*produc_price(n,i))
            endif
            if (j .eq. 7)then
              SP_bw(n,i) = SP_bw(n,i) + BMParea(i,7)*avg_produc_price(n,i)
            endif
            if(j .eq. 8)then
              SP_vaw(n,i) = SP_vaw(n,i) + BMParea(i, 8)*avg_produc_price(n,i)
            endif
          endif
        enddo
          SP(n,i) = SP(n,i) + ((SP_fs(n, i) + SP_bw(n, i)+ SP_vaw(n,i))* factor)
          TotalSP(i) = TotalSP(i) + SP(n,i)
      enddo
    enddo

    !Calculate Cash Renter rent

    do n = 2, modyears
      aux_p = 1
      factor = 1/((1+int)**n)
      do aux_i = 1, num_subbasins
        do p = aux_p, (aux_p + num_hruSB(SB(aux_i))-1)
          RR(n,aux_i) = RR(n,aux_i) + ((0.0021*((yield2(n,p))**2-(yield2base(n,p))**2)
) + (0.4078*(yield2(n,p)-yield2base(n,p)))* hru_area(aux_p))
        enddo
        if (aux_i .lt. num_subbasins) then
          if ((SB(aux_i + 1) - 1) .gt. SB(aux_i)) Then
            do p = SB(aux_i) + 1,SB(aux_i + 1) - 1
              aux_p = aux_p + num_hruSB(p)
```

```
            enddo
          endif
        endif
        RR(n,aux_i) = RR(n,aux_i) * factor
        TotalRR(aux_i) = TotalRR(aux_i) + RR(n,aux_i)
      enddo
    enddo

    !Write the outputs into a file

    open(7, file = 'Total price SB.txt', status = 'unknown')

    do i = 1, num_subbasins
      if(tenure(i) .eq. 1)then
        if(act(3) .eq. 1)then
          NPVcost(i) = cost0(i)+ net_Uniformtot(i) - TotalPI_cc(i) - TotalPI(i) - TotalSP(i)
        else
          NPVcost(i) = cost0(i)+ net_Uniformtot(i) - TotalPI(i) - TotalSP(i)
        endif
      else if(tenure(i) .eq. 2)then
          NPVcost(i) = cost0(i)+ net_Uniformtot(i) - TotalRR(i)
      else if(tenure(i) .eq. 3)then
        if(act(3) .eq. 1)then
          NPVcost(i) = cost0(i)+ net_Uniformtot(i) - ((TotalPI_cc(i) + TotalPI(i) + TotalSP(i))*fraction)
        else
          NPVcost(i) = cost0(i)+ net_Uniformtot(i) - ((TotalPI(i) + TotalSP(i))*fraction)
        endif
      endif
      TotalWatershed = TotalWatershed + NPVcost(i)
    enddo

    write(7,*) 'Total price by SB in $'
    write(7,*) TotalWatershed
    do i = 1, num_subbasins
      write(7,*)SB(i), ',', NPVcost(i)

    enddo

    end program Cost_function_v1
```

A8. Fortran algorithm for the Sediments function objective

```
!  Sediments.f90
!
```

```
!
!
!  FUNCTIONS:
!  sediments - Author: Adriana Piemonti. IUPUI. 2012
!****************************************************************************
!
!  PROGRAM: Nitrogens
!
!  PURPOSE:  Calculate the objective function for the sediment loads in the
!          evaluation of diferent BMPs. This loads are based in the difference
!          between outputs and new results from BMP usage modification
!
!****************************************************************************

   program sediments


   implicit none
   integer :: i, SubBasins, mon, modyears, k, j, dummy2, arr, dummy_reach,
numDaysUsed, lastSubBasin ,lastDay, reachdummy
   real :: area, flowi, flowo, evap, evapn, tloss, tlossn, sedia, sedin
   real :: sedo, dcon, onin, onout, opin, opout, nitratesin
   real :: totalreduc
   character :: dummy1*6
   integer, allocatable, dimension (:) :: reach
   real, allocatable, dimension (:) :: Total_dif, baseline, newmodel, sedi, sedimentsn

