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Modeling the impacts of agricultural best management practices on runoff, sediment, and crop yield in an agriculture-pasture intensive watershed

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Best management practices (BMPs) are commonly used to control sediment yields. In this study, we modeled the Fort Cobb Reservoir watershed located in southwestern Oklahoma, USA using the Soil and Water Assessment Tool (SWAT) and evaluated the impacts of agricultural five different BMP scenarios on surface runoff, sediment load, and crop yield. The hydrological model with 43 sub-basins and 15,217 hydrological response units was calibrated (1991– 2000) and validated (2001– 2010) against the monthly observations of streamflow, sediment grab samples, and crop-yields. The coefficient of determination (R^2), Nash-Sutcliffe efficiency (NS) and percentage bias (PB) were used to determine model performance with satisfactory values of R^2 (0.64) and NS (0.61) in the calibration period and a good model performance ($R^2 = 0.79$; NS = 0.62) in the validation period for streamflow. We found that contouring practice reduced surface runoff by more than 18% in both conservation tillage and no-till practices for all crops. In addition, contour farming with either conservation tillage or no-till practice reduced sediment yield by almost half. Compared to the conservation tillage practice, no-till system decreased sediment yield by 25.3% and 9.0% for cotton and grain sorghum, respectively. Using wheat as cover crop for grain sorghum generated the lowest runoff followed by its rotation with canola and cotton regardless of contouring. Converting all the crops in the watershed into Bermuda grass resulted significant reduction in sediment yield (72.5-96.3%) and surface runoff (6.8-38.5%). The model was capable of providing precise information for stakeholders to prioritize ecologically sound feasible BMPs at fields that are capable of reducing overland soil erosion and sediment delivery to channels while increasing crop yield.

1 Modeling the impacts of agricultural best 2 management practices on runoff, sediment, and crop 3 yield in an agriculture-pasture intensive watershed 4 5

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22 Abstract

23 Best management practices (BMPs) are commonly used to control sediment yields. In this study,
24 we modeled the Fort Cobb Reservoir watershed located in southwestern Oklahoma, USA using
25 the Soil and Water Assessment Tool (SWAT) and evaluated the impacts of agricultural five
26 different BMP scenarios on surface runoff, sediment load, and crop yield. The hydrological
27 model with 43 sub-basins and 15,217 hydrological response units was calibrated (1991–2000)
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29 samples, and crop-yields. The coefficient of determination (R^2), Nash-Sutcliffe efficiency (NS)
30 and percentage bias (PB) were used to determine model performance with satisfactory values of
31 R^2 (0.64) and NS (0.61) in the calibration period and a good model performance ($R^2 = 0.79$; NS
32 = 0.62) in the validation period for streamflow. We found that contouring practice reduced
33 surface runoff by more than 18% in both conservation tillage and no-till practices for all crops.
34 In addition, contour farming with either conservation tillage or no-till practice reduced sediment
35 yield by almost half. Compared to the conservation tillage practice, no-till system decreased
36 sediment yield by 25.3% and 9.0% for cotton and grain sorghum, respectively. Using wheat as
37 cover crop for grain sorghum generated the lowest runoff followed by its rotation with canola
38 and cotton regardless of contouring. Converting all the crops in the watershed into Bermuda
39 grass resulted significant reduction in sediment yield (72.5–96.3%) and surface runoff (6.8–

40 38.5%). The model was capable of providing precise information for stakeholders to prioritize
41 ecologically sound feasible BMPs at fields that are capable of reducing overland soil erosion and
42 sediment delivery to channels while increasing crop yield.

43 **Key words:** Watershed, Sediment; Runoff; Crop yield; Conservation; SWAT model;
44 Oklahoma

45

46 **Introduction**

47 Sediments, originating from land use activities including farming and urbanization, constitute
48 one of the major non-point source (NPS) pollutions and have impaired water bodies, reduced
49 reservoir capacity and lifespan, threatened drinking water supply, increased water treatment cost,
50 and reduced the overall ecosystem health globally (Abdulkareem et al., 2018; Falconer et al.,
51 2018, FAO, 2013; Simon and Klimetz, 2008; Palmieri et al., 2001). In the United States of
52 America (USA), more than 50% of water bodies are NPS impaired, with sediment ranking the
53 sixth among the leading causes of water quality impairments (United States Environmental
54 Protection Agency, 2016).

55 The Great Plains region, characterized by highly intensive agricultural production system in the
56 USA, is subject to water quality issues mostly due to agricultural NPS pollution (Osteen et al.,
57 2012). To reduce agricultural NPS pollution, several management practices including
58 conservation tillage system, are encouraged and adopted in the region. For example, Great Plains
59 Conservation Program provides financial and technical assistance as water quality protection
60 activities in the Great Plains states to ranchers and farmers who adopt total conservation
61 treatment of their entire operation. This approach has increased soil organic carbon in the Great
62 Plains (Lewis et al., 2018). It was reported that replacing just about 10–23% of conventional
63 tillage system to conservation tillage system in Great Plains, could save one billion tons of soil
64 on highly erodible lands (Bernard et al., 1996). Despite the ongoing efforts in reducing
65 agricultural NPS pollution, the water quality issues still persist in the region.

66

67 **BMPs for sediment load reduction**

68 Several studies evaluated the effectiveness of various BMPs in reducing sediment loads from
69 agricultural fields. For example, Zhang and Zhang (2011) reported that the use of sediment
70 ponds as BMPs reduced up to 54-85% sediment from field runoff in Orestimba Creek
71 Watershed, California. Lam and Fohrer (2011) found that the implementation of BMPs related to
72 extensive land use management, grazing management practice, field buffer strip, and nutrient
73 management plan reduced sediment load by 0.8% to 4.9% in a North German lowland
74 catchment. Rousseau et al. (2013) applied vegetated riparian buffer strips, precision slurry
75 application, grassland conversion of cereal and corn fields, and no-till corn in Beaurivage River
76 watershed, Quebec, Canada and found that riparian buffer strips and grassland conversion were
77 highly effective in reducing sediment yield compared to other BMPs. Maharjan et al. (2017)
78 tested three BMPs including split fertilizer application, winter cover crop cultivation, and a
79 combination of the two BMPs in the Haean catchment, South Korea and found that the

80 combination of split fertilizer application and cover crop cultivation resulted the highest positive
81 effect in terms of reduced sediment and nitrate loads and increased crop yield. Teshager et al.
82 (2017) analyzed fourteen scenarios based on systematic combinations of five BMP strategies:
83 fertilizer/manure management, changing row-crop land to perennial grass, vegetative filter strips,
84 cover crops and shallower tile drainage systems, in the Raccoon River watershed in west-central
85 Iowa, USA. Their findings suggest that planting switchgrass in half of the watershed would
86 reduce the sediment load by up to 67% and meet the drinking water standard. Yang et al. (2009)
87 estimated about 51.8-71.4% reduction in sediment loads from the Black Brook Watershed in
88 northwestern New Brunswick, Canada with the implementation of flow diversion terraces.
89 In this study, we evaluated different agricultural best management practices (BMPs) and
90 estimated changes in sediment load, surface runoff and crop yield. For this, we selected a rural
91 agricultural watershed, Fort Cobb Reservoir watershed, located in southwestern Oklahoma,
92 USA. This watershed is reported to have water quality issues related to sediment, despite of
93 BMP implementation in most parts of the watershed for years. Therefore, this study area
94 provides a good site to evaluate how sediment loads alter with the selection and placement of
95 BMPs in the watershed.

