Crop Conversion Impacts on Runoff and Sediment Loads in a Small Watershed in Northern Iowa, United States

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PGEO 6040, *Geospatial Systems and Application*

Middle Tennessee State University

Spring 2021

1. Introduction

The principal objective of this term project is to contrast existing conditions with alternative scenarios of land use land cover (LULC) in a small watershed in north central Iowa with the application of the annualized agricultural non-point source (AnnAGNPS) model. Using data gathered from USDA along with auxiliary programs TopAGNPS, agGEM, and NITA to provide inputs for the AnnAGNPS model, six scenarios of LULC were investigated titled 'Severe,' 'Less Severe,' and 'Average' with either corn or soybeans as the chief crop for a 5-year simulation. Outputs of the existing conditions of the watershed were compared to the outputs of each scenario with the expected result that sediment and runoff load would increase with each worsening scenario.

2. Materials and Methods

2.1. Study site description

The watershed derived from digital elevation model (DEM) #70802030304 is located in northern central Iowa, between the city of Mason City in Iowa and the bottom border of Minnesota. As shown in Figure 1, the watershed encompasses the entirety of hydrological unit code (HUC) 12 Spring Creek watershed and the bottom half of HUC 12 Wharam Creek and City of Mason City-Winnebago River watersheds. For simpler purposes, the name of the study site will be the Spring Wharam Mason (SWM) watershed. The SWM watershed covers an area of 13,714 hectares and spans the counties of Cerro Gordo and Worth. The southernmost tip of the watershed, its outlet, is only 4.8 km from the county seat of Cerro Gordo county, Mason City. According to its 2010 census, the population of Mason City is 28, 079 (*Data from the 2010 Census*, n.d.), marking it as a less populated city compared to Iowa's larger cities Des Moines (203,433) and Cedar Rapids (126,326) (*GCT-PH1*, n.d.). The general land cover of the Cerro Gordo county are former wetlands that have been drained and used for farming (Dewitt, 1981). Worth County consist mainly of farmland with its principal crops as corn, soybeans, oats, hay, and pasture (Buckner, 1976). Most of these crops in Worth and Cerro Gordo counties except for soybeans are fed to the farmers' livestock (Buckner, 1976; Dewitt, 1981) since the chief sources of income are beef cattle, hogs, and dairy (Buckner, 1976). The land use of the SWM watershed in the last ten years consist mostly of corn and soybeans, as shown in Figure 2. Corn has the highest percentage of land use with the average percentage of 50.4%, followed by soybeans (36.4%), and grassland/ pasture (7.3%).

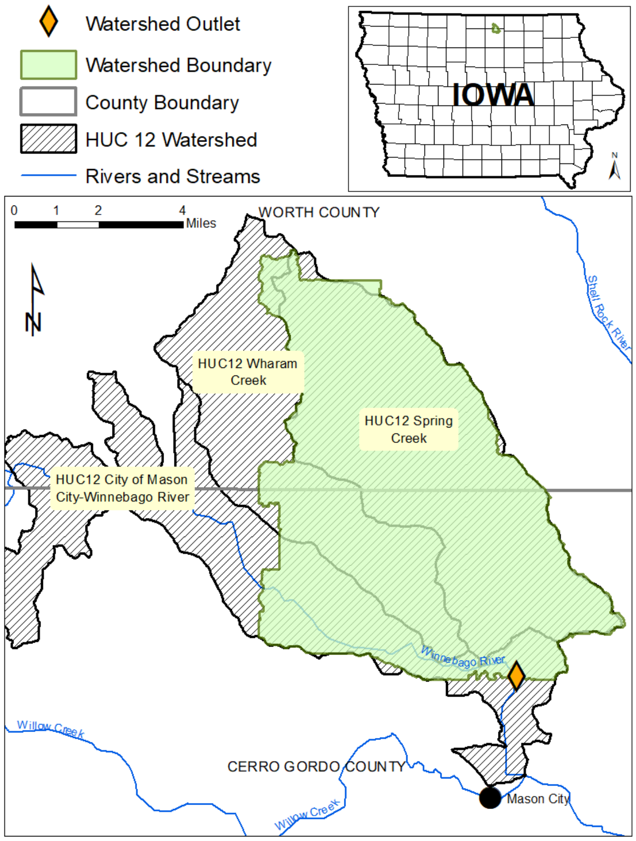

Figure 1. Location of the watershed boundary in Iowa, United States, with the respective HUC 12 watersheds it covers: Spring Creek, Wharam Creek, and City of Mason City-Winnebago River.