   SubBasins = 127
   lastSubBasin = 130 ! This is lowermost sub-basin in the watershed
   modyears = 5
   lastDay = 366 ! This the is the last day of the last month of the total simulation period.
   numDaysUsed = 1461 !These are the number of days used to do the flow calculations.
For example, 365 days in 2005 + 365 days in 2006 + 365 days in 2007 + 366 days in
2008 = 1461 days.

   open(2,file = 'Sediments_reduction.txt', status ='unknown')
   open(3, file = 'baseline.rch',status ='old')
   open(4, file = 'output.rch', status = 'old')

   read (3,*)
   read (3,*)
   read (3,*)
   read (3,*)
   read (3,*)
   read (3,*)
   read (3,*)
```

```
   read (3,*)
   read (3,*)

   read (4,*)
   read (4,*)
   read (4,*)
   read (4,*)
   read (4,*)
   read (4,*)
   read (4,*)
   read (4,*)
   read (4,*)

   arr = SubBasins*(numDaysUsed)

   allocate(reach(arr), sedi(arr), sedimentsn(arr), Total_dif(SubBasins),
baseline(SubBasins), newmodel(SubBasins))



   do i = 1, 47580  !Read Baseline year 1
      read (3,1001) dummy1, reachdummy, dummy2, mon
   enddo

   mon = 0
   do i = 1, arr
      read (3,1001)  dummy1, reach(i), dummy2, mon, area, flowi, flowo, evap, tloss,
sedia, sedi(i), dcon, onin, onout, opin, opout, nitratesin
      if (reach(i) .gt. SubBasins-1) then
         read (3,1001)  dummy1, dummy_reach
         read (3,1001)  dummy1, dummy_reach
         read (3,1001)  dummy1, dummy_reach
         if (dummy_reach .eq. lastSubBasin .and. mon .eq. lastDay)then
            go to 100
         endif
      endif
   enddo

100 baseline = 0
   do k = 1, Subbasins
      do i = 1,arr
         if (k .eq. reach(i))then
            baseline(k) = baseline(k) + sedi(i)
         endif
      enddo
   enddo
```

```
   do i = 1, 47580 !Read new output
      read (4,1001) dummy1
   enddo

   mon = 0
   do i = 1, arr
      read (4,1001)  dummy1, reach(i), dummy2, mon, area, flowi, flowo, evap, tloss,
sedia, sedimentsn(i), dcon, onin, onout, opin, opout, nitratesin
      if (reach(i) .gt. SubBasins-1) then
         read (4,1001)  dummy1, dummy_reach
         read (4,1001)  dummy1, dummy_reach
         read (4,1001)  dummy1, dummy_reach
         if (dummy_reach .eq. lastSubBasin .and. mon .eq. lastDay)then
            go to 101
         endif
      endif

   enddo

101 newmodel = 0
   do k = 1, Subbasins
      do i = 1,arr
         if (k .eq. reach(i))then
            newmodel(k) = newmodel(k) + sedimentsn(i)
         endif
      enddo
   enddo

   do k = 1, SubBasins
      Total_dif(k) = baseline(k) - newmodel(k)
      totalreduc = totalreduc + Total_dif(k)
   enddo


   write (2,*) 'Sediments reduction by subbasin in Tons'
   write (2,*) totalreduc
   do i = 1, SubBasins
      write(2,1002)i,',',Total_dif(i)
   enddo

   close(2)

1000 format (A10,1X,A10,1X,A10)
```

```
1001 format (A6,i4,1X,i8,1X,i5,20e12.4)
1002 format (I3,A1,e12.4)

   end program sediments
```

A9. Fortran algorithm for the Nitrates function objective.

