Simulation of Conservation Practices Using the APEX Model

P. Tuppad, C. Santhi, X. Wang, J. R. Williams, R. Srinivasan, P. H. Gowda

Abstract. *Information on agricultural Best Management Practices (BMPs) and their effectiveness in controlling agricultural non-point source pollution is crucial in developing Clean Water Act programs such as the Total Maximum Daily Loads for impaired watersheds. A modeling study was conducted to evaluate various BMPs including pasture planting, nutrient management, brush management, clearing and range planting, prescribed grazing, critical area planting, conservation cropping, contour farming, terrace, ponds, grade stabilization structures, and grassed waterways implemented in a 280-km^2 Mill Creek Watershed in north-central Texas. The main objective of this study was to assess the long-term impacts of BMPs, at both field and subwatershed levels, on surface runoff, sediment, and nutrient losses using the Agricultural Policy/Environmental eXtender (APEX) model. Considering all BMPs, average annual reductions in runoff, sediment, total nitrogen (TN), and total phosphorus (TP) at the field level ranged from 0 to 52%, 36% to 99%, 0 to 96%, and 15% to 92%, respectively, reflecting the variability in topography, soils, landuse, climate, and relative magnitude of these constituents entering the field from upstream contributing area. However, at the subwatershed level, the reductions only ranged from 2.9% to 6.5% in runoff, 6.3% to 14.8% for sediment, 11% to 15.1% for TN, and 6.3% to 8.6% for TP. The impacts of BMPs on water quality varied depending on the type of practice and its location in the landscape. This study also showed that reduction in sediment at the watershed outlet was proportional to the area treated with BMPs.*

Keywords. *APEX, Best Management Practices (BMPs), Sediment, Nutrient, Watershed modeling.*

Agricultural Best Management Practices (BMPs) are on-farm or in-stream activities that are designed to reduce sediment, nutrients, and pesticides in drainage waters to an environmentally acceptable level while maintaining economically viable farming operations (Bottcher et al., 1995). The design and implementation are generally carried out by the United States Department of Agriculture – Natural Resources Conservation Service's (USDA-NRCS) local Soil and Water Conservation Districts (SWCDs) in response to farmers' interests. Information on the effectiveness of BMPs is necessary for decision makers to evaluate the existing conservation programs and develop new programs effectively. In field studies, there are two main ways to assess the effectiveness of BMPs: (i) assessing the trends in measured data with respect to time (Meals, 1987; Walker and Graczyk, 1993; Edwards et al., 1997; Tuppad et al., 2009a); and (ii) direct comparison of field measured data from paired fields/watersheds (Sharpley and Smith, 1994; Sharpley et al., 1996; Edwards et al., 1997; Chow et al., 1999; Bishop et al., 2005). Although field studies have been the primary way of evaluating the effects of BMPs, in recent years hydrologic/watershed simulation models have been used as an alternative approach due to time and cost-constraints in field studies. The predictive capability of simulation models in assessing future conditions and additional scenarios is highly advantageous and such capability is often needed for conservation program evaluation.

Agricultural BMPs applied to the landscape can be "structural" in nature such as terrace, grade stabilization structures, grassed waterways, and ponds or "nonstructural" such as pasture planting, brush management, nutrient management, contour farming, conservation tillage, and critical area planting. The benefits of several of these BMPs have been demonstrated through field and simulation studies. Previous studies on evaluation of BMP effectiveness along with the type of study and the study location are summarized in table 1. Additional information on BMP modeling can be found in Chen et al. (2000), Vache et al. (2002), and Gitau et al. (2005). However, not many reported documentations are available for every BMP in practice. In addition, assessing the impacts of a combination of BMPs on a complex heterogeneous watershed represents a daunting task (Meals,

Submitted for review in November 2009 as manuscript number SW 8283; approved for publication by the Soil & Water Division of ASABE in May 2010.

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Table 1. Summary of reported past studies on conservation practices.

Location	Size	Study Type	BMPs Studied	Reductions (%) Sediment	TN	Nitrate	TP	Reference	Remarks
Southern plain regions of Kansas, Oklahoma, and Texas	0.016 to 0.048 km^2	Measured data	No-till	95	75		80[a] 20[b] -183[c]	Sharpley and Smith (1994)	No-till practice is compared with conventional tillage practice. Dissolved P increased by 183% and this was attributed to possible leaching of P from decomposed crop residue and preferential transport of clay sized particles.
Riesel, Texas	0.04 to 0.084 km^2	EPIC	No-till	89		52		King et al. (1996)	
Illinois NRI cropland sites	---	EPIC	No-till	80				Phillips et al. (1993)	While there was considerably larger organic N and P losses under conventional till, nitrate N and P losses in surface runoff were higher in no-till.
Northwestern Alabama	0.038 km^2	Measured data	Conservation tillage	56	-38		-192	Soileau et al. (1994)	Increase in TN and TP is due to high runoff events that occurred during the spring following surface application of N fertilizer
Coshocton, Ohio	Paired watersheds sized 0.006 & 0.03 km^2	Measured data	Contour farming	75	63		70[b]	Weidner et al. (1969)	There was an increase in the amount of fertilizer and manure applied under contour farming condition
Grand Falls in the upper Saint John River Valley of New Brunswick, Canada		Measured data	Contoured-terraced/ grassed waterways	95				Chow et al. (1999)	Compared with conventional cultivation up-and-down the slope
Okeechobee/ Everglades basin in south Florida	5,160 km^2	Measured data	Grazing management				20	Bottcher et al. (1995)	
Agawam, Oklahoma	Paired watersheds sized 0.011 & 0.023 km^2	Measured data	Heavy grazing compared with moderate grazing	80	70		83	Smith et al. (1992)	
Ninnekah, Oklahoma	0.057 km^2	Measured data	Critical area planting	77	2		6	Smith et al. (1992)	The gullies (critical areas) comprised 11% of the watershed area. Critical area treatment included a pond at the upstream of main gully. Other critical areas in the watershed were shaped and smoothed followed by establishing Bermuda grass.
Southeastern Franklin County, Kansas	0.003 to 0.015 km^2	Measured data	No-till	60				Maski et al. (2008)	
Chickasha, Oklahoma	0.078 to 0.111 km^2	Measured data	Rotational grazing	96	55		42	Olness et al. (1980)	Compared with continuous grazing
El Reno, Oklahoma	0.016 km^2	Measured data	Pasture	99	91		94	Smith et al. (1991)	Pasture (heavily grazed) is compared to conventionally tilled cropland
Woodward, Oklahoma	Paired watersheds sized 0.027 & 0.055 km^2	Measured data	Pasture	99	98		98	Smith et al. (1991)	Pasture (moderately grazed) is compared to conventionally tilled cropland
Cyril, Oklahoma	Paired watersheds sized 0.005 & 0.023 km^2	Measured data	Pasture	97	98		98	Smith et al. (1991)	Pasture (lightly grazed) is compared to reduced tilled cropland
West Fork Watershed in Trinity River Basin, Texas	4,554 km^2	SWAT	Nutrient management	85-97	77-93		53-78	Santhi et al. (2006)	
West Fork Watershed in Trinity River Basin, Texas	4,554 km^2	SWAT	Forage harvest management	21-76	4-23		1-11	Santhi et al. (2006)	

West Fork Watershed in Trinity River Basin, Texas	4,554 km^2	SWAT	Brush management	40-64	1-37		8-42	Santhi et al. (2006)	
West Fork Watershed in Trinity River Basin, Texas	4,554 km^2	SWAT	Contour-terrace	84-86	56-59		60-65	Santhi et al. (2006)	
West Fork Watershed in Trinity River Basin, Texas	4,554 km^2	SWAT	Range seeding	97-98	89-92		77-88	Santhi et al. (2006)	
Little Washita River Basin, Oklahoma		Measured data	Land shaping, Bermuda grass establishment, and runoff detention pond	82	56		60	Sharpley et al. (1996)	
West Fork Watershed in Trinity River Basin, Texas	4,554 km^2	SWAT	Critical area planting	98-99	90-96		82-95	Santhi et al. (2006)	
West Fork Watershed in Trinity River Basin, Texas	4,554 km^2	SWAT	Grade stabilization structure	98-99	95-98		93-97	Santhi et al. (2006)	
Sand Creek Watershed in south-central Minnesota	650 km^2	ADAPT	Conventional tillage to conservation tillage	40			10	Dalzell et al. (2004)	
Lincoln Lake Watershed in north-western Arkansas	Moores Creek drainage area: 21.2 km^2 Beatty Branch drainage area: 11.2 km^2	Trend in water quality	Nutrient mgmt, pasture/ hayland mgmt, waste utilization, dead poultry composting, pond/ lagoon			34 47[d] 50[e] 58 62[d] 75[e]		Edwards et al. (1997)	
Black Earth Creek Watershed in southern Wisconsin	Brewery Creek Watershed: 27.2 km^2 Garfoot Creek Watershed: 14 km^2	Measured WQ data analysis	Conservation tillage, contour strip-cropping, streambank protection, and barnyard-runoff control	45		30[d]		Walker and Graczyk (1993)	Insufficient data was thought to be the reason for not detecting any changes in the Garfoot Creek Watershed
Nomini Creek Watershed, Virginia	14.6 km^2	Measured WQ data analysis	No-till, critical area planting, grazing land protection, diversions, and sediment retention structures	20		42[e]	35	Park et al. (1994)	
Black Creek Watershed in north-eastern Indiana	Driesbach Watershed: 6.23 km^2 Smith-Fry Watershed: 7.3 km^2	SWAT	Grassed waterways, grade stabilization structures, field borders, parallel terraces	32 16			25 10	Bracmort et al. (2006)	
Iowa	2,051 to 37,496 km^2	SWAT	Land set-asides, terraces, grassed waterways, contouring, conservation tillage, nutrient reduction	6-65		6-20	28-59	Secchi et al. (2007)	
Deep Hollow Lake, Mississippi	0.12 km^2	AnnAGNPS	No-till impoundment pasture	50 57 98				Yuan et al. (2002)	