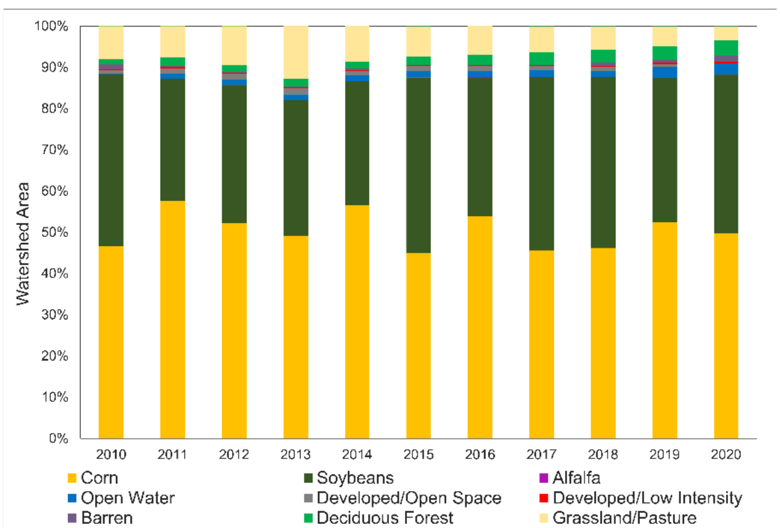

Figure 2. Column graph showing land use in the last 11 years, from 2010 – 2020, in the SWM watershed, which is derived from the discretized data of 2010 – 2020 Cropland Data Layer.

2.2. Description of the annualized agriculture non-point source pollution model

A software program called the Annualized Agriculture Non-Point Source (AnnAGNPS) was used to generate the simulation representing existing conditions and alternative scenarios of crop conversion in a small watershed in northern central Iowa. AnnAGNPS is a popular watershed model that has been designed to simulate sediment or nutrient transport and measure the impact of agricultural management practices on hydrological and water qualities in watersheds (Papanicolaou, et al, 2009; Perez-Gutierrez, et al, 2020). To correctly run a simulation in AnnAGNPS, there was a numerous effort into data collection and processing for weather, soil, topography, and land use land cover data (Figure1). Other software packages like agGEM, NITA, and TopAGNPS were also used to generate the required inputs for a successful AnnAGNPS simulation.