96 In the Fort Cobb Reservoir watershed, several BMPs such as contour and strip farming, terraces,
97 conversion of crop land to Bermuda pasture, reduced till and no-till farming, drop structures,
98 shelter belts, flood retarding structures, etc. have been currently implemented with about 50% of
99 the cropland under conservation tillage or minimum disturbance tillage (Garbrecht and Starks,
100 2009). Although hydrological modeling studies of this watershed are available (Storm et al.,
101 2003; Moriasi et al., 2007, 2008; Mittelstet, 2015), these studies neither included existing BMPs
102 in their studies nor assessed the effectiveness of these BMPs on water quality. The Oklahoma
103 Department of Environmental Quality recommended a conversion of 50% of the cultivated area
104 in the watershed to no-till practices to control sediment and nutrient loads (Oklahoma
105 Conservation Commission, 2015). Osei et al. (2012) compared the effects of no-till systems on
106 wheat yield with other tillage systems and found that no-till would be more profitable than
107 conventional tillage or the current mix of tillage practices in the watershed. On contrary, the
108 continuous no-till practice showed decreased wheat yield (Decker et al., 2009; Patrignani et al.,
109 2012), which could be due to increased risk of weeds and diseases cycles associated with wheat
110 production (Edwards et al., 2006). To the best of our knowledge, there are no studies available in
111 the study watershed that estimated the impact of rotation of no-till winter wheat with other viable
112 crops on sediment loads reduction.

113 Therefore, in this study we estimated the effectiveness of different possible BMPs to reduce
114 sediment loads while increasing the crop yield. To this end, first, a SWAT hydrological model
115 was developed and calibrated and validated based on streamflow, sediment, and crop yield data.
116 Then, the effectiveness of these BMPs was estimated targeted at sediment reduction and
117 maximization of crop yields.

118

119 **Materials & Methods**

120 A hydrological model of Fort Cobb Reservoir watershed that includes the target study area of
121 Five-Mile Creek sub-watershed was developed using the Soil and Water Assessment Tool
122 (SWAT) modeling framework (Arnold et al., 1998). The model was calibrated both
123 automatically and manually. The verified model was then used to study the impacts of
124 agricultural BMPs on hydrology, sediment, and crop yield of major crops. The steps used in this
125 study as illustrated in Fig. 1 are explained in the sections below.

126

127 Figure 1. Schematic representation of Best management practices (BMP) implementation in a
128 watershed

129

130 **Study area**

131 The selected study area is Five-Mile Creek sub-watershed (FMC) located within Fort Cobb
132 Reservoir watershed in southwestern Oklahoma (Fig. 2). FMC has an area of 113.05 km² with
133 land uses comprised of 50% cropland, 41% pastureland and 9% others. The major crops in FMC
134 include 30% winter wheat, 16% cotton (dryland 3.5%, irrigated 12.5%), and grain sorghum
135 (1.5%). The Five-Mile Creek is one of the four tributaries of the Fort Cobb Reservoir (Fig. 2).
136 The reservoir water quality has been of concern for decades and is included in the impaired and
137 threatened waters, 303(d) list, because of high levels of sedimentation, phosphorous, nitrogen,
138 bacteria, and ammonia caused primarily by intensive agriculture and pastoral activities
139 (Oklahoma Conservation Commission, 2009; Oklahoma Department of Environmental Quality,
140 2014). The 303(d) list comprises those waters that are in the polluted water category, for which
141 beneficial uses like drinking, aquatic habitat, industrial, recreation and use are impaired by
142 pollution. Despite several additional BMPs being implemented, the issues of sedimentation still
143 exist in the study area.

144

145 Figure 2. Five-Mile Creek sub-watershed (FMC) located within the Fort Cobb Reservoir
146 watershed. Land types, slope and soil classes and elevation maps are included.

147

148 **Hydrological model**

149 The Soil and Water Assessment Tool (SWAT) was employed to construct a hydrological model
150 of the study area using the gaging station (USGS 07325800) of the United States Geological
151 Survey as a watershed outlet. This station is the only available monitoring station with
152 continuous records of streamflow. It receives runoff from two sub-watersheds- Cobb Creek and
153 FMC sub-watersheds (Fig. 2). A ten-meter Digital Elevation Model was used for watershed
154 delineation, stream network creation and topographic information. The study area was divided
155 into spatially related 43 sub-basins with an average area of 8 km² (0.2–28 km²). The watershed
156 topography was grouped into four slope classes of 0-2%, 2-4%, 4-6%, and >6%. Existing
157 waterbodies including ponds in the watershed were obtained from U.S. Fish and Wildlife Service
158 (2014) and modeled these waterbodies as ponds in each sub-basin (Appendix A). The SSURGO
159 soil database (Soil Survey Staff, 2015), the finest resolution soil data available, was used to

160 define soil attributes in the watershed (Appendix B). The land use data were obtained from the
161 2014 crop data layer (USDA-NASS, 2014). The cultivated land cover types were further
162 separated into irrigated and non-irrigated lands based on the locations of the center pivot
163 irrigation circles. These locations were identified from the 2014 one-meter resolution aerial
164 images (<https://datagateway.nrcs.usda.gov/>). We found 30 pivot circles encompassing 13.7 km²
165 (12.1%) of irrigated land dedicated for cotton production in the FMC sub-watershed. An Overlay
166 of land use, soil and slope with respective SWAT threshold percentages of 10% for land, 10%
167 for soil and 20% for slope in each sub-basin resulted into 15,217 Hydrologic Response Units
168 (HRUs). An HRU in SWAT captures watershed diversity by combining similar land, soil and
169 slope areas in each sub-basin. In SWAT, loadings of water, sediments, and crop yield are
170 calculated first at HRU level, summed at each sub-basin and then routed to the watershed outlet.
171 These HRUs were assigned agricultural BMPs (conservation tillage, no-till, contouring, crop
172 rotation, and conversion to pasture - Bermuda grass) that are most commonly practiced in the
173 study area. Existing contour in the study watershed were identified by using aerial photographs
174 (Barber and Shortridge, 2005). The broken terraces were recognized using two-meter LiDAR
175 drainage lines from satellite imagery
176 (<https://gdg.sc.egov.usda.gov/Catalog/ProductDescription/LIDAR.html>). The HRUs with more
177 than 65% contour were classified as being terraced with contour farming. It was found that 8 km²
178 of FMC were terraces and contour without breaking, which modeling existing terraces and
179 contours resulted into 28% reduction in sediment.

180 Information about tillage type and fertilizer application for the selected crops was obtained from
181 relevant literature (Storm et al, 2006; ODEQ, 2006) and consultation with local Oklahoma State
182 University Cooperative Extension Service and Conservation District personnel (Appendix C.1-
183 9). Additionally, cattle information including cattle stocking rate (0.5 head/ha), consumed
184 biomass (3 kg/ha/day), trampled biomass (0.47 kg/ha/day) and deposited manure (1.5 kg/ha/day)
185 were obtained from other sources (USDA-NASS, 2012; Storm et al., 2006) and used in the
186 model.

187 The current climate pattern (1982-2016) in the watershed was represented by six climate
188 variables: precipitation, minimum temperature, maximum temperature, solar radiation, relative
189 humidity and wind speed. The climate data at daily scale were collected from a combination
190 sources including the USDA Agricultural Research Service (USDA-ARS)
191 (<http://globalweather.tamu.edu/>), the Oklahoma MESONET (<https://www.mesonet.org/>).
192 Between 1982 and 2016, the study area received 2.2 mm/day precipitation with daily average
193 temperature (15.8°C), solar radiation (16.9 MJ/m²), relative humidity (0.6 fractional), and wind
194 speed (4.3 m/s).

195

196 **Model calibration and validation**

197 First, the model was calibrated manually to improve the model performance based on operation
198 management parameters and associated cropping schedules and then automated iterative
199 calibration was performed using SWAT-CUP tool (Abbaspour et al., 2007) for three important

200 components: streamflow, sediment, and crop yield. Crop operation management parameters and
201 associated cropping schedules were adjusted manually. Model sensitivity was tested prior to
202 model calibration to determine the most sensitive parameters. Observed data on streamflow, crop
203 yields and sediment loads from 1990 to 2010 were used for model calibration and validation.
204 Three different statistical matrices- coefficient of determination (R^2), Nash-Sutcliffe efficiency
205 (NSE) and percent bias (Pbias) were used to evaluate the model performance.