[a] Particulate-P.
[b] Bioavailable-P.
[c] Dissolved P.
[d] NH_3-N.
[e] TKN.

1987). The Agricultural Policy/Environmental eXtender (APEX; Williams and Izaurralde, 2006) model has the capability to simulate a multitude of BMP practices. To date, a few studies have been implemented to demonstrate the use of the APEX model in simulating the impact of an extensive range of BMPs on runoff and water quality. The main objective of this study was to demonstrate the use of APEX hydrologic/water quality model to represent and assess the long-term impacts of various structural and non-structural BMPs on surface runoff, sediment, and nutrients in a complex agricultural watershed. The study does not involve use of field measured data on flow or water quality as limited data were available. Modeling results of BMP effectiveness were compared to those obtained from published field and modeling studies under similar conditions, when available.

Materials and Methods

Agricultural Policy/Environmental Extender (APEX) Model Description

The APEX model is an extension of Environmental Policy Integrated Climate (EPIC; previously referred to as "Erosion Productivity Impact Calculator") model (Williams and Sharpley, 1989), which was developed for use in whole farm/small watershed management. The model is capable of detailed field scale modeling and routing by connecting farm/field sized subareas. The EPIC/APEX models have been widely tested for their ability to simulate different agricultural management practices at both field and watershed scales (Phillips et al., 1993; King et al., 1996; Chen et al., 2000; Osei et al., 2000; Wang et al., 2005, 2006a; Saleh and Gallego, 2007; Mudgal et al., 2008; Wang et al., 2008, 2009; Yin et al., 2009). A review of the EPIC/APEX models' historical development and applications can be found in Gassman et al. (2005). Applications of APEX, including livestock manure, feedlot, pesticide, forestry, buffer strip, conservation practices, and other management or land use scenarios, are reviewed in Gassman et al. (2010). The theoretical and technical documentation of the APEX model can be found in Williams and Izaurralde (2006) and Williams et al. (2006).

Management capabilities of APEX include tillage, terraces, waterways, fertilizer and pesticide applications, manure management, buffer strips, reservoirs, crop rotation, irrigation, drainage, furrow diking, lagoons, and grazing. The model operates on a continuous basis on a daily time step. The smallest computational unit in APEX is a subarea which is homogeneous with respect to weather, topography, landuse, soil, and management. Slope within the subarea is assumed to be uniform. Each subarea is simulated using the EPIC model to predict the upland hydrology, including runoff, infiltration, percolation, lateral subsurface flow, evapotranspiration, and snow-melt. Although EPIC operates on a daily time step, the option exists for using the Green-Ampt infiltration equation to simulate rainfall excess rates at shorter time intervals (0.1 h). Also, the model offers options for simulating several other processes: five Potential EvapoTranspiration (PET) equations, seven erosion/sediment yield equations [which are variations of the Universal Soil Loss Equation (USLE)], and two peak runoff rate estimation equations. The options used in this study are given in table 2. Once the overland processes are simulated, APEX then routes water, sediment, nutrients, and pesticides across complex landscapes and channel systems to the watershed outlet. The APEX model also has groundwater and reservoir components. The routing mechanisms provide for evaluation of interactions between subareas involving surface runoff, return flow, sediment deposition and degradation, nutrient transport, and groundwater flow. Thus, flow and water quality in terms of nitrogen (soluble and organic nitrogen), phosphorus (soluble and organic phosphorus), and pesticide concentrations can be estimated for each subarea and at the watershed outlet.

Table 2. Method used in the study to compute different components.

Component	Method
Runoff	NRCS[a]-curve number (rigid estimator)
Curve number	Variable daily CN[b] soil moisture index
Peak flow	Modified rational equation rigid peak estimator
Erosion	Modified USLE[c]
Potential evapotranspiration	Hargreaves

[a] NRCS: Natural Resources Conservation Service.
[b] CN: Curve Number.
[c] USLE: Universal Soil Loss Equation.

In APEX, channel flow rate is estimated using Manning's equation assuming a trapezoidal channel. The overland flow from the subareas can only be passed to channels. However, floodplain flow and subsurface flow can be passed between subareas. Manning's equation is also used to calculate the floodplain flow velocity. The sediment routing equation in the APEX model is a variation of Bagnold's sediment transport equation (Bagnold, 1977). Reentrainment or deposition of sediments in the reach or flood plain is based on the maximum amount of sediment that can be transported.

The studies employing EPIC and APEX demonstrate that these models are suitable for simulating the impacts of climate, soil, topography, changing landuse, crop rotation, tillage, and other management practices on erosion and nutrient losses at both field and watershed scales. The APEX model is currently being used as a field-scale modeling tool to simulate various conservation practices on cultivated cropland in the Conservation Effects Assessment Project (CEAP) national assessment (Wang et al., 2006b; USDA-NRCS, 2007a). From APEX model calibration results from 14 research plots within Goodwater Creek Experimental Watershed in north central Missouri, Mudgal et al. (2008) reports coefficient of determination (R^2) values of 0.52 to 0.93 and Nash-Sutcliffe modeling efficiency (NS) values of 0.46 to 0.67 for storm events from 1997-1999. Saleh et al. (2004) reported storm event based NS values, from an uncalibrated model, of 0.84-0.88, 0.12-0.33, 0.58 to 0.84, and 0.55 to 0.67 for runoff, sediment, total N, and total P, respectively for three undisturbed control watersheds in eastern Texas. Wang et al. (2009) reports R^2 values from 0.6 to 0.8 and NS values 0.58 to 0.77 for daily runoff and sediment yield, over 22.5 km^2 Shoal Creek watershed within the Fort Hood military reservation in central Texas. The percent error between predicted and observed runoff ranged from 1.5% to 15% and between predicted and observed soil erosion ranged from 2.4% to 13% in the study by Wang et al. (2006c) over a watershed in Shaanxi Province in northwestern China. The error between the predicted and observed mean monthly surface runoff and sediment yield were within $\pm$5% during the calibration period and within $\pm$6% during the validation period over two small watersheds at the USDA Deep Loess Research station near Treynor, Iowa (Wang et al., 2008). Similarly, Yin et al. (2009) reported that the errors between the predicted and observed daily surface runoff and sediment yield were within 14% and 19%, respectively, during the calibration period and they were within -19% and $\pm$25% during the validation period in their study of three plots located in the middle Huaihe River Watershed in China. These studies emphasize that the APEX model is able to replicate the watershed hydrology and water quality response reasonable well, both uncalibrated (Saleh et al., 2004) and calibrated (Wang et al., 2006c; Wang et al., 2008, 2009; Yin et al., 2009).

Study Area

Mill Creek Watershed (MCW), 280 km^2 in area, is a subwatershed of Richland-Chambers (RC) Reservoir Watershed (5,157 km^2) (fig. 1). The RC Reservoir supplies water to a major portion of the 1.6 million people in north-central Texas. The Mill Creek, a tributary of Chambers Creek (fig. 1), is identified as one of the major contributors of sediment and nutrient loading to the stream and the RC Reservoir. In the 2006 303(d) list, Chambers Creek has been listed as a category 5c with a rank D indicating that additional data and information will be collected before a TMDL (Total Maximum Daily Load) is scheduled (TCEQ, 2006). A TMDL is the maximum amount of a pollutant that a waterbody can receive in a day and still meet water quality standards for the designated use. In the 2008 Texas Water Quality draft report (TCEQ, 2008), orthophosphorus and total phosphorus in Chambers Creek are listed as parameters of concern, for general use, based on the screening levels. The major landuses in MCW are pasture (60.5%), cropland (35.1%), and others (4.4%) including range, forest, water, and urban. Corn, grain sorghum, and winter wheat are the major crops produced in the watershed. There has been an intensive implementation of BMPs within MCW, since 1996, coordinated by TRWD in order to reduce sediment and nutrient loadings from the watershed.