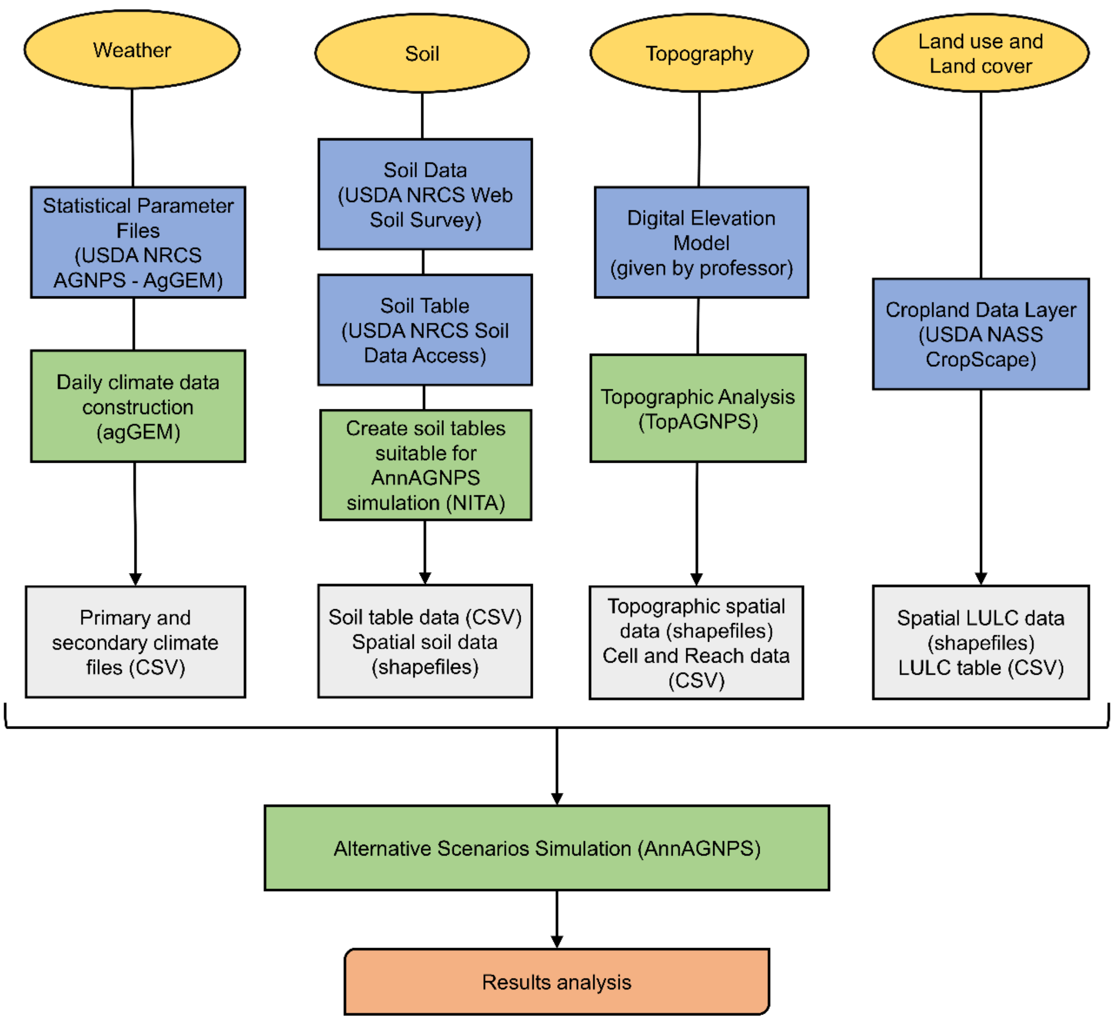

Figure 3. Flowchart describing the methodology of this report.

2.3. Spatial data collection and processing
2.3.1. Watershed delineation and subdivision

TopAGNPS, also known as TOPAZ (TOPographic PARameteriZation), was utilized to create the topographic inputs needed for AnnAGNPS simulation. TOPAZ is an automated program used to analyze digital landscape for common uses of topographic evaluation, drainage identification, watershed segmentation, and subcatchment parametrization (Garbrecht and Lawrence, 1999). Required input to run TopAGNPS software is DEM #70802030304 (which was given by the professor). DEM #70802030304 has a maximum elevation in meters of 389.217 and a minimum elevation of 318.891 with a range of slope degree from 0.000419 to 18, as portrayed in Figure 4. With the DEM input and thresholds of a critical source area value (CSA) of 30 hectares and a minimum source channel length (MSCL) in 200 meters for a TopAGNPS simulation, the SWM watershed subdivided into a total of 488 subcatchments with an average cell area value of 28.1 hectares and an average slope degree of 0.02. Total outputs from TopAGNPS include the following: channel drainage network (shapefile), watershed boundary (shapefile), watershed subcatchments (shapefile), cell data (attribute table), and reach data (attribute table). These outputs were copied to folder with AnnAGNPS simulation software. ArcMAP program was used to spatially display the watershed's cell delineation (c) and channel network (d), as seen in Figure 4.

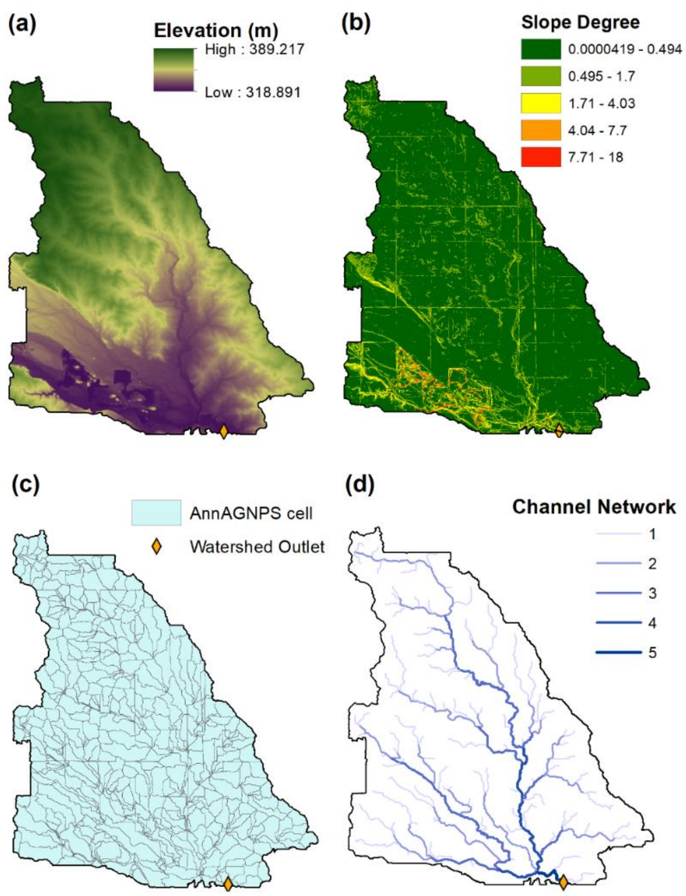

Figure 4. Four maps displaying the elevation derived from given DEM raster (a), degrees of slope (b), and cell delineation (c) and channel network (d) derived from TopAGNPS software.

2.3.2. Soil characterization

To retrieve soil data required for AnnAGNPS simulation, soil data (shapefile) and its corresponding soil table (csv) for my watershed was respectively obtained from the United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Web Soil Survey and Soil Data Access.