206

207 **Streamflow**

208 Monthly streamflow observed at the USGS gaging station- Cobb Creek near Eakely gage (USGS
209 07325800) for a ten-year period (1991–2000) was used for model calibration. Prior to model
210 calibration, the sensitivity of the model to streamflow was tested in SWAT-CUP for 17
211 parameters. The p-value and t-state indicators were used to identify the most sensitive parameters
212 in the watershed. The smaller the p-value and the larger the absolute value of t-state, the more
213 sensitive the parameter is. The six parameters related to water balance: Curve number (CN), soil
214 evaporation compensation factor (ESCO), groundwater delay (GW_DELAY), deep aquifer
215 percolation fraction (RCHRG_DP), Manning's n value for the main channel (CH_N2), and
216 available water capacity of soil layer (SOL_AWC) were found to be the most sensitive
217 (Appendix D), similar to what other studies found (Moriassi et al., 2008; Storm et al., 2006).
218 According to Moriassi et al. (2015), model performance can be judged “satisfactory” for flow
219 simulations if daily, monthly, or annual $R^2 > 0.60$, $NSE > 0.50$, and $PBIAS \leq \pm 15\%$ for
220 watershed-scale models. The model was calibrated satisfactorily for streamflow with values of
221 R^2 (0.64) and NSE (0.61) and Pbias (5.1%) (Fig. 3). The validation of the model with an
222 independent set of monthly observed streamflow at the same gage station for a different ten-year
223 period (2001–2010) indicated a robust model performance with values of R^2 (0.79) and NSE
224 (0.62) and Pbias (-15%) (Fig. 3). Calibrated parameters and their final value ranges are listed in
225 Table 1.

226

227 Figure 3. Calibration and validation monthly time series (2000–2010) for observed and
228 SWAT predicted streamflow at the Cobb Creek near Eakley, Oklahoma gauging station

229

230 **Sediment**

231 Suspended sediment was calibrated for ten years (1991–2000) and validated for another ten years
232 (2001–2010) at the watershed outlet. For this, grab suspended sediment sample data that were
233 available from 2004 to 2012 (usually 1 to 3 samples per month with a few months missing) was
234 used. This grab sample data provided us an opportunity to estimate sediment loads for the time
235 period that lacked observations using sediment rating curve method as suggested by Horowitz
236 (2003). This method is a regression relationship between the observed streamflow and sediment
237 data used popularly to generate sediment information for missing period in many modeling
238 studies (Salimi et al., 2013; Shabani, 2012; Jothiprakash and Grag, 2009; Sarkar et al., 2008;
239 Gray and Simoes, 2008). A strong correlation ($R^2=0.9$) between the observed grab sample
240 sediment data and runoff in the study watershed (Fig. 4) was observed. This regression

241 relationship was used to estimate the missing sediment data for the model simulation period.
242 Then these data were used to calibrate the model by modifying ten parameters that were related
243 to sediment load (Storm et al., 2006; Moriasi et al., 2008). The model calibration with values of
244 R^2 (0.30), NSE (0.35) and Pbias (<20%), (Fig. 5) and validation with values of R^2 (0.33), NSE
245 (0.43) and Pbias (<55%) (Fig. 5) was considered acceptable. Calibrated parameters and their
246 final value ranges are listed in Table 1.

247 We found that the largest errors in sediment prediction were associated with errors of peak flow
248 estimation. This could be due to the “second storm effect” problem in hydrological models,
249 including SWAT (Abbaspour et al. 2007). The first storm event causes a larger sediment
250 transport and makes remaining surface layers difficult to mobilize. As a result, the second and
251 third storm events regardless of their event sizes, will result in smaller sediment loads. For this
252 study area, the “second storm effect” was not tested since there were no observed sediment data
253 representing flood events (May 1993, June 1995, June 2007) during model calibration-validation
254 period. The simulated sediment data failed to accurately capture these events, resulting
255 uncertainty in sediment calibration. The over-and under-estimation of sediment during flood
256 events was reported in other SWAT based studies (Oeurng et al., 2011).

257

258 Figure 4. Observed daily discharge and observed daily suspended sediment concentration
259 trend

260

261 Table 1. Streamflow and sediment calibration parameter values in study area

262

263 Figure 5. Calibration and validation monthly time series (2000–2010) for observed and
264 SWAT simulated suspended sediment concentration at the Cobb Creek near Eakley,
265 Oklahoma gauging station

266

267 **Crop yield**

268 Crop yield and biomass production affect watershed hydrology through altered erosion and water
269 balance (Hu et al. 2007; Ng et al. 2010a; Andersson et al. 2011; Nair et al. 2011). A combination
270 of the Oklahoma State University variety trial data from 2001 to 2016

271 (<http://croptrials.okstate.edu/>), and the county level data (1986–2005) obtained from the USDA

272 National Agricultural Statistics Service were used to calibrate yield of crops (winter wheat, grain
273 sorghum, cotton- both dry and irrigated) (USDA-NASS, 1986 to 2005,

274 <http://digitalprairie.ok.gov/cdm/ref/collection/stgovpub/id/11177>). The variety trial crop yields

275 were collected from sites in seven Oklahoma counties (Apache, El Reno, Homestead, Chickasha,
276 Altus, Tipton, and Thomas) that are located within and nearby the study area. A list of crop yield

277 parameters with their initial and calibrated values is provided in Appendix E.1 and E.2. In this

278 study the PB was used as an indicator to compare the SWAT simulated yield with the

279 observation. Ten crop model parameters were selected (Appendix E.1 and E.2) and their

280 associated value ranges were set based on recommendation made by Sinnathamby, et al., (2017)

281 and Nair et al. (2011). The values were then manually adjusted until the PB for the crop models

282 reached satisfactory values for cotton (-4.5%), grain sorghum (-27.3%) and winter wheat (-6.0%)
283 over the years 1986 to 2010 (Figure 4).

284

285 **Agricultural Best Management Practices Scenarios**

286 Studies identified sedimentation as one of the water quality issues in the region with the
287 associated ecological and economic impacts (Zhang et al., 2015). As a result, various agricultural
288 BMPs have been implemented in the watershed to abate sediment loading and transport (Becker,
289 2011). Despite these efforts, there are still soil erosion problem in agricultural fields causing
290 degraded water quality.

291 Often, conservation tillage and no-till practices can be employed to improve the success of new
292 cropping systems and help assure the sustainability of the land. No-till cropping systems in
293 Oklahoma have proved important resources for the economic viability of producers and
294 landowners operations (Malone, J., 2008). Conversion to no-till practices on at least half of the
295 cultivated area in the study watershed was one of the recommendations to reduce sediment and
296 nutrient loadings for this Watershed (OCC, 2015). Conservation practices such as contour and
297 strip farming, terraces, conversion of crop land to Bermuda pasture, reduced till and no-till
298 farming, drop structures, shelter belts, flood retarding structures, etc. have been currently
299 implemented in the study region as the effective BMPs for mitigating NPS pollution (Garbrecht
300 and Starks, 2009). However, records detailing types and time of installation of these management
301 practices prior to the 1990s are not readily available in either the state offices of the Natural
302 Resources Conservation Service (NRCS) or the local conservation districts. According to
303 Garbrecht and Starks (2009), 80%-90% of cropland in the study area that needed terraces, has
304 been terraced over the last 50 years. Over the last decade, about 50% of the cropland was in
305 conservation tillage or minimum disturbance tillage. In addition to these management practices,
306 gully reshaping and grad stabilization structures were implemented by conservation funds. Other
307 conservation practices have been implemented without cost sharing assistance. Also, some
308 selected channel bank sections were stabilized and some channels have been fenced to prohibit
309 cattle from eroding banks, small impoundments were constructed, and a number of gravel roads
310 were paved to control cropland erosion in this watershed. Despite these efforts, there are issues
311 of NPS pollution in the region. Therefore, we developed five scenarios that reflect the commonly
312 used agricultural BMPs in the study area and throughout the Great Plains region (Table 2). These
313 BMPs included practices of conservation tillage and no till on both contouring and no-contouring
314 along with the rotation of winter wheat with other crops. The BMPs were applied to three major
315 crops- cotton, grain sorghum and winter wheat. Because of weed and disease problems
316 associated with continuous no-till wheat, wheat was rotated/cover cropped with canola, cotton
317 and grain sorghum. A combination of land use and these five scenarios resulted into 22 SWAT
318 model simulations. In scenarios 1–4, the study area was simulated for one crop at a time by
319 converting all crops into one (for example, all crops converted to wheat and so on). In scenario 5,
320 all the cropland in the study area was converted to Bermuda grass because of its popularity in the
321 study watershed (Moriassi et al. 2008).