Model Setup

The APEX model Ver. 0604 was used in this study. For simulation purposes, the MCW was subdivided into four subwatersheds: MC1, MC2, MC3, and MC4 (fig. 1). Each subwatershed was a site in APEX which was further divided into a number of subareas. The variations in drainage area, number of subareas, slope, soils, and portion of the subwatershed under BMPs are given in table 3. The simulated BMPs included NRCS-implemented 319-funded BMPs as well as BMPs implemented through a TRWD initiative. Model input data are given in table 4. Simulations were made for a period of 36 years from 1970 through 2005.

BMPs and their Representation in Pre-BMP and Post-BMP Conditions

A brief description of the BMPs and their representation in the APEX model is given in the sub-sections below (also see table 5). The number of parameters chosen to represent any single BMP could vary depending on the type of BMP. The parameters and their values used to represent the BMPs were selected based on the published literature, expert opinion, the processes affected by the proposed BMPs, and the model algorithms to simulate hydrologic/water quality processes. A detailed description of the practices can be found in the USDA National Handbook of Conservation Practices (USDA-NRCS, 2007b). The term ‘pre-BMP’ represents land management before implementing the BMP and ‘post-BMP’ represents land management after implementing the BMP. Pre-BMP simulation was the baseline to which post-BMP simulation results were compared.

Pasture Planting

Pasture planting is establishing and well managing native or introduced forage species on cropland, hayland, pasture land, or any other agriculture land. Besides providing forage for livestock, carefully managed pasture lands provide good

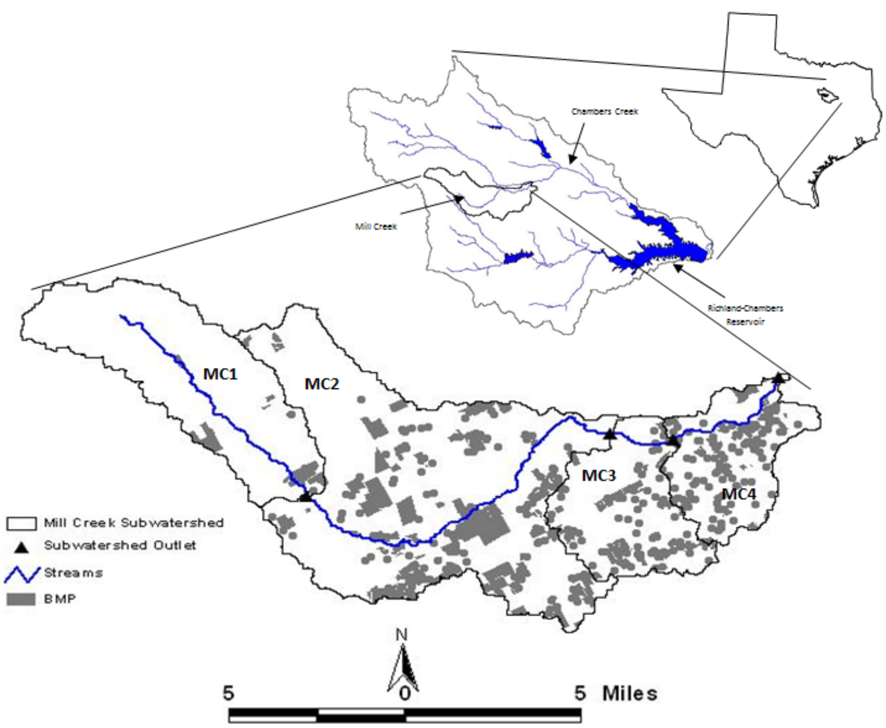

Figure 1. Location of BMPs in the Mill Creek Watershed.

Table 3. Characteristics of subwatersheds in Mill Creek (MC) Watershed.

	MC1	MC2	MC3	MC4
Area, ha	6,564	14,082	3,865	3,426
Number of subareas	438	510	476	522
Average subarea area (range), ha	15 (0.09 to 109)	28 (0.33 to 186)	8 (0.09 to 43.92)	7 (0.09 to 40)
Average slope (range), %	2.92 (0.44 to 7.86)	1.61 (0.22 to 4.33)	2.6 (0.15 to 6.35)	3.07 (0.06 to 10.03)
Dominant soils Soil type, texture %clay ,%silt	Austin Fine, silty-clay 45,48	Houston black fine, clay 30,37	Heiden fine, clay 50,28	• Trinity very fine, clay 70,21 • Heiden fine-clay 50,28 • Ferris fine, clay 53,29
Percentage of subwatershed area with BMPs	7.7	28.6	24.4	30.6

Table 4. Model input data.[a]

Data Type	Source
DEM	30-m resolution, USGS
Landuse	NLCD-USGS
Soil	SSURGO soil database, USDA-NRCS
Weather	Daily precipitation, and minimum and maximum daily temperature data from NCDC-NWS
BMP	TRWD, TSSWCB
Land management	TRWD, SWCD

[a] Acronym expansion is given below:
NCDC: National Climatic Data Center
NLCD: National Landcover Dataset
NRCS: Natural Resources Conservation Service
NWS: National Weather Service
SSURGO: Soil Survey Geographic
SWCD: Soil and Water Conservation Districts
TRWD: Tarrant Regional Water District
TSSWCB: Texas State Soil and Water Conservation Board
USDA: United States Department of Agriculture
USGS: United States Geological Survey

ground cover to reduce soil erosion and improve water quality. In the MCW, there were locations where pasture planting was implemented on the landscape which was previously cropped or was rangeland. Therefore, pre-BMP land conditions varied accordingly. The APEX model uses Landuse Number (LUN) to designate a curve number based on soil hydrologic group, landuse type, conservation practice, and cropland management decisions on surface hydrology (table 6). In both pre- and post-BMP conditions, hay was cut four times a year, which is the typical practice in the MCW area.

Nutrient Management

Nutrient management involves managing the amount, source, placement, form, and timing of nutrient applications. In the MCW, nutrient management BMP was implemented in combination with other BMPs such as pasture planting, conservation cropping, and prescribed grazing. The vegetation simulated on pastureland was Coastal Bermuda. Cropland was in a 3-year grain sorghum-winter wheat-corn rotation. In the pre-BMP condition, nutrients were applied one-time before planting and the amounts applied were based on the recommendations by the local SWCD personnel (personal communication, 13 December 2006). The APEX model has an automatic nitrogen (N) application feature which applies the user-specified amount of N fertilizer when the plant stress reaches a user-specified level. This mimics the amount, placement, and timing of the nutrient application which is the primary purpose of nutrient management. Thus, the post-BMP scenario was simulated with automatic N fertilizer application at varying amounts depending on the crop type.

Brush Management and Pasture Planting

Brush management is removal or reduction of tree and shrub species which otherwise compete with forage species for water, space, and sunlight. Land with brush vegetation is prone to erosion due to poor ground cover.

Clearing and Range Planting

Trees, stumps, brush, and other vegetation make the land unproductive. Clearing involves removing existing vegetation in order to implement a conservation plan.

Range Planting

Range planting is establishing adapted perennial vegetation on areas where vegetation cover on the ground is poor and/or is below the acceptable level for natural reseeding to occur. In some rangeland areas within the watershed, range grass was poor, resulting in inadequate vegetation cover on the ground and greater potential for erosion.

Prescribed Grazing

Overgrazing results in inadequate ground cover and exposure of soil on the land surface. Prescribed grazing is managing the harvest of vegetation with grazing animals in such a way that there is adequate cover on the ground.

Critical Area Planting

This practice consists of planting vegetation on highly erodible areas where ordinary planting methods cannot provide adequate erosion control.

