The Effects of Land Cover and Conservation Practices on Sediment Retention in the Clear Creek Watershed

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Abstract

As intensive agricultural practices continue to be used on land in the Midwestern United States, soil erosion is likely to remain a pervasive problem for surface water quality. The Clear Creek watershed in Southeastern Iowa is exemplary of many watersheds in the Midwest; it is dominated by agricultural land cover - primarily row crops - with a few areas of natural vegetation and urban development. We examined this watershed in hopes of gaining a better understanding of the effects of land cover and conservation practices on sediment retention. We used the TerrSet InVEST sediment retention model and data from a variety of sources to examine the problem. Our results show that conservation practices - when those practices are independent of land cover change - have a significantly lesser impact on sediment retention than changes in land cover.

1 INTRODUCTION

1.1 Background/Lit Review

The Clear Creek Watershed is an integral part of Eastern Iowa's landscape and economy. Nearly 80% of the watershed has been transformed from natural prairies to agricultural fields, primarily producing corn and soybeans (Rayburn and Schulte 2009). While the intensive nature of most farming practices that take place in the Clear Creek Watershed can help lead to more successful harvests, research has shown that the management practices on these farms has serious long term effects, including severe soil erosion and declines in water quality (Abaci, Ozan, and Papanicolaou 2009). The impacts that the continuation of poor management practices will have on the 6,000+ landowners in the Clear Creek Watershed, both directly in terms of soil erosion and water quality, and indirectly in terms of human health and economic output, is concerning.

According to the Environmental Protection Agency (EPA), excess sediment has a negative effect on water quality (EPA 2005). The excess sediment increases the likelihood that pathogenic bacteria will be present in water, and increases levels of phosphorus. When phosphorus levels are high the concentration of dissolved oxygen is low, leading to negative impacts for aquatic ecosystems (Abaci, Ozan, and Papanicolaou 2009). In Abaci, Ozan, and Papanicolaou's article (2009) on management practices and soil erosion, the authors found that long-term land management practices can significantly amplify or decrease the impact of precipitation on soil erosion. They found that the correspondence between soil erosion rates and high precipitation events are strongly affected by land management practices. The timing and type of tillage impacted the retention of the soil surface also. Keestra and Pereira discussed the effects of soil management techniques on soil water erosion in their 2016 article. They found that vegetation cover, soil moisture, and organic matter were significantly higher in areas where there had been no till. In areas of till, runoff sediment concentrations were much higher (Keestra, Saskia, and Pereira 2016).

This project follows in the footsteps of previous works, like those mentioned above, in seeking to gain a better understanding of what affects soil erosion, focusing specifically on the Clear Creek Watershed. We already know that the soils in this watershed are highly erodible (Dideriksen et al. 2007), but what else, besides the soil itself, is affecting soil erosion and sediment retention? Do changes in land cover affect how much sediment is retained? What about changes in conservation practices? We will be using TerrSet's InVEST sediment retention model to explore just how much sediment is making its way from farm fields in the watershed to the stream. We hypothesize that changes in land cover will affect sediment retention and that sediment retention will increase as conservation practices increase.

1.2 Study Site

The Clear Creek watershed, shown below in *Figure 1* and *Figure 2*, covers 104 square miles (66,132 acres) in East Central Iowa and empties into the Iowa River. Over 86 square miles (83%) of the watershed are rural, while 17.9 square miles (17%) are urban (Clear Creek Watershed Coalition). The predominant soil type in