322

323 Table 2. Agricultural Best Management Practices (BMPs) scenarios simulated for, cotton,
324 grain sorghum and winter wheat to evaluate their impacts on hydrology, sediment and crop
325 yield in the study area
326

327 **Results**

328 **Surface runoff**

329 All five scenarios except for S3 with wheat-cotton and wheat-canola rotations and cotton in S1
330 and S3 decreased surface runoff compared with the baseline scenario (Fig. 6). When contouring
331 was applied in conservation tillage (S2), surface runoff reduced by 18.4% for cotton and grain
332 sorghum and by 19.2% for winter wheat. Similarly, implementation of contouring on the existing
333 no-till BMP (S4) led to surface runoff reduction by 18.4% (cotton and grain sorghum) and 19.4%
334 for wheat compared to the no-till BMP (S3). Between the three major crops in scenarios 1 to 4,
335 grain sorghum was the least runoff generator followed by winter wheat and cotton. When all
336 crops were converted to Bermuda grass (S5) surface runoff reduced by 31.7% as compared to
337 rest of the scenarios. Application of different grazing operations and stocking rates in S5 resulted
338 virtually the similar runoff generation (37.96 to 38.08 mm) with less than one-third of a
339 percentage point difference between them. Of the 22 combinations of agricultural BMPs
340 simulated in all five scenarios, wheat rotated with cotton under no-till resulted the highest runoff
341 followed by wheat rotated with canola. We found that there was virtually no change in surface
342 runoff between the conservation and no-till systems. But, the implementation of contouring
343 reduced surface runoff in both conservation and no-till systems.
344

345 Figure 6. Changes in surface runoff generation under different scenarios of Best
346 Management Practices

347

348 **Sediment**

349

350 Figure 7. Average annual sediment loss (tons per hectare) under each five agricultural Best
351 Management Practices scenarios compared with the baseline scenario

352

353 We found that implementation of contouring on conservation tillage (S2) and on no-till (S4)
354 reduced sediment loss nearly by half (Fig. 7 and Table 3). Between all 22 combinations of
355 BMPs, cotton was the lead contributor to sediment. For cotton, contouring on no-till practice
356 generated the least sediment (1.27 tons/ha) while the conservation tillage with no contouring
357 released most sediment (3.01 ton/ha). Wheat's contribution to sediment loss was as half as that
358 of grain sorghum and one-fourth of that of cotton (S1–S4). Wheat, under the conservation tillage
359 with contour (S2), was the least contributor of sediment (0.4 ton/ha). Rotating wheat with canola
360 was found to be the most effective in controlling sediment loss under no-till system with only
361 0.87 ton/ha loss as compared to wheat as a cover crop for cotton (2.0 ton/ha) and grain sorghum

362 (1.57 ton/ha). Converting all crops to Bermuda grass pasture with combinations of different
363 grazing time and stocking rate (S5) released only 0.10 to 0.12 ton/ha sediment. We found
364 virtually no difference in simulated sediment loss between the combination of grazing timings
365 and stocking rates applied.

366

367 Table 3. Sediment reduction in percentage as a result of contouring on conservation tillage
368 and no-till practices for cotton, grain sorghum and winter wheat

369

370 In the business-as-usual baseline scenario (BL), the four out of 11 sub-basins (#7, 15, 16, 18)
371 generated sediments at an average of 1.2–1.5 ton/ha (Fig. 8.a). These four sub-basins have
372 erosive soil texture (fine sandy loam and silty clay loam) with wheat (28.5%) and cotton (18.5%)
373 as major crops. The amount and location of sediment loadings varied between the scenarios. For
374 example, 90% of sediment load was reduced when the crops were converted to Bermuda grass
375 (Fig. 8 b), while the sediment load was increased by 76% and 135% with cotton under no-till and
376 under conservation tillage respectively (Fig. 8 e-h).

377

378 Figure 8. Sub-basin level SWAT simulated sediment loadings (tons/ha) in Five-Mile Creek
379 sub-watershed under different BMP scenarios

380

381 **Crop yield**

382 We found no significant effect of contouring and tillage systems on the simulated yields of
383 cotton, grain sorghum and winter wheat. However, we found differences in yields of these crops
384 when they were used as cover crop or in rotation. For example, under the no-till practice, the
385 yield of grain sorghum when wheat was used as a cover crop decreased by 28.4% (S3) and once
386 there was no-till plus contour farming it decreased by 14.8% (S4). It was found that
387 covering/rotation with winter wheat resulted into reduced yield for both cotton and grain
388 sorghum regardless of contouring (S3 and S4). When covering/rotated with winter wheat, cotton
389 yield decreased by 52% with or without contouring while grain sorghum yield decreased by
390 28.4% (no contour) and by 14.8% with contour (S3 and S4). This decreased yield is attributed to
391 the presence of wheat residues and lack of available soil moisture for the second crop. We found
392 that cotton yield decreased more than that of grain sorghum when wheat was used as a cover
393 crop. We found virtually no effect of stocking rate and grazing start months on pasture yield
394 (Fig. 9).

395

396 Figure 9. Crop yields under different scenarios of Best Management Practices

397

398 **Discussion**

399 Five Mile Creek is one of the main contributing sub-watersheds of the Fort Cobb Reservoir
400 watershed. It is a typical example of agriculture-pasture intensive watershed in the US Great
401 Plains that may present a test bed for simulating the impacts of agricultural activities in

402 combination with various BMPs on crop yield, water quality and quantity. In order to reduce
403 erosion in the Fort Cobb Reservoir watershed, several BMPs and conservation measures
404 including terraces, changing cropping patterns, and progressive adoption of no-till and
405 conservation tillage systems among others have been implemented (OCC, 2014). There are
406 conservation programs with financial and technical assistance available to install new tillage or
407 cropping systems in the study region (USDA, Farm Service Agency, 2016). Some farmers have
408 converted the highly erosive parts of their crop land to Bermuda grass pastureland (USDA-FSA,
409 2015). These initiatives reduced sediment loadings by three to five times as compared to the time
410 prior to 1963 (Zhang et al. 2015). Garbrecht et al. (2008) stated that there was substantial
411 reduction in sediment yield in the Five Mile Creek sub-watershed in the second half of the 20th
412 century mainly due to conversion of cropland to pasture land. However, the sediment loads in the
413 study area are still high and need to be reduced (ODEQ, 2014). Therefore, in this study, we
414 evaluated the effectiveness of agricultural BMPs on surface runoff, and crop and sediment
415 yields.

416

417 **Impacts of contouring and tillage on runoff, sediment and crop yield:**

418 Contouring and terracing are popularly used practices to control erosion in the study region
419 (Garbrecht, et al., 2009). We found that contouring with either conservation tillage or no-till
420 farming prevented sediment yield by almost half while the surface runoff was reduced by at least
421 18% in the watershed. Compared to the conservation tillage practice, no-till farming decreased
422 sediment yield by 25.3% and 9.0% for cotton and grain sorghum respectively. In several other
423 watersheds, no-till practice was found to generate less sediment yield (Dickey et al., 1983; Olson
424 et al., 2010; Parajuli et al., 2013; Sharpley and Smith, 1994). We found virtually no difference in
425 surface runoff and yields of cotton and grain sorghum between the conservation till and no till
426 practices similar to what was observed by Sharpley and Smith (1994) in the Southern Plains
427 region of Kansas, Oklahoma, and Texas. However, Fawcett et al. (1994) in their review of
428 several paired watersheds reported that conservation tillage usually led to reduced sediment and
429 surface runoff.