Table 5. Type of BMP, and the corresponding pre- and post-BMP land management inputs and model parameters used in APEX.[a]

BMP (NRCS code)	Variable in APEX	Without BMPs (Pre-BMP)	With BMPs (Post-BMP)
Nonstructural BMPs			
Pasture planting (512)	LUN (for pasture in pre-BMP) HI	20 0.95 (95% of above ground biomass is removed)	22 0.75 (75% of above ground biomass is removed)
Nutrient management (590)	BFT FNP4 FMX	One time fertilizer application	0.8 Varied depending on the crop type 300.0
Brush management (314) Clearing (460) and either pasture planting or range planting in post-BMP	Crop type	Mesquite grown	Mesquite replaced by pasture or range grass in good condition
Range planting (550)	LUN	Poor growing range grass 20	Good range grass 22
Prescribed grazing (528)	Grazing limit	Poor growing range grass 0.5 Mg/ha	Good range grass 1.0 Mg/ha
Critical area planting (342)	LUN	Fallow land 1	Range grass in good condition 22
Conservation cropping (328)	Tillage operations	Conventional tillage	No tandem disc and chisel plow operations before planting
Contour farming (330)	PEC LUN	1.0 Based on crop type and no conservation practice	0.6 (for upland slope ≤ 2% 0.5 (for upland slope 3 - 5%) Based on crop type with contour practice
Structural BMPs			
Terrace (600)	PEC LUN	1.0 Based on crop type and no conservation practice	0.12 Based on crop type and contour-terraced conservation practice
Pond (378)	PCOF	0.0 (No pond)	Varied based on the area of the subarea (Note: assumed drainage area for pond = 5 ha)
Grade stabilization structure (GSS) (410)	Elevation, surface area, and storage at principal and emergency spillways	No reservoir	GSS added as reservoir
Waterway/Grassed waterway (412) (shaping, vegetation, and nutrient management)	LUN RCHN RCHC RFPW	20 0.05 0.2 0.0 m	22 0.25 0.001 20.0 m Extremely shallow and small channel

[a] Variable definitions are given below:
- BFT: Auto fertilizer trigger; when the plant nitrogen (N) stress level reaches BFT, N fertilizer will be applied automatically.
- FMX: Maximum annual N fertilizer applied for a crop, kg/ha.
- FNP4: Amount of fertilizer per automatically scheduled application, kg/ha.
- HI: Harvest Index., defined as the fraction of the aboveground biomass removed.
- LUN: Landuse Number from NRCS Landuse-Hydrologic Soil Group Table (for looking up Curve Number values).
- PCOF: Fraction of the subarea that drains into the pond.
- PEC: Universal Soil Loss Equation (USLE) conservation support practice factor, defined as the ratio of soil loss with a specific support practice such as terrace, contour farming to the corresponding loss with up-and-down slope cultivation.
- RCHN: Channel Mannings N of the Routing Reach.
- RCHC: Channel Cover factor of the Routing Reach, defined as the ratio of degradation from a channel with a specified vegetative cover to the corresponding degradation from a channel with no vegetative cover. The vegetation reduces the stream velocity, and further its erosive power, near the bed surface. The C-factor ranges from 0.0 to 1.0. A value of 0.0 indicates that the channel is completely protected from degradation by vegetal cover whereas a value of 1.0 indicates that there is no vegetative cover on the channel.
- RFPW: Floodplain width, m.

Conservation Cropping

Conservation cropping practice involves less tillage. It increases the residue from the crop that remains in the field after harvest through planting. In this study, conservation cropping was simulated using appropriate CN values and maintaining residue on the surface. Crop rotations and amounts of fertilizers applied in the conservation cropping practice were the same as in land under conventional tillage practice except that the intensive tillage operations such as tandem disc and chisel plow before planting and after harvest were eliminated. Mostaghimi et al. (1997) simulated conservation tillage practices using CN, C factor, surface roughness condition constant, and Manning's roughness coefficient in AGNPS.

Contour Farming

Contour farming consists of performing field operations including plowing, planting, cultivating, and harvesting, approximately, along the contour. Contouring intercepts runoff and reduces development of rills.

Table 6. Curve numbers and landuse number settings for land cover classes and soil hydrologic groups (USDA-NRCS, 2004a).

Landuse Type	Conservation Practice	Hydrologic Condition	Landuse Number (LUN)	Curve Numbers: Soil Hydrologic Group A	B	C	D
Fallow	All	All	1	77	86	91	94
Row crops	None	Poor	2	72	81	88	91
		Good	3	67	78	85	89
	Contour, strip cropping or terrace	Poor	4	70	79	84	88
		Good	5	65	75	82	86
	Two or more of contour, strip and terrace	Poor	6	66	74	80	82
		Good	7	62	71	78	81
Small grain	None	Poor	8	65	76	84	88
		Good	9	63	75	83	87
	Contour, strip or terrace	Poor	10	63	74	82	85
		Good	11	61	73	81	84
	Two or more of contour, strip and terrace	Poor	12	61	72	79	82
		Good	13	59	70	78	81
Close-seeded legume	None	Poor	14	66	77	85	89
		Good	15	58	72	81	85
	Contour, strip or terrace	Poor	16	64	75	83	85
		Good	17	55	69	78	83
	Two or more of contour, strip and terrace	Poor	18	63	73	80	83
		Good	19	51	67	76	80
Pasture or range	None	Poor	20	68	79	86	89
		Fair	21	49	69	79	84
		Good	22	39	61	74	80
	Two or more of contour, strip and terrace	Poor	23	47	67	81	88
		Fair	24	25	59	75	83
		Good	25	6	35	70	79
Woods	None	Poor	27	45	66	77	83
		Fair	28	36	60	73	79
		Good	29	25	55	70	77
Brome Grass	All	All	21	49	69	79	84
Other	All	All	0	86	86	86	86

Terrace

Terraces are broad earthen embankments or channels constructed across the slope to intercept runoff water and control erosion. Terraces decrease hill slope-length, prevent formation of gullies, and intercept and conduct runoff to a safe outlet thereby reducing sediment content in runoff water. To determine the PEC value for the post-BMP condition, waterways or graded channel outlets were considered in conjunction with terraces (table 7, column (e) x 0.2). Bracmort et al. (2006) simulated the effect of parallel terraces by modifying the curve number, USLE support factor, and slope-length. Secchi et al. (2007) also used the USLE support factor based to represent contouring and terraces.

Pond

A pond is a type of water impoundment made either by constructing a dam (called “embankment pond”) or by excavating a pit (called “excavated pond” or “pit-type pond”). Ponds serve as a source of water for livestock, fish and wildlife, fire control, and cropland and orchards. Ponds receive runoff from the upstream drainage area and aid in the settling of sediment. In this study, ponds were simulated as water bodies located within subareas, receiving inflow from a fraction of the subarea. Also, ponds were assumed to have a drainage area of 5 ha (USDA-NRCS, 2004b). The pre-BMP condition was absence of pond in the subarea.

Grade Stabilization Structure

Grade stabilization structures (GSSs) control the grade and head-cutting in natural or artificial channels to prevent the formation or advancement of gullies. Santhi et al. (2006) simulated the areas having GSSs with poor grass cover, steeper landslope, and higher cover factor (USLE C-factor) in the pre-BMP scenario. In the post-BMP scenario, they were simulated with a good grass cover, milder slopes, and lower C-factor. Bracmort et al. (2006) simulated GSSs by modifying the channel slope and channel erodibility factor in the SWAT model. Alternatively, in the present study, GSSs were simulated as reservoirs in an attempt to represent the on-ground appearance of the structure and also give due

Table 7. Conservation practice factor (PEC) for the Universal Soil Loss Equation (USLE).[a]

Farming Up and Down Slope PEC = 1.0					
For Contour Farming				PEC Factors	
	Maximum Slope Length (feet)				
(a) Land Slope (%)	(b) Contouring	(c) Strip Cropping	(d) Maximum Strip Width	(e) Contour	(f) Strip Crop
1 to 2	400	800	130	0.6	0.3
3 to 5	300	600	100	0.5	0.25
6 to 8	200	400	100	0.5	0.25
9 to12	120	240	80	0.6	0.3
13 to16	80	160	80	0.7	0.35
17 to 22	60	120	60	0.8	0.4
21 to 25	50	100	50	Too steep	0.45
For terraces			Use revised LS factor		
Loss from crop			Same PEC as contouring factor		
Loss from terrace with graded channel outlet			Contour PEC factor × 0.2		
Loss from terrace with underground outlet			Contour PEC factor × 0.1		

[a] Source: Schwab et al. (1995) originally based on Wischmeier and Smith (1978).

consideration to its intended purpose and functionality. The reservoir is considered to be located in the reach and at the outlet of the subarea. Inflow to the reservoir is derived from the subarea plus all other contributing subareas upstream of it.