To spatially present the soil data displayed in Figure 5, ArcMap was used. As the watershed spanned across two counties (Cerro Gordo and Worth), each county's soil data (shapefile) was separately downloaded from the Web Soil Survey website. In ArcMap, the downloaded shapefiles were projected in NAD 1983 UTM Zone 15N and merged. To retrieve and join the soil data to each AnnAGNPS cell, a new field with integer type was added using the values from column MUKEY. The polygon was converted to raster (tif) using a tool in ArcMAP and zonal statistics as table was applied to calculate the majority of the soil type in the zones of each AnnAGNPS cell. Multiple joins occurred with an initial join between soil table to soil shapefile followed with a second join between AnnAGNPS cell shapefile to soil shapefile. The final spatial output of the existing conditions of the majority of soil in the watershed is displayed in part b of Figure 5.

A program called NITA was used to format the soil table downloaded from the USDA NRCS Soil Data Access to a correct format accepted by AnnAGNPS simulation. Outputs from NITA used for AnnAGNPS include the attribute tables for soil data and soil layers data, which were copied to folder with AnnAGNPS model.

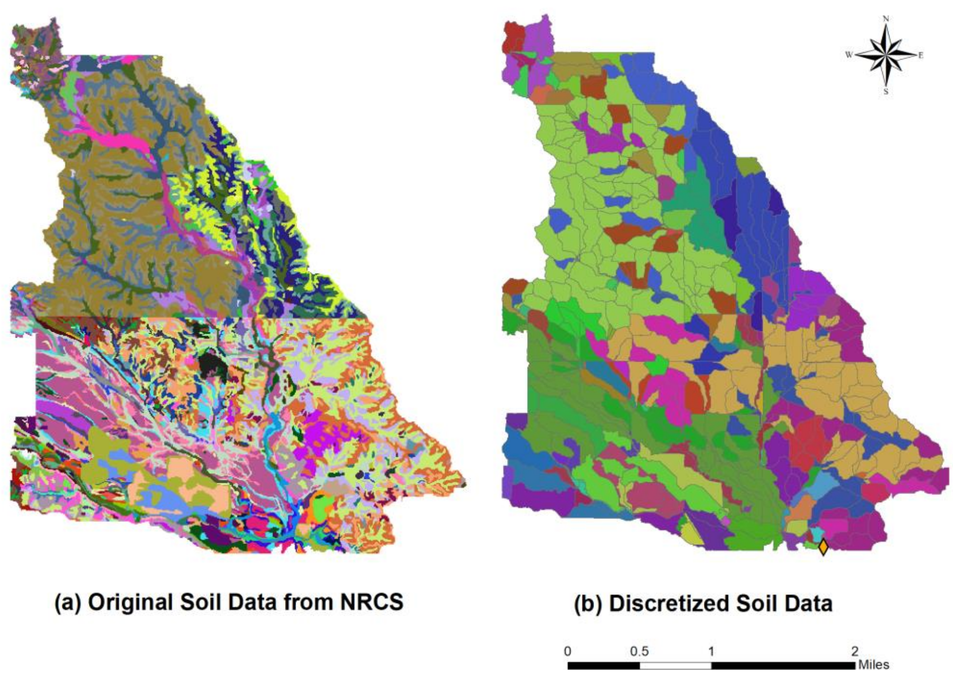

Figure 5. Two maps of the SWM watershed comparing the original soil data (a) gathered from USDA NRCS Web Soil Survey and the discretized soil data (b), with a majority analysis joined to the 488 AnnAGNPS cells.

2.3.3. Climate characterization and description

Since there weren't any successful daily climate stations less than 30 km away from my watershed (according to NOAA's Climate Data Online), I used the statistical parameter file for Mason City retrieved from USDA NRCS AGNPS – AgGEM website. The Mason City statistical parameter file was used as input for agGEM software package, which will then provide daily climate data needed for AnnAGNPS simulation. According to the statistical parameter file from Mason City, the average annual precipitation around the area of Mason City is 32.2 inches with the average annual number of wet days equivalent to 94.3 days. The final climate data outputs retrieved from the agGEM software are attribute tables called climate daily and climate station.

To prepare the climate attribute tables for an AnnAGNPS simulation of five years from 2013 to 2017, I manually changed the year type in climate daily, which were originally numbered from one to five to represent each simulation year. In the attribute table for climate station, I changed the beginning and ending climate date to coincide with 1/1/2013 to 12/31/2017. In the attribute table for simulated period, I updated the beginning and ending simulation dates similarly. Finally, I copied the attributes tables for climate daily and climate station into the folder with AnnAGNPS software to start my first run to show the existing conditions followed by other runs to represent simulated conditions.

2.3.4. Characterization of farming management

The most recent land use and land cover data (2020) were downloaded from USDA National Agricultural Statistics Service (NASS) CropScape – Cropland Data Layer. Tools in ArcMAP were used to determine the type of land use within each AnnAGNPS cell from the Cropland Data Layer raster. Again, the application called zonal statistics as table was applied to calculate the majority of cropland data encompassed within each subcatchment, with most AnnAGNPS cell designated land use for corn and soybean crop production (Figure 6). To simplify and prepare the farming management for simulation, I applied and designated a management code based on AnnAGNPS management schedule to each original land use (Figure 7).