430

431 **Impacts of crop rotation/cover on runoff, sediment and crop yield:**

432 We found differences in runoff and crop yields as a result of crop rotation. Surface runoff
433 decreased for sorghum (-4.6% vs. -8.1% with contour) and increased for cotton (+5% regardless
434 of contouring) when these crops were rotated with winter wheat. The effect of wheat as cover
435 crop for grain sorghum generated lowest runoff followed by its rotation with canola and cotton
436 regardless of contouring. Sediment yield increased for sorghum (13.7% vs. 8.0% with contour)
437 and it decreased for cotton (11.0% regardless of contouring) when these crops were rotated with
438 winter wheat. The sediment yield was the highest for cotton followed by grain sorghum and
439 canola when rotated with winter wheat regardless of contouring.
440 Yields of both cotton and grain sorghum decreased when winter wheat was used as a cover crop.
441 Cotton yields decreased by 52.2% regardless of contouring (51% dry land cotton and 62%

442 irrigated lands cotton). Grain sorghum yields decreased by 28.4% vs. 14.8% under contour
443 farming. Winter wheat yield remained virtually the same when rotated with canola and used as a
444 cover crop for grain sorghum and cotton regardless of contouring. Osei (2016) applied three
445 conservation practices in the FCR watershed to find the optimal distribution of conservation
446 practices and indicated that no-till winter wheat production in central Oklahoma results in a
447 small cost reduction while maintaining yields and is the win-win option. But since continuous
448 no-till wheat is not possible because of weeds and other disease, it is not the good scenarios for
449 adoption.

450

451 **Impacts of crop conversion to pasture on runoff, sediment and crop yield:**

452 We found that converting all the crops in the watershed into Bermuda grass would significantly
453 reduce runoff by 6.8 to 38.5%, and decrease sediment loss by 72.5 to 96.3%. We did not find
454 major difference on surface runoff and sediment loss due to two different stocking rates (1,200
455 and 1,600) on three grazing timings. Although conversion to pasture may be costly without
456 government incentives, it leads substantial and consistent reductions in all environmental
457 indicators through reduced sediment and nutrient losses (Osei, 2016).

458 Success of the BMP installation in the FCR watershed is of interest to many groups because
459 erosion and transport of sediment and associated nutrients are common problems in the
460 surrounding agricultural watersheds (Becker, 2011). Moreover, state and federal funding has
461 supported the implementation of conservation practices in the watershed (Steiner and others,
462 2008). Boyer et al. (2017) stated that farming experience, gender and attitudes towards soil and
463 water conservation increases the total number of practices adopted. According to Tong et al.
464 (2017), negative externalities are the main challenges for adoption of conservation practices in
465 the FCR watershed, and this point indicates the need for new extension educational efforts,
466 economic incentives from government, and research efforts to reduce to negative externalities.
467 These negative effects of sediment and other NPS pollutions are not paid for by the producers
468 and landowners. Instead, downstream users (e.g. recreationists and municipal systems) face the
469 costs. The principal approach for adoption of conservation practices for reduction of NPS
470 pollution from agricultural fields in the USA is subsidizing adoption of conservation practices
471 instead of taxing inputs like sediment and phosphorous. So, there should be motivations from
472 government for landowners and producers to implement conservation practices. In this regard,
473 apart from the environmental impact of different agricultural BMPs, there should be economic
474 consideration of these management practices for selecting the most cost efficient BMPs since
475 funding agencies are better appreciating the link between farm economics and producer adoption
476 of the conservation practices.

477

478 **Conclusions**

479 We employed SWAT model to estimate changes in surface runoff, sediment load and crop-yield
480 under five different scenarios of agricultural BMPs in an agriculture-pasture intensive watershed
481 located in southwestern Oklahoma. We found that no-till system released less sediment load than

482 conservation tillage system. Compared to the conservation tillage practice, no-till system
483 decreased sediment load by 25.3% and 9.0% for cotton and grain sorghum respectively. The
484 contour farming with either conservation tillage or no-till practice significantly reduced sediment
485 load. Similarly, contour tillage practices reduced surface runoff by more than 18% in both
486 conservation tillage and no-till practices for all crops. We found varying impacts of wheat used
487 as a cover crop on surface runoff, sediment load and crop yield. We found decreased runoff for
488 grain sorghum and increased runoff for cotton when wheat was used as a cover crop with no-till
489 system. However, we found increase in sediment load for both cotton and grain sorghum when
490 no-till wheat was used as a cover crop. A hypothetical conservation scenario that converted all
491 crops to Bermuda grass pasture land reduced runoff sediment yield significantly but the
492 practicality of this scenario can be realized only with financial incentive programs.

493

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499

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695

Table 1 (on next page)

Streamflow and sediment calibration parameter values in study area

1 Table 1. Streamflow and sediment calibration parameter values in study area

Component	Parameter	Parameter value range	Calibrated value
Streamflow	V_GWQMN.gw	0.20_0.60	0.60
	V_GW_REVAP.gw	0.02_0.03	0.02
	V_REVAPMN.gw	0.50_1.50	1.38
	V_RCHRG_DP.gw	0.10_0.50	0.47
	V_GW_DELAY.gw	320_390	376
	R_CN2.mgt	-0.16_-0.13	-0.13
	V_ALPHA_BF.gw	0.80_1.00	0.95
	V_ESCO.hru	0.80_0.90	0.83
	V_EPCO.bsn	0.10_0.60	0.30
	V_CH_K1.sub	0.00_0.40	0.09
	V_SURLAG.bsn	0.50_4.00	3.05
	V_EVRCH.bsn	0.00_0.50	0.34
	V_TRNSRCH.bsn	0.00_0.10	0.10
	V_ALPHA_BNK.rte	0.60_1.00	0.84
	R_SOL_AWC(..).sol	-0.02_0.06	0.04
	V_CH_N2.rte	0.05_0.30	0.18
V_CH_K2.rte	1.85_2.15	1.98	
Sediment	R_USLE_P.mgt	-1.000_0.000	-0.240
	R_SLSUBBSN.hru	0.000_0.230	0.217
	R_USLE_K().sol	-0.500_0.300	-0.247
	V_RSDCO.bsn	0.010_0.100	0.083
	V_BIOMIX.mgt	0.000_0.300	0.297
	V_SPCON.bsn	0.000_1.000	0.009
	V_SPEXP.bsn	1.000_2.000	1.714
	V_CH_ERODMO(..).rte	0.050_0.700	0.355
	V_CH_COV1.rte	0.001_0.800	0.518
	V_CH_COV2.rte	0.001_0.800	0.332

2 Note: "R" before the parameter name stands for relative change (the parameter is multiplied by 1+value); "V" stands for
3 replacement (the parameter is replaced by a value within the range)

4

Table 2 (on next page)

Agricultural Best Management Practices (BMPs) scenarios simulated for, cotton, grain sorghum and winter wheat to evaluate their impacts on hydrology, sediment and crop yield in the study area

1 Table 2. Agricultural Best Management Practices (BMPs) scenarios simulated for, cotton,
 2 grain sorghum and winter wheat to evaluate their impacts on hydrology, sediment and crop
 3 yield in the study area

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

4 Note: Details of each scenario are provided in Appendix F

5

Table 3 (on next page)

Sediment reduction in percentage as a result of contouring on conservation tillage and no-till practices for cotton, grain sorghum and winter wheat

1 Table 3. Sediment reduction in percentage as a result of contouring on conservation tillage
2 and no-till practices for cotton, grain sorghum and winter wheat

Grain sorghum		Cotton		Wheat			
Conservation tillage	No-till	Conservation tillage	No-till	Conservation tillage	No-till (In cover cropping/rotation with)		
					Grain sorghum	Cotton	Canola
44	44	45	46	43	46	43	43

3

4

Figure 1(on next page)

Schematic representation of Best management practices (BMP) implementation in a watershed