Waterways/Grassed Waterways

Waterways safely conduct and dispose of overland flow from upstream areas. They are vegetated channels with increased surface roughness which reduces the velocity of flow. These combined features protect the soil against surface scouring. In the present study, waterways were almost always found in combination with terraces (represented by modifying PEC explained in the 'terrace' BMP description) but there were some cases where waterways were installed as a stand-alone management practice. In such cases, the pre-BMP channel condition was simulated as erosive. Effects of waterways were simulated by the Channel C-factor, Channel Manning's Roughness Coefficient (Channel Manning's N), and channel dimensions (table 5). Similar to the study by Bracmort et al. (2006), a Channel C-factor of 0.2 in the pre-BMP and 0.001 in the post-BMP conditions was used. Also, in the post-BMP condition, the channel was made extremely shallow with dimensions set to: depth = 0.01 m; top width = 0.5 m; bottom width = 0.1 m; and flood plain width = 20 m so that the runoff water would flow in the floodplain, mimicking the flow through an actual grassed waterway (GWW). The channel dimensions in the pre-BMP condition for GWW were about 0.7 m in depth, 1 m wide at the bottom, and 3 to 4 m wide at the top. Secchi et al. (2007) represented GWW in the SWAT model by changing the P-factor (to 0.4) and Manning's N. Mostaghimi et al. (1997) adjusted Manning's N and specified zero gully sources in AGNPS to represent GWWs.

Analysis of BMP Effectiveness

The benefits of BMPs are reported as percent reductions in key constituents including runoff, sediment, total nitrogen (TN), total phosphorus (TP), both at the subarea level (overland processes) and at the subwatershed outlet (which includes overland contribution and routing of the constituent through the stream network within the subwatershed). Constituent loadings generated in the post-BMP conditions were compared with the pre-BMP loadings to calculate the percent reduction. This approach quantifies BMP effectiveness compared to baseline and because of the limited measured data, no analysis of the absolute prediction were made. Arabi et al. (2007) showed that the uncertainty associated with estimated BMP effectiveness is substantially smaller than the uncertainty associated with the absolute prediction. The model predicted BMP effectiveness results were compared with those reported in the literature (field measured data and/or simulation modeling data), where available, and experts (USDA-NRCS, Temple, Tex., personal communication, 15 August 2007) were consulted where benefit/effectiveness information was not available.

In many cases, a BMP was present in more than one subarea having different soils and weather conditions and therefore a range in load reductions was presented. For a given BMP, this range reflected the variability in soil type, weather, and topographic characteristics of the subareas. Subarea level reductions were estimated from only those subareas where BMPs were implemented. Overall reduction in the loadings at the subwatershed outlet, including both BMP and non-BMP subareas, was also reported for all four subwatersheds.

Results and Discussion

The results presented in this article are from long-term simulation (36 years), assuming good conditions of BMP establishment and maintenance. The benefits of the BMPs in terms of percent reduction were at the edge-of-field (or field level). Also, the benefits were quantified considering the relative performance of the BMP compared with the pre-BMP condition.

Effectiveness of BMPs at Subarea Level

Subarea level annual average, minimum, and maximum values of surface runoff, sediment, TN, and TP are presented in figures 2a, 2b, 2c, and 2d, respectively. In this study watershed, some farms/fields had 'pasture planting' as the

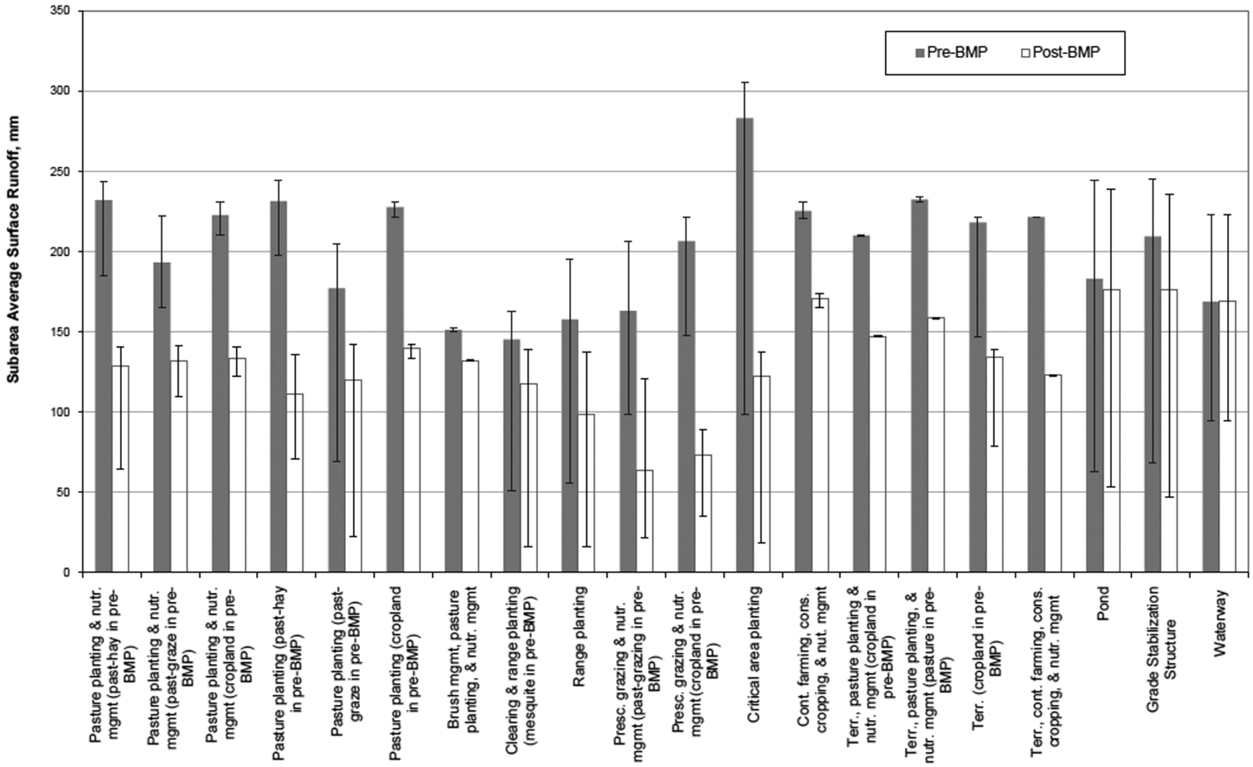

Figure 2a. The APEX model simulated subarea average surface runoff (bars) and range (minimum-maximum represented by the line through the bars) in pre- and post-BMP conditions, considering only BMP subareas (Cont.–contour; Cons.–conservation; Mgmt–management; Nutr.–nutrient; Past–pasture; Presc.–prescribed; Terr.–terrace).

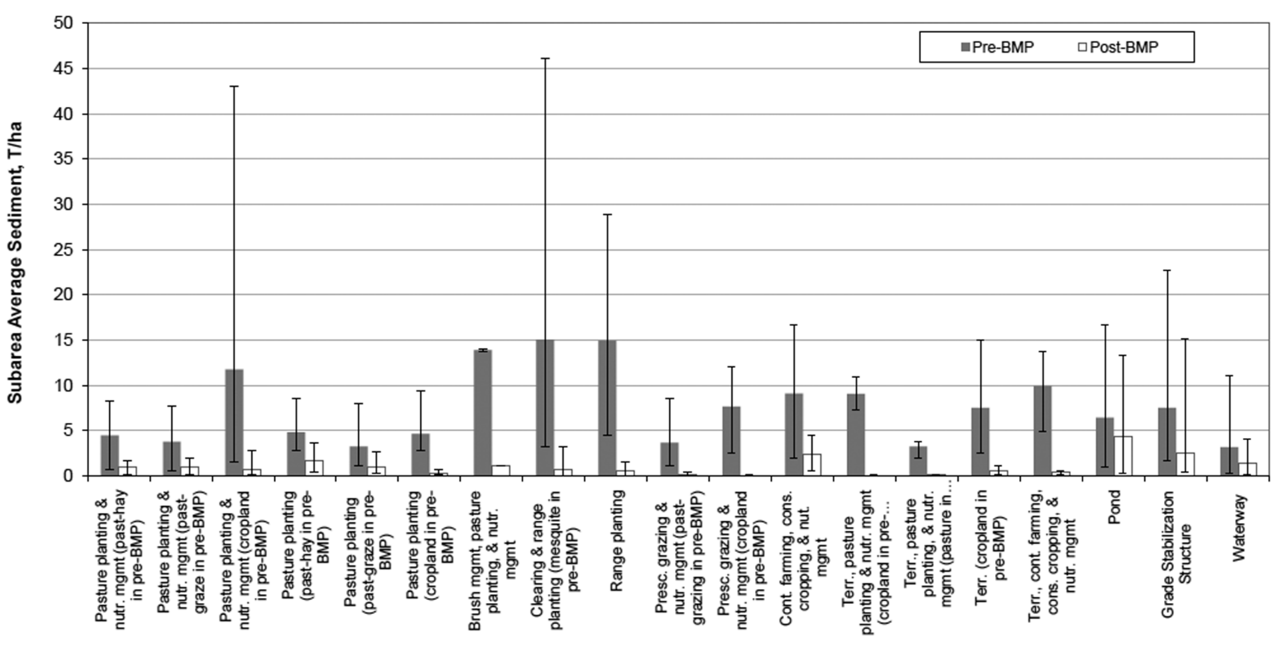

Figure 2b. The APEX model simulated subarea average sediment load (bars) and range (minimum-maximum represented by the line through the bars) in pre- and post-BMP conditions, considering only BMP subareas (Cont.–contour; Cons.–conservation; Mgmt–management; Nutr.–nutrient; Past–pasture; Presc.–prescribed; Terr.–terrace).

only BMP and some other farms/fields had pasture planting in combination with nutrient management. These BMP areas were pasture for hay or pasture that is grazed or cropland in the pre-BMP period. Overall, pasture planting reduced runoff by up to 67%, sediment by up to 95%, TN by up to 86%, and TP by up to 87% (table 8).