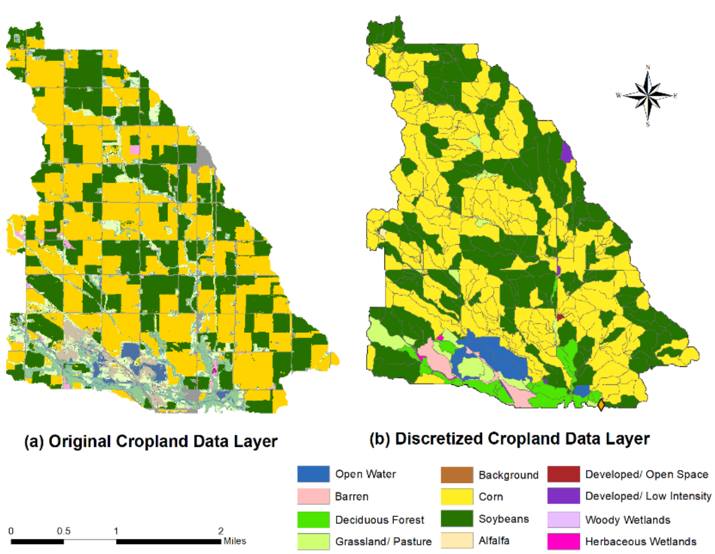

Figure 6. Two maps comparing the original cropland data layer (a) and the discretized cropland data layer (b), with a majority analysis joined to the AnnAGNPS cells.

CDL		AnnAGNPS Code	
1	Corn	**1**	Corn
5	Soybeans	**2**	Soybeans
36	Alfalfa	**3**	Grass
111	Open Water	**WATER**	
121	Developed/Open Space	**6000**	Urban
122	Developed/Low Intensity	**6000**	Urban
131	Barren	**7000**	Forest
141	Deciduous Forest	**7000**	Forest
176	Grassland/Pasture	**3**	Grass
190	Woody Wetlands	**7000**	Forest
195	Herbaceous Wetlands	**7000**	Forest

Table 1. Table depicting the new characterization of land use to follow the prepared management schedule used for AnnAGNPS.

2.4. Development of alternative scenarios

After the successful generation of outputs in AnnAGNPS for the base condition, the folder with the AnnAGNPS simulation for the base condition (Run_0) was copied for a separate model simulation of the six alternatives. The types of crop to be changed in the six scenarios were corn and soybeans. Either it was soybeans or corn for all five years. In addition, each crop were to be planted in different areas, with the severity of the alternative scenario increasing as more non-agricultural land, including normally considered urban areas, were transformed to agricultural land. As shown in Table 2, an average scenario meant that either crop could be planted in the usual areas for agricultural, which in the base condition could have been designated as corn, soybeans, alfalfa, or other. A Less Severe scenario meant that forest was changed to be designated as a farm land, in addition to normal agricultural land, which either crop could now be planted on. A Severe scenario is defined as all cells in the watershed besides those characterized as 'water' could be open to either corn or soybeans.

	100% corn all five years	**100% soybeans all five years**
SEVERE: All areas besides bodies of water	Run 1	Run 4
LESS SEVERE: All areas besides bodies of water and urban areas	Run 2	Run 5
AVERAGE: Agricultural areas	Run 3	Run 6

Table 2. Table depicting six alternative scenarios that will be compared to the existing conditions.

3. Results and Discussions

For the simulation representing existing conditions, I used all data mentioned in the methodology section without changing any values besides data correction during data processing. After the AnnAGNPS model successfully finished its simulation for the watershed's base condition, sediment data was retrieved from one of its output attribute tables called Gaging Station Data. Figure 7 depicts the three types of sediments classified as sheet and rill (SNR) erosion at the outlet: clay, silt and sand. Although small and large aggregates are types of sheet and rill erosion, they were excluded since they only had values of zero during this simulation. After every rainfall event, there is a spike in the total sediment in the outlet. Out of the three sediments, silt is the highest contribution to erosion in the outlet. During the five-year simulation, spikes of erosion occurred during the spring to summer months, which correlates to the fact that AnnAGNPS is an event-driven model, with precipitation as its main source of trigger.