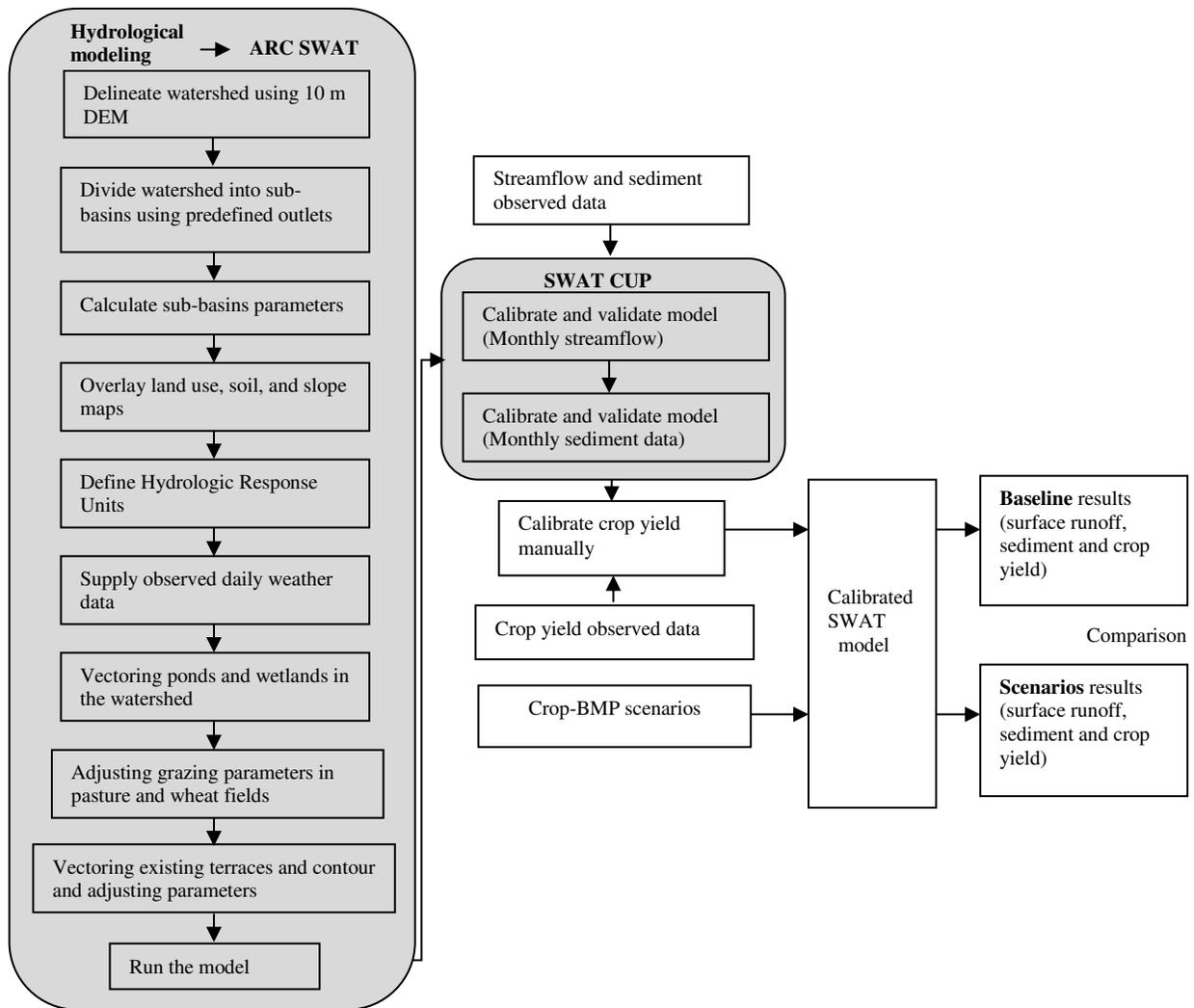


Figure 1. Schematic representation of Best management practices (BMP) implementation in a watershed

Figure 2(on next page)

Five-Mile Creek sub-watershed (FMC) located within the Fort Cobb Reservoir watershed. Land types, slope and soil classes and elevation maps are included.

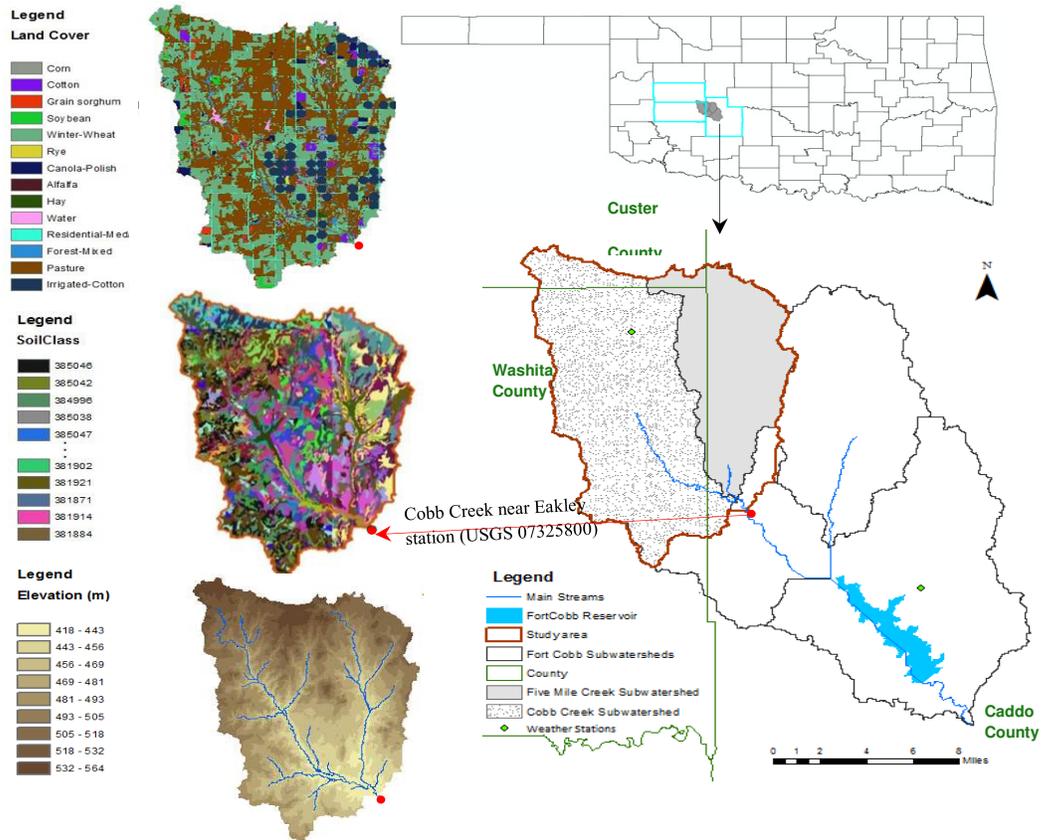


Figure 2. Five-Mile Creek sub-watershed (FMC) located within the Fort Cobb Reservoir watershed. Land types, slope and soil classes and elevation maps are included.