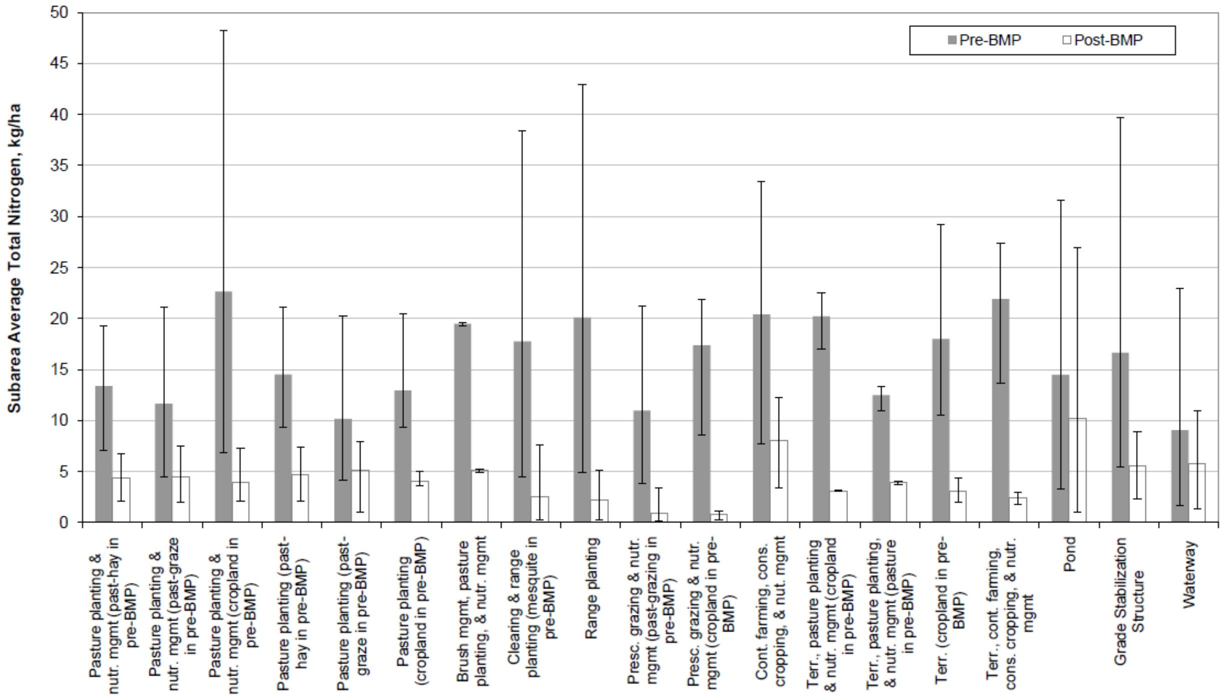

Figure 2c. The APEX model simulated subarea average total nitrogen load (bars) and range (minimum-maximum represented by the line through the bars) in pre- and post-BMP conditions, considering only BMP subareas (Cont.–contour; Cons.–conservation; Mgmt–management; Nutr.–nutrient; Past–pasture; Presc.–prescribed; Terr.–terrace).

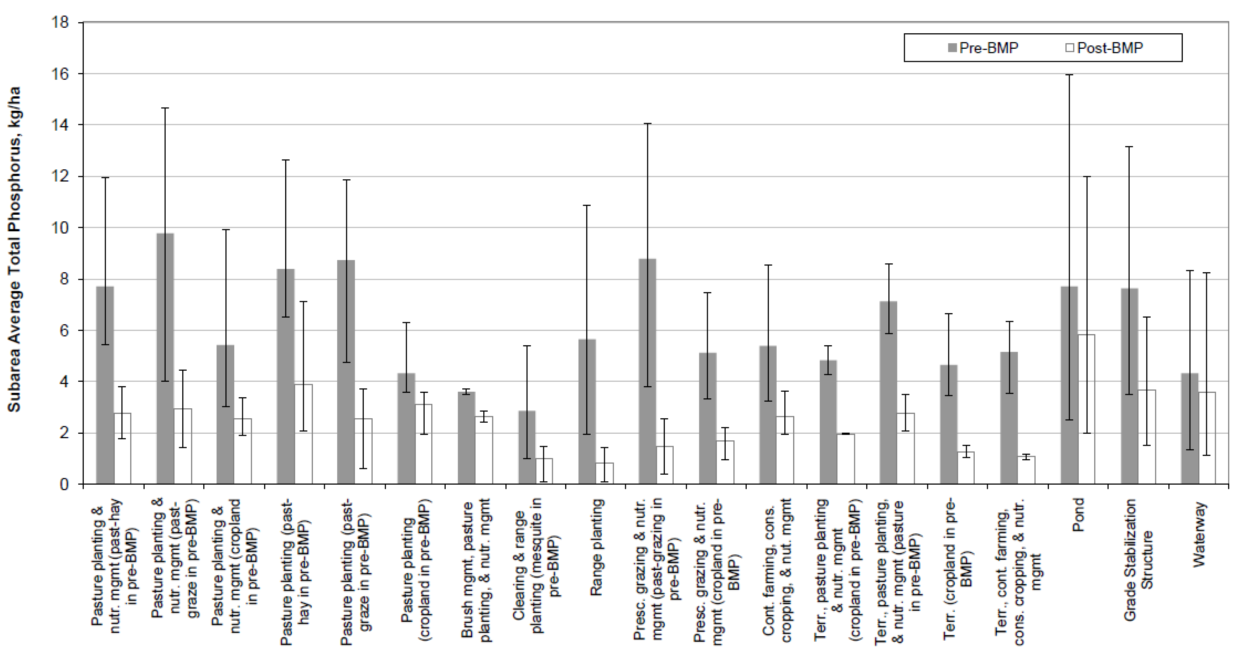

Figure 2d. The APEX model simulated subarea average total phosphorus load (bars) and range (minimum-maximum represented by the line through the bars) in pre- and post-BMP conditions, considering only BMP subareas (Cont.–contour; Cons.–conservation; Mgmt–management; Nutr.–nutrient; Past–pasture; Presc.–prescribed; Terr.–terrace).

Mesquite simulated as the pre-BMP landuse in 'brush management' and 'clearing and range planting' BMPs produced runoff ranging from 51 to 163 mm (fig. 2a). Decreased runoff generation potential for mesquite landuse is partly due to its good water use efficiency. Converting mesquite to pasture (for hay) along with nutrient management or to range grass resulted in a moderate decrease in runoff, averaging 13% and 22% (table 8), respectively. Conservation Practice Physical Effects (CPPE) by NRCS (USDA-NRCS 2007b) reports a moderate decrease in runoff due to brush management. Brush removal followed by pasture planting reduced on average 92% of sediment, 74% of TN, and 27% of TP (table 8) whereas brush removal followed by range planting resulted in a 96% reduction in

Table 8. The APEX model simulated subarea percent reduction in predicted overland runoff, and sediment and nutrient loads between pre-BMP and post-BMP conditions.