Once simulations for the six alternative scenarios were finished, the Gaging Station Data for each run were compared. The total monthly values for the base scenario and the alternative scenarios were calculated using Excel software, along with its descriptive statistics (Table 3). In comparison to the three corn alternative scenarios, soybean simulations for Severe and Less Severe scenarios dominated with a mean total monthly sheet and rill erosion values of 1312.522 mg (Run 4) and 1305.635 mg (Run 5), which is almost twice the amount for its corn counterpart scenarios (Run 1 = 660.5348 mg and Run 2 = 657.1068 mg) (Table 3). In the Average alternative scenario, soybean emitted less SNR erosion than corn with a difference of total monthly SNR of 550.3652 mg (687.2568 – 136.8916). In comparison, the Severe and Less Severe scenarios of corn closely match the statistics for the base condition, Run_0, with a total monthly SNR of 660.5348 mg and 657.1068 mg, respectively, for Run_1 and Run_2. Out of the three SNR sediments, silt continues to be the highest contributor to erosion in the outlet, with an average total monthly SNR value for all three corn alternative scenarios as 383.6626 and an average total monthly SNR value for soybeans as 690.5852 mg. Differences between the corn and soybean crops were closely looked at with the clay sediment, as can be seen in Figures 8 and 9, with Figure 8 showing soybeans and Figure 9 showing corn. The trend of the scatterplot is similar between both graphs, but the graph for soybeans (Figure 9) is almost double the amount of the corn values. The scatterplots in Figure 8 show a more visual comparison of SNR values for the seven total scenarios used for this study.

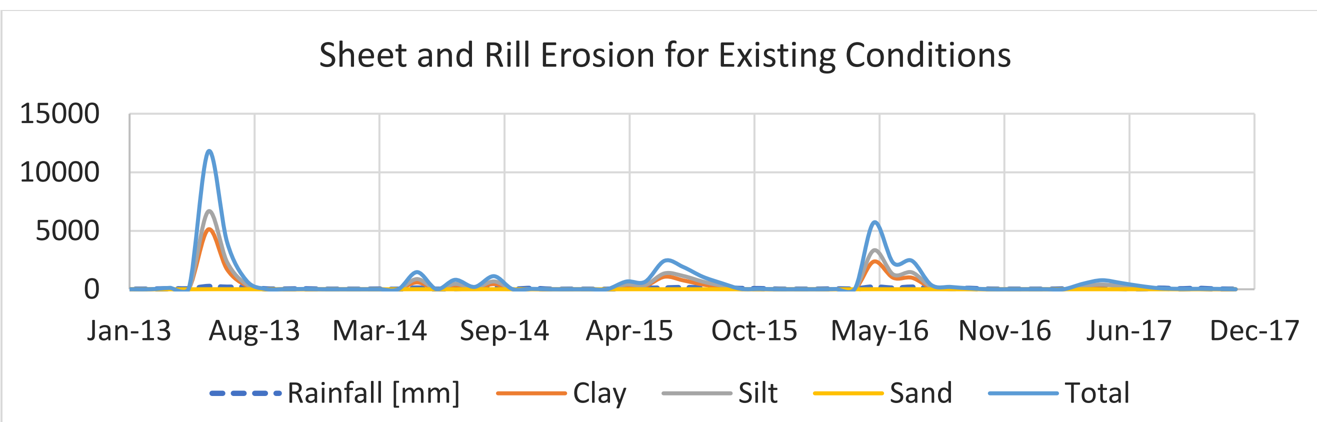

Figure 7. Scatter plot of the rainfall and total SNR sediment values in the 5-year simulation.

	Existing Conditions		Alternative Scenarios					
		RUN_0	RUN_1	RUN_2	RUN_3	RUN_4	RUN_5	RUN_6
Clay	**Min.**	0	0	0	0	0	0	0
	1st Qu.	0.556505	0.230995	0.230003	0.556505	1.24075	1.236	1.057458
	Median	16.734	20.578	20.481	16.734	31.2015	31.056	26.11079
	Mean	293.298	278.1823	276.8234	293.298	572.5801	569.7385	479.2942
	3rd Qu	265.7641	263.2873	261.962	265.7641	447.093	444.9735	374.3007
	Max.	5115.889	4302.529	4281.572	5115.889	10775.68	10722.74	9030.175
Silt	**Min.**	0	0	0	0	0	0	0
	1st Qu.	0.745743	0.41056	0.40981	0.745743	1.60753	1.598778	1.320845
	Median	20.0465	21.533	21.408	20.0465	37.62	37.4185	30.6845
	Mean	392.4071	380.264	378.1969	392.4071	737.7281	733.6839	600.3438
	3rd Qu	314.6983	309.2745	307.5645	314.6983	540.037	536.9525	434.3383
	Max.	6654.372	5720.857	5690.777	6654.372	13472.81	13401.83	11008.26
Sand	**Min.**	0	0	0	0	0	0	0
	1st Qu.	0.15925	0.12928	0.12853	0.15925	0.2255	0.22575	0.19675
	Median	0.6325	0.62161	0.62011	0.6325	0.9905	0.9885	0.8635
	Mean	1.551832	2.088895	2.086715	1.551832	2.214182	2.212846	1.805722
	3rd Qu	2.307345	3.3395	3.33625	2.307345	3.33775	3.3325	2.756615
	Max.	7.23282	10.17	10.166	7.23282	12.502	12.518	7.332
Total	**Min.**	0	0	0	0	0	0	0
	1st Qu.	1.601308	0.836768	0.834768	1.601308	3.424818	3.407818	0.4235
	Median	38.132	42.696	42.4725	38.132	68.3875	68.056	56.825
	Mean	687.2568	660.5348	657.1068	687.2568	1312.522	1305.635	136.8916
	3rd Qu	559.5585	538.499	535.417	559.5585	1053.365	1047.927	863.2898
	Max.	11775.87	10032.78	9981.755	11775.87	24261	24137.09	20045.6

Table 3. Descriptive statistics comparing total monthly sheet and rill erosion of base conditions and alternative scenarios.