Figure 3(on next page)

Calibration and validation monthly time series (2000–2010) for observed and SWAT predicted streamflow at the Cobb Creek near Eakley, Oklahoma gauging station

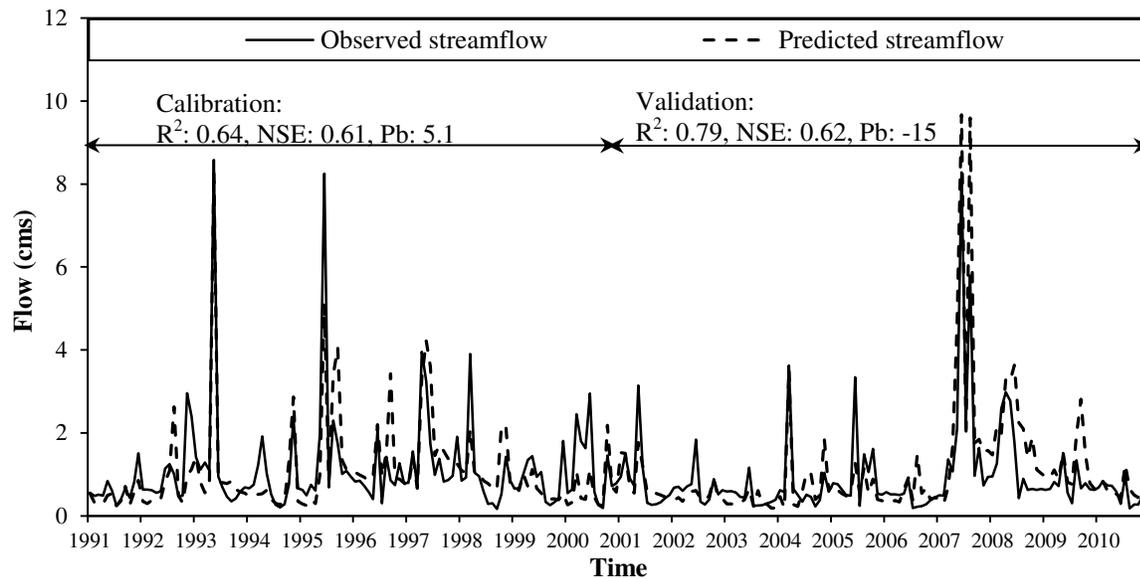


Figure 3. Calibration and validation monthly time series (2000–2010) for observed and SWAT predicted streamflow at the Cobb Creek near Eakley, Oklahoma gauging station

Figure 4 (on next page)

Observed daily discharge and observed daily suspended sediment concentration trend

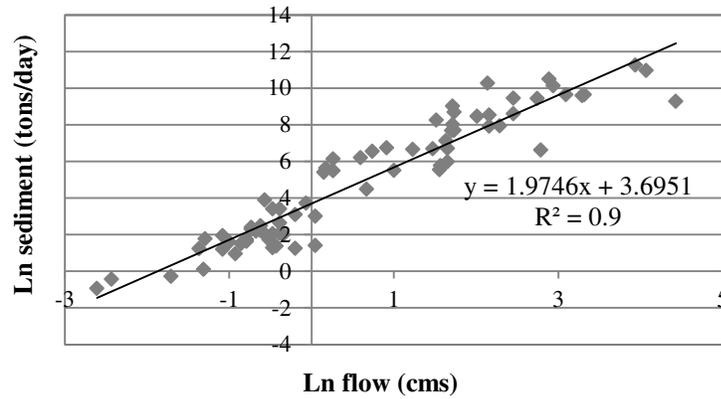


Figure 4. Observed daily discharge and observed daily suspended sediment concentration trend

Figure 5(on next page)

Calibration and validation monthly time series (2000–2010) for observed and SWAT simulated suspended sediment concentration at the Cobb Creek near Eakley, Oklahoma gauging station

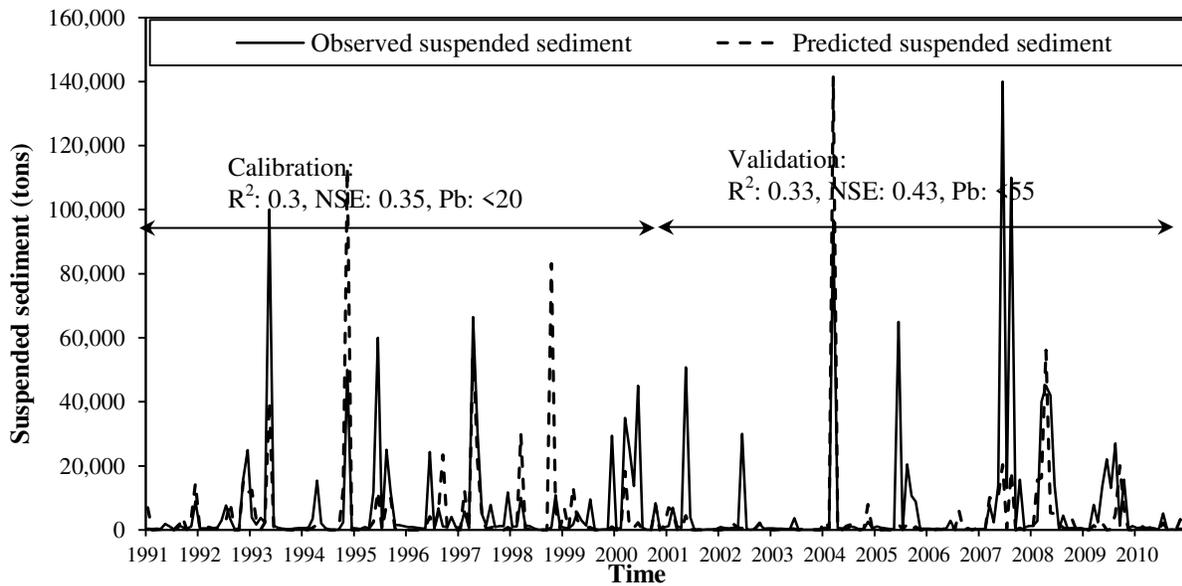


Figure 5. Calibration and validation monthly time series (2000–2010) for observed and SWAT simulated suspended sediment concentration at the Cobb Creek near Eakley, Oklahoma gauging station

Figure 6 (on next page)

Changes in surface runoff generation under different scenarios of Best Management Practices

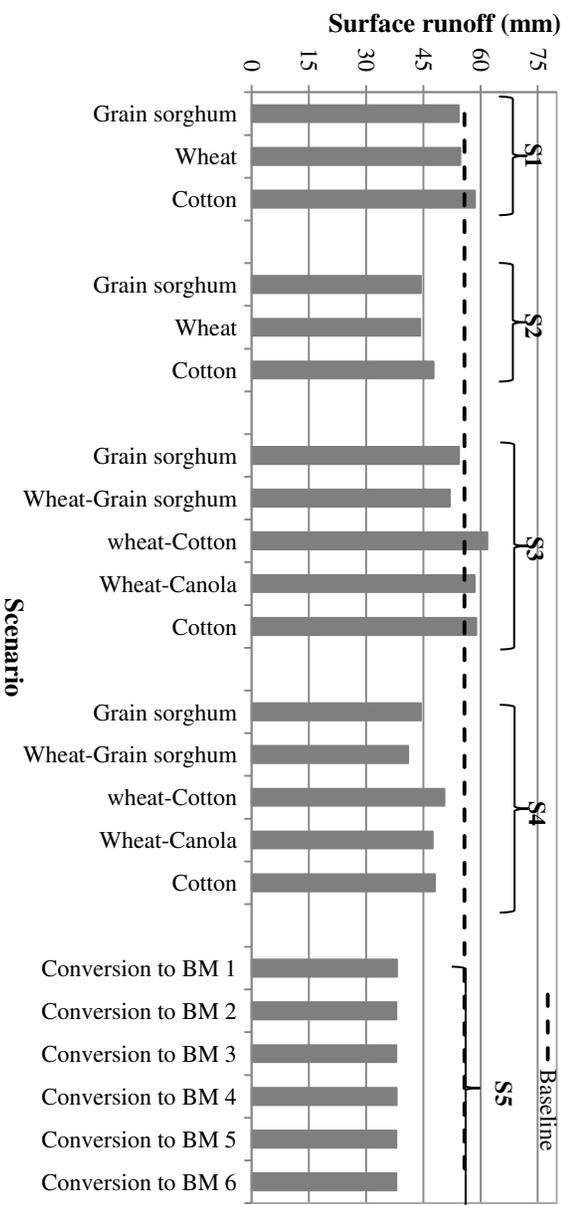


Figure 6. Changes in surface runoff generation under different scenarios of Best Management Practices

Figure 7 (on next page)

Average annual sediment loss (tons per hectare) under each five agricultural Best Management Practices scenarios compared with the baseline scenario