```
!  Nitrogens.f90
!
!
!
!  FUNCTIONS:
!  Nitrates -  Author: Adriana Piemonti. IUPUI. 2012
!****************************************************************************
!
!  PROGRAM: Nitrogens
!
!  PURPOSE:  Calculate the objective function for the nitrates loads in the
!          evaluation of diferent BMPs. This loads are based in the difference
!          between outputs and new results from BMP usage modification
!
!****************************************************************************

   program Nitrogens

   implicit none
   integer :: i, SubBasins, mon, modyears, k, j, dummy2, arr, dummy_reach,
numDaysUsed, lastSubBasin ,lastDay, reachdummy
   real :: area, flowi, flowo, evap, evapn, tloss, tlossn, sedi, sedin
   real :: sedo, dcon, onin, onout, opin, opout, nitratesin
   real :: totalreduc
   character :: dummy1*6
   integer, allocatable, dimension (:) :: reach
   real, allocatable, dimension (:) :: Total_dif, baseline, newmodel, nitrates, nitratesn

   SubBasins = 127
   lastSubBasin = 130 ! This is lowermost sub-basin in the watershed
   modyears = 5
   lastDay = 366 ! This the is the last day of the last month of the total simulation period.
   numDaysUsed = 1461 !These are the number of days used to do the flow calculations.
For example, 365 days in 2005 + 365 days in 2006 + 365 days in 2007 + 366 days in
2008 = 1461 days.

   open(2,file = 'Nitrates_reduction.txt', status ='unknown')
   open(3, file = 'baseline.rch',status ='old')
   open(4, file = 'output.rch', status = 'old')
```

```
    read (3,*)
    read (3,*)
    read (3,*)
    read (3,*)
    read (3,*)
    read (3,*)
    read (3,*)
    read (3,*)
    read (3,*)

    read (4,*)
    read (4,*)
    read (4,*)
    read (4,*)
    read (4,*)
    read (4,*)
    read (4,*)
    read (4,*)
    read (4,*)

    arr = SubBasins*(numDaysUsed)

    allocate(reach(arr), nitrates(arr), nitratesn(arr), Total_dif(SubBasins),
baseline(SubBasins), newmodel(SubBasins))



    do i = 1, 47580  !Read Baseline year 1
       read (3,1001) dummy1, reachdummy, dummy2, mon
    enddo

    mon = 0
    do i = 1, arr
       read (3,1001)  dummy1, reach(i), dummy2, mon, area, flowi, flowo, evap, tloss,
sedi, sedo, dcon, onin, onout, opin, opout, nitratesin, nitrates(i)
       if (reach(i) .gt. SubBasins-1) then
          read (3,1001)  dummy1, dummy_reach
          read (3,1001)  dummy1, dummy_reach
          read (3,1001)  dummy1, dummy_reach
          if (dummy_reach .eq. lastSubBasin .and. mon .eq. lastDay)then
             go to 100
          endif
       endif
    enddo

100 baseline = 0
```

```
   do k = 1, Subbasins
      do i = 1,arr
         if (k .eq. reach(i))then
            baseline(k) = baseline(k) + nitrates(i)
         endif
      enddo
   enddo



   do i = 1, 47580 !Read new output
      read (4,1001) dummy1
   enddo

   mon = 0
   do i = 1, arr
      read (4,1001)  dummy1, reach(i), dummy2, mon, area, flowi, flowo, evap, tloss,
sedi, sedo, dcon, onin, onout, opin, opout, nitratesin, nitratesn(i)
      if (reach(i) .gt. SubBasins-1) then
         read (4,1001)  dummy1, dummy_reach
         read (4,1001)  dummy1, dummy_reach
         read (4,1001)  dummy1, dummy_reach
         if (dummy_reach .eq. lastSubBasin .and. mon .eq. lastDay)then
            go to 101
         endif
      endif

   enddo

101 newmodel = 0
   do i = 1,arr
      do k = 1, Subbasins
         if (k .eq. reach(i))then
            newmodel(k) = newmodel(k) + nitratesn(i)
         endif
      enddo
   enddo

   do k = 1, SubBasins
      Total_dif(k) = baseline(k) - newmodel(k)
      totalreduc = totalreduc + Total_dif(k)
   enddo


   write (2,*) 'Nitrates reduction in Kg'
   write (2,*) totalreduc
```

```
    do i = 1, SubBasins
       write(2,1002) i,',', Total_dif(i)
    enddo

    close(2)

1000 format (A10,1X,A10,1X,A10)
1001 format (A6,i4,1X,i8,1X,i5,20e12.4)
1002 format (i3,A1,e12.4)

    end program Nitrogens
```

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