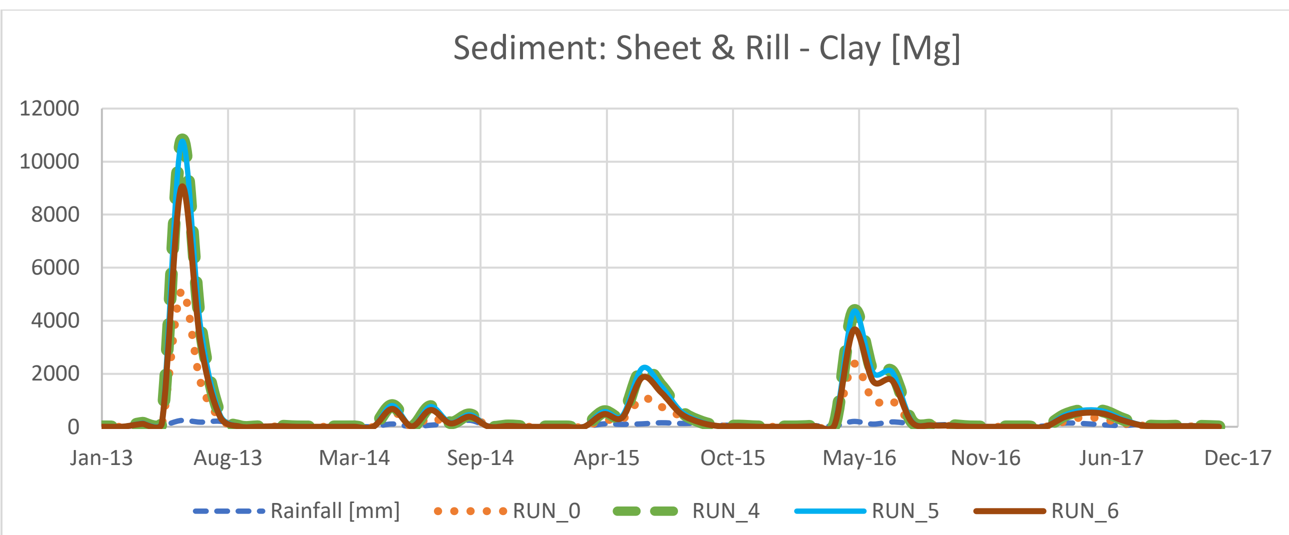

Figure 8. Scatter plot of the rainfall and total sheet and rill sediment values in the 5-year simulation representing existing conditions.

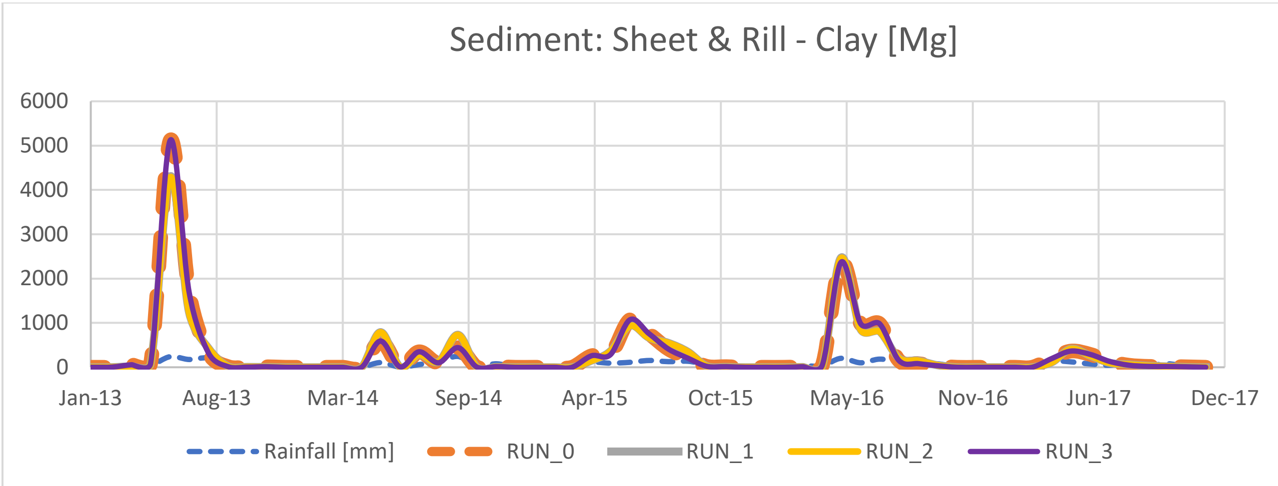

Figure 9. Scatter plot of the rainfall and total sheet and rill sediment values in the 5-year simulation representing existing conditions.