	Surface Runoff			Sediment Yield			TN			TP		
BMP Type[a]	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Pasture planting & nutr. mgmt (past-hay in pre-BMP)	45	42	65	79	76	91	67	64	79	63	53	81
Pasture planting & nutr. mgmt (past-graze in pre-BMP)	31	28	40	73	60	85	60	45	74	69	27	76
Pasture planting & nutr. mgmt (cropland in pre-BMP)	40	38	42	94	93	95	81	70	86	47	3	71
Pasture planting (past-hay in pre-BMP)	52	42	64	66	58	87	69	56	78	54	44	74
Pasture planting (past-graze in pre-BMP)	35	26	67	67	51	89	49	28	84	72	66	87
Pasture planting (cropland in pre-BMP)	39	38	40	93	93	93	67	62	76	27	13	46
Brush mgmt, pasture planting, & nutr. mgmt	13	12	13	92	92	92	74	73	75	27	19	35
Clearing & range planting (mesquite in pre-BMP)	22	15	69	96	93	99	86	78	96	66	51	92
Range planting	41	26	72	96	94	99	89	83	97	85	75	96
Presc. grazing & nutr. mgmt (past-grazing in pre-BMP)	64	42	79	97	93	100	93	83	98	84	75	92
Presc. grazing & nutr. mgmt (cropland in pre-BMP)	65	60	76	99	98	100	95	92	99	63	42	87
Critical area planting	58	54	81	99	99	100	97	96	99	92	90	99
Cont. farming, cons. cropping, & nut. mgmt	24	23	25	73	73	77	60	56	66	49	36	57
Terr., pasture planting, & nutr. mgmt (cropland in pre-BMP)	30	30	30	99	99	99	84	82	86	59	54	63
Terr., pasture planting, & nutr. mgmt (pasture in pre-BMP)	32	31	33	96	96	97	69	65	70	61	55	65
Terr. (cropland in pre-BMP)	39	37	47	93	93	94	82	77	87	72	60	79
Terr., cont. farming, cons. cropping, & nutr. mgmt	45	44	45	96	96	96	89	87	89	78	73	82
Pond	5	0	16	38	5	81	32	4	80	23	3	52
Grade stabilization structure	16	1	55	71	21	95	64	45	84	51	27	77
Waterway	0	0	0	36	0	85	25	0	69	15	0	56

[a] Cont.–contour; Cons.–conservation; Mgmt–management; Nutr.–nutrient; Past–pasture; Presc.–prescribed; Terr.–terrace.

sediment, 86% in TN, and 66% in TP. Range planting (good range grass in the post-BMP compared with poorly managed range grass in pre-BMP) reduced runoff by 26 to 72%, sediment by 94 to 99%, TN by 83 to 97%, and TP by 75 to 96% (table 8). Predicted reduction in sediment by 97 to 98%, TN by 89 to 92%, and TP by 77 to 88% as reported by Santhi et al. (2006) were in a similar range (table 1) as with those obtained in this study. Olness et al. (1980) reported average annual sediment loss of 7.3 Mg/ha and TN and TP losses of 4.0 kg/ha each from continuous grazing. In the present study, poor grazing resulted in overland sediment, TN, and TP losses of 3.6 Mg/ha, 11 kg/ha, and 9 kg/ha, respectively. Prescribed grazing reduced runoff by 65%, sediment by 99%, TN by 95%, and TP by 84% (table 8).

The APEX model predicted the highest runoff and erosion rates for areas under the 'critical area planting' BMP that were simulated as fallow during pre-BMP condition. Greater reductions were predicted for these areas under post-BMP conditions, as expected (figs. 2a and 3; table 8). Establishment of vegetation on these critically eroding areas, on average, reduced runoff by 58%, sediment by 99%, TN by 97%, and TP by 92% (table 8). These reductions were similar to those reported in Santhi et al. (2006) and Smith et al. (1992) (table 1).

Terracing and pasture planting produced moderate reductions in runoff (averaging to 32%), and substantial reductions in sediment (up to 99%), TN (up to 84%), and TP (up to 61%).

In the present study, annual average sediment loss was predicted to be in the range of 1.5 to 43 Mg/ha and TN in the range of 6.8 to 48 kg/ha from croplands with average slope of 0.15 and average annual precipitation of 950 mm. Sharpley and Smith (1994) reported sediment load ranging from 0.24 to 19.9 Mg/ha and TN ranging from 3.63 to 30 kg/ha-yr from conventionally tilled wheat areas in seven small watersheds in Oklahoma. Dalzell et al. (2004) reported a 3-Mg/ha sediment loss and 5.3 kg/ha of phosphorus loss

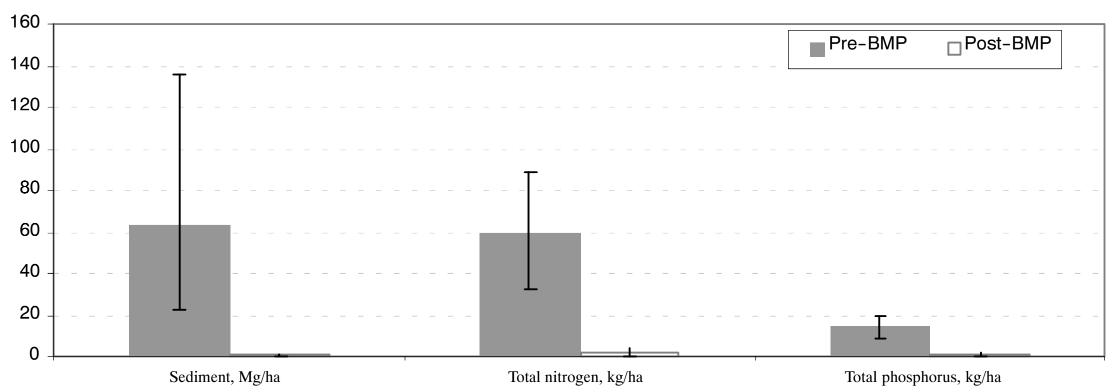

Figure 3. The APEX model simulated subarea average constituent loading (bars) and range (minimum-maximum represented by the line through the bars) from Critical area planting in pre- and post-BMP conditions, considering only BMP subareas.

from edge-of-field from CT row crops from 652-km^2 Sand Creek Watershed in south-central Minnesota.

Terraces (on cropland in both pre- and post-BMP) reduced runoff by up to 47% with an average of 39%, and resulted in reduction of sediment, TN, and TP by 93%, 82%, and 72%, respectively. Similarly, terraces in combination with contour farming, conservation cropping, and nutrient management resulted in runoff reduction, that averaged 45% (table 8). Also, this combination resulted in reductions of 96, 89, and 78% in sediment, TN, and TP, respectively. A field scale study by Chow et al. (1999) and modeling study by Santhi et al. (2006) found similar benefits (table 1).

In general, ponds did not appreciably impact runoff reduction (average of 5%). This complies with CPPE (USDA-NRCS 2007b) that reports a slight decrease in runoff due to the presence of ponds. The ponds simulated in this study were relatively small with assumed drainage areas of 5 ha and were not expected to produce much benefit in terms of pollutant load reduction. However, the presence of ponds resulted in 38% reduction in sediment, 32% in TN, and 23% in TP.

The GSSs performed well by reducing runoff by 16%, sediment by 71%, TN by 64%, and TP by 51% (table 8). These reductions followed closely the percent reductions reported in Sharpley et al. (1996). The study by Santhi et al. (2006) also found that GSS reduced sediment by 98% to 99%, TN by 95% to 98%, and TP by 93% to 97% (table 1). Waterways did not affect runoff generation potential but were effective in reducing sediments (by 36%), TN (by 25%), and TP (by 15%) (table 8).

Overall, critical area planting, which was simulated as fallow land in the pre-BMP, produced the highest annual runoff ranging from 98 to 306 mm (fig. 2a). Poor growing grass, overgrazed land, and cropland produced runoff in the range of 163 to 232 mm. The average reduction in sediment from all BMPs at the farm level ranged from 36% to 99% (table 8). No reduction in sediment was an outlier that resulted from a subarea with a waterway draining an area of 3 ha. A pond upstream of this subarea settled 48% of the sediment entering it. As a result, the sediment load entering the waterway was small without leaving any scope for further settling. Simulation results in this study showed that there was a higher percent reduction in sediment compared with reductions in runoff, TN, and TP as most of the BMPs are primarily designed to reduce the erosion potential and sediment bound nutrient losses. 'Critical area planting' pre-BMP produced the highest erosion rates followed by mesquite, range grass in poor condition, and cropland in conventional tillage practice (figs. 2b and 3).

Comparing the modeled pollution generation potential of Mill Creek Watershed with Richland-Chambers Watershed (Tuppad et al., 2009b), the overland sediment, and TN losses generated from cropland areas in Mill Creek was within the range of values predicted by the calibrated SWAT model. Annual average overland erosion was greater from the Mill Creek Watershed, as the proportion of cropland in Mill Creek Watershed is larger (35%) than that in the entire Richland-Chambers Watershed (20%). In general, there is a higher amount of sediment deposition in streams within MCW, partly because of the presence of several instream BMPs such as grassed waterways, GSSs, and ponds. The APEX model predicted sediment, TN, and TP loads at the outlet of MCW were 2.9, 8, and 4.9 kg/ha compared with the calibrated SWAT model predicted values of 4.9, 8.6, and 0.6 kg/ha at the outlet of RC Watershed.