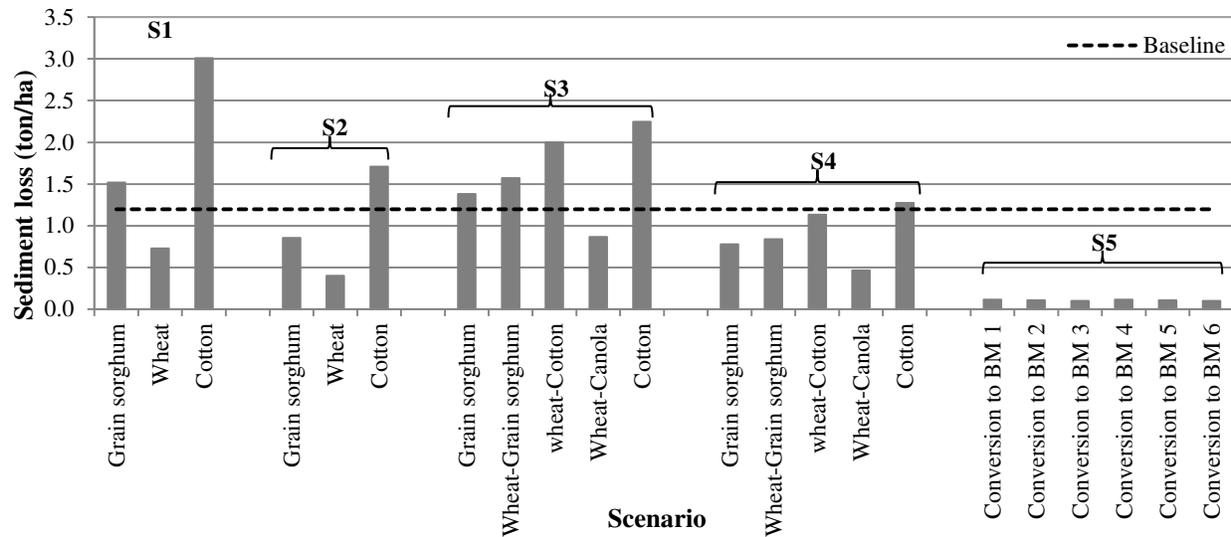


Figure 7. Average annual sediment loss (tons per hectare) under each five agricultural Best Management Practices scenarios compared with the baseline scenario

Figure 8(on next page)

Sub-basin level SWAT simulated sediment loadings (tons/ha) in Five-Mile Creek sub-watershed under different BMP scenarios

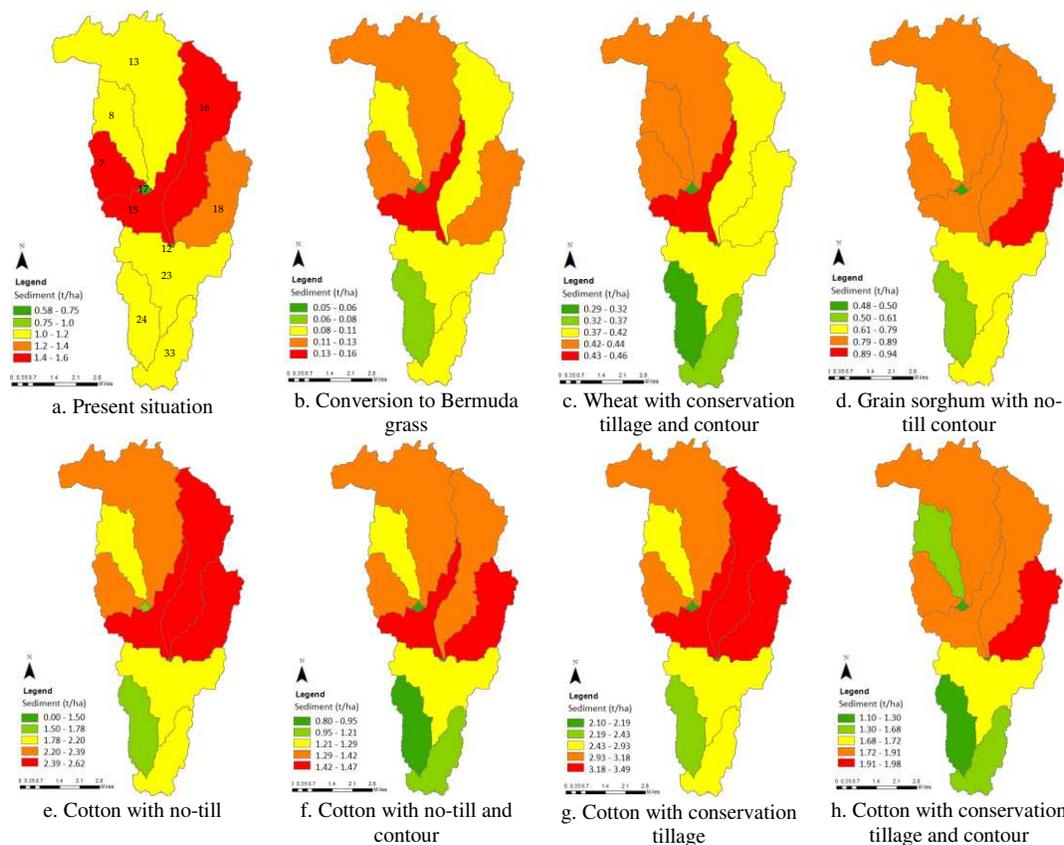


Figure 8. Sub-basin level SWAT simulated sediment loadings (tons/ha) in Five-Mile Creek sub-watershed under different BMP scenarios

Figure 9 (on next page)

Crop yields under different scenarios of Best Management Practices

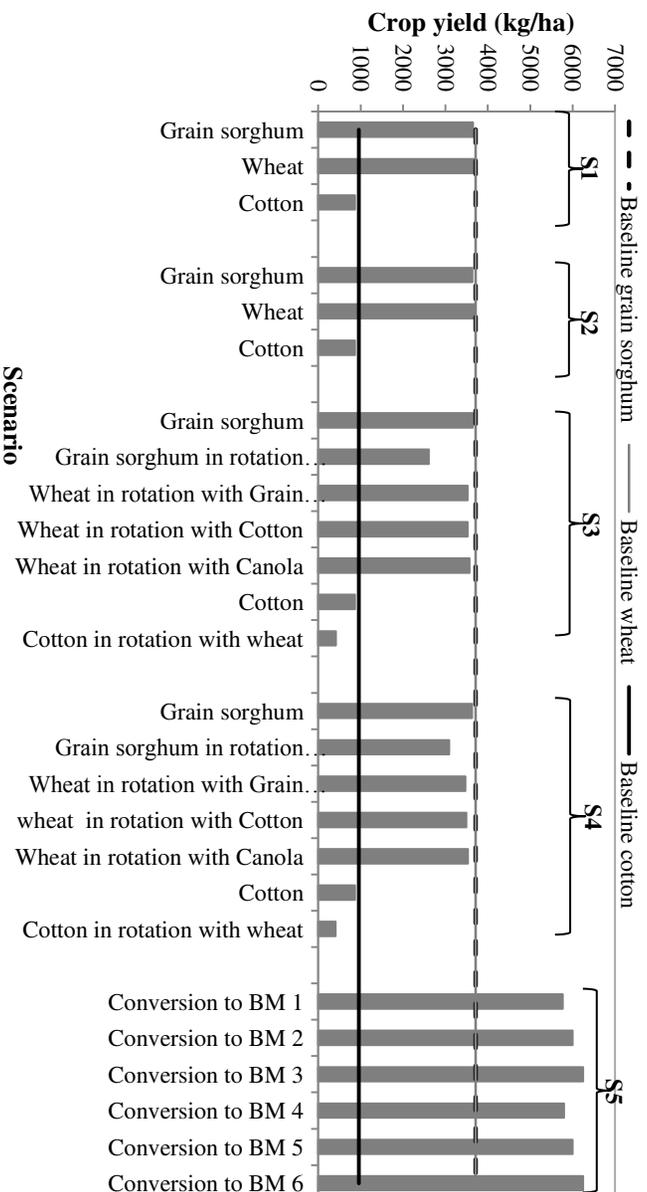


Figure 9. Crop yields under different scenarios of Best Management Practices