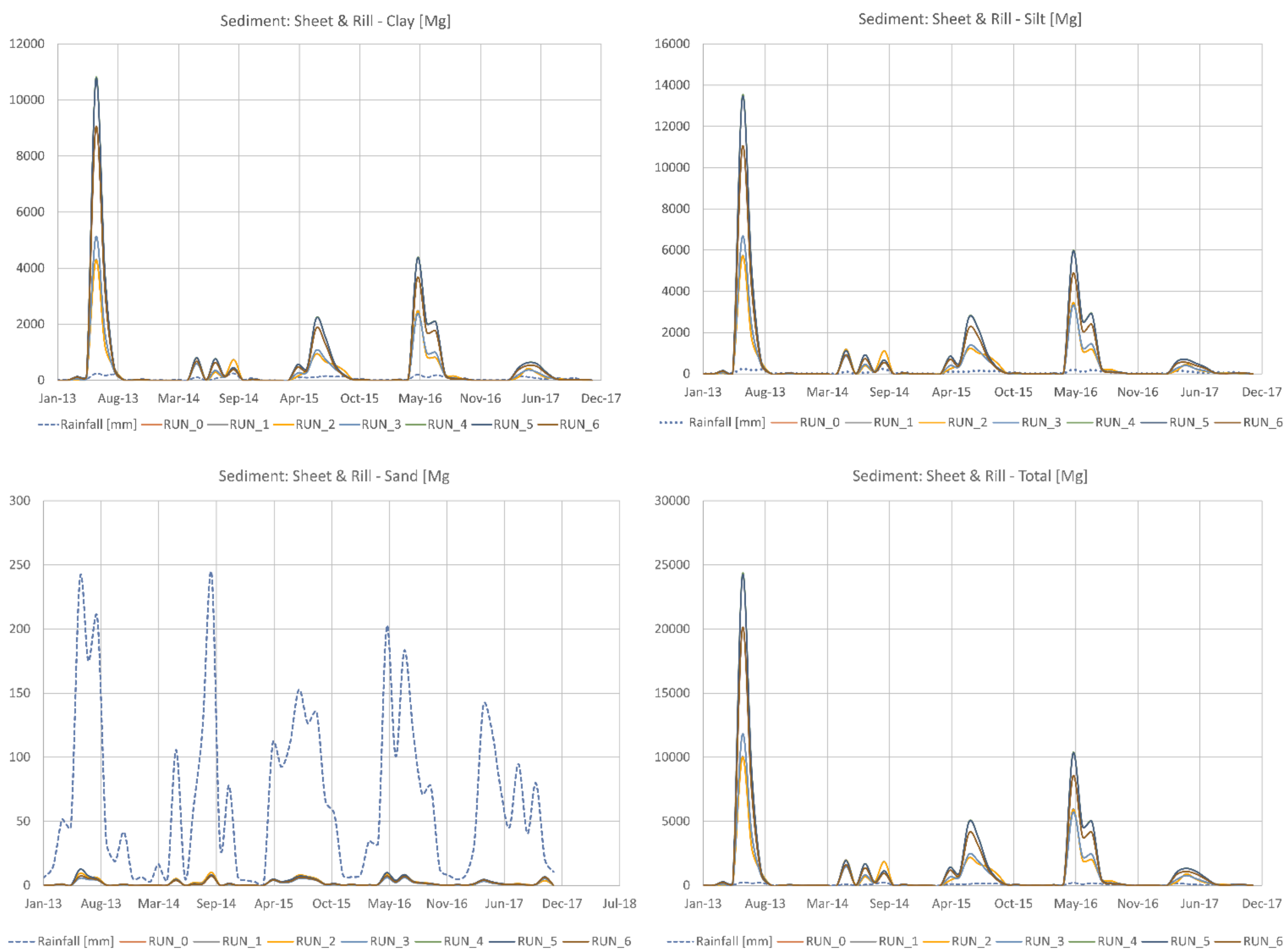

Figure 10. Four scatter plots depicting the three sediment types (clay, silt, and sand) and total SNR for each scenario, including the base conditions and alternative conditions.

4. Conclusion

Findings from the study include the following: a correlation between precipitation events and increase in erosion in outlets, the planting of soybeans produce more SNR erosion than corn, and the sediment silt as the main contributor to SNR erosion in the SWM watershed during all seven scenarios (singular base condition and six alternative simulations). Errors from the study could be due to human error with the calculation or transferring of data or numbers in Excel. The results could be also strengthened if farming practices were included in the study. Future work would definitely include that.

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