It should be noted that for the various subareas, APEX simulations resulted in a wide range in sediment loads as evidenced in figure 2b. For example, in the case of 'pasture planting and nutrient management (cropland in pre-BMP)' the minimum load of 1.5 Mg/ha resulted from a subarea with a slope of 0.2% whereas a subarea that produced the maximum load of 43 Mg/ha had a slope of 6.7%. Similarly, a subarea that produced 46 Mg/ha sediment in 'clearing and range planting' BMP (fig. 2b) had a slope of 8.5% and soil in hydrologic group D (high runoff and erosion potential). The predicted average annual percent reduction in TN ranged from 25% to 97% and TP ranged from 15% to 92% (table 8; figs. 2c and 2d). The range in constituent loading and their percent reduction is, primarily, due to the variations in soil type, upland slope gradient and slope-length, contributing drainage area, the magnitude of load entering the in-stream BMP structures, and geographic location with variations in weather.

Effects of BMPs at the Subwatershed Level

Simulated flow, sediment, and nutrients for BMP and non-BMP areas were used to estimate the effects of BMPs at the subwatershed level. The percent reductions in flow and nutrient loadings at four individual subwatershed outlets in the MCW after being routed through the stream network within the subwatersheds are shown in figure 4. The reductions at the subwatershed outlets were less compared to the large reductions predicted at the subarea level. Depending on the areas of BMP implementation, soils, and landuse characteristics (table 3), the percent reduction in runoff, and sediment and nutrient loads varied among the subwatersheds. Simulation results show that runoff from the four subwatersheds was reduced in the range of 2.9% to 6.5%. Sediment reduction at the subwatershed outlet ranged from 6.3% to 14.8%, TN from 11.0% to 15.1%, and TP from 6.3% to 8.6%. The reduction in sediment at the watershed outlet (fig. 4) was proportional to the area treated with BMPs. This general trend was not displayed by the other three constituents (runoff, TN, and TP) because most of the BMPs implemented were for control of erosion. Some BMPs (for example, pasture planting with nutrient management) have the additional benefit of nutrient management. MC1 had the lowest proportion of the subwatershed area with BMPs (7.7%; table 3) and the dominant BMP in MC1 was prescribed grazing with nutrient management, resulting in a higher percent reduction in total nitrogen loading. MC2, MC3, and MC4 had comparable proportions of subwatershed area treated with BMPs (table 3). Higher percent reduction in sediment and nutrients in MC4 was due to larger areas treated with BMPs, especially the 'critical area planting' BMP. All the BMPs simulated in this study except grade stabilization structures, grassed waterways, and ponds help reduce overland pollution generation.

Because of the lack of precise field information on land management such as exact amounts and dates of nutrient application, exact dates of tillage operation on a field-by-field basis, and drainage areas of ponds and grade stabilization structures, the magnitude and distribution of the inputs to the model might not be precisely captured. The CN method used to estimate runoff is used widely due to simplicity, predictability, and its responsiveness to soil type, landuse,

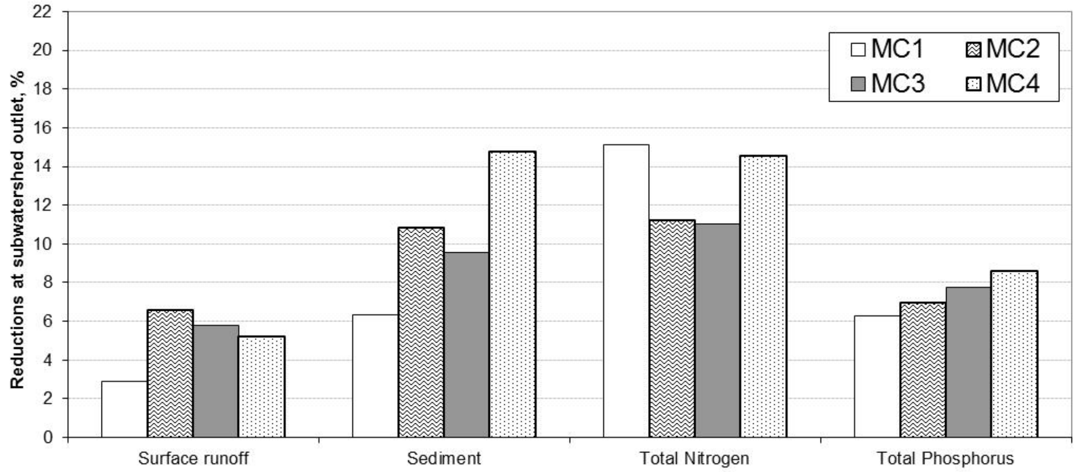

Figure 4. Percentage reduction in flow, sediment, and nutrient loadings at the outlets of the four Mill Creek subwatersheds, as simulated by the APEX model; MC1 through MC4 are the four subwatersheds in Mill Creek (MC) Watershed (see fig. 1).

and land condition, and antecedent soil moisture; although the method has no explicit provision for spatial scale effects, is sensitive to low CNs and low rainfall depths (Ponce and Hawkins, 1996), and it only considers total rainfall volume and not rainfall intensity and duration.

CONCLUSIONS

Throughout the United States, Federal and state regulatory agencies are investing substantial amounts in implementing various kinds of conservation practices and programs. Information on the quantitative benefits of water quality management programs is necessary for future planning and resource allocation. Long-term monitoring data is not available for most watersheds due to the level of expense involved in collecting such data. Also, there is not adequate documentation or literature available showing the quantitative benefits of conservation practices/BMPs at the watershed level. Within this context, a modeling study was conducted to demonstrate an approach to assess the impact of BMPs on water quantity and quality at the field and subwatershed levels.

The APEX model was used to simulate various structural and non-structural BMPs implemented in the 280-km^2 Mill Creek Watershed, a subwatershed of Richland-Chambers Watershed in north-central Texas. The BMPs simulated include pasture planting, nutrient management, brush management, clearing and range planting, prescribed grazing, critical area planting, conservation cropping, contour farming, terraces, ponds, grade stabilization structures, and waterways. The long-term impacts of BMPs on water quality in the Mill Creek Watershed were estimated by percent reduction in surface runoff, sediment, total nitrogen (TN), and total phosphorus (TP) loadings between pre-BMP (without BMP) and post-BMP (with BMP) conditions. Average annual field level reductions obtained by these BMPs (considering only BMP subareas) were 35% in runoff, 83% in sediment, 72% in TN, and 58% in TP. At the subwatershed outlets, the reductions ranged from 2.9% to 6.5% in runoff, 6.3% to 14.8% in sediment, 11% to 15.1% in TN, and 6.3% to 8.6% in TP. Increasing the areas with BMP implementation would further reduce the overland pollutant loads and the loads at the watershed outlet. More research is needed to study the impacts of additional in-stream BMPs that have the potential to reduce channel erosion and/or trap sediment and sediment-bound nutrients.

The results presented are from an uncalibrated model and perhaps, calibrating the model for measured data would improve prediction absolute values. Also, this study uses fixed values to represent a BMP adding uncertainty to the predicted pollutant reductions. A detailed investigation on the sensitivity of the BMP parameter values is highly recommended to understand the importance of BMP parameter value selection and the uncertainty in predicted impacts of the BMPs on water quantity and quality. The uncertainty could perhaps be well understood, quantified and further reduced when clear guidelines on the model parameterization to represent these BMPs will be developed based on validation using the measured data.

The modeling approach presented here can provide methods to represent the BMPs and quantitative information on BMP benefits to support projects such as the Conservation Effects Assessment Project's watershed assessment and national scale assessment that are focused on assessing the effects of conservation practices on water quality. Watershed/ water quality models represent a robust approach that can be used to predict and verify the effectiveness of existing agricultural conservation practices. They can also be used to provide supporting information for further implementation of BMPs within the watershed and to aid in the development of watershed protection plans and Total Maximum Daily Loads.

ACKNOWLEDGEMENTS

The authors acknowledge the United States Environmental Protection Agency (USEPA) 319 Non-point Source program and the Texas State Soil and Water Conservation Board (TSSWCB) for providing funding for this modeling work. Also, Mr. Todd Marek and Mr. Carl Amonett from NRCS; Mr. Darrel Andrews from TRWD, District Conservationists of Ellis, Navarro, Hill, Johnson, and Limestone Counties; Dr. Wyatte Harman from the Blackland Research and Extension Center, Temple, Texas; and Dr. Balaji Narasimhan from the Spatial Science Laboratory, Texas

A&M University, Texas are duly acknowledged for their support in providing BMP related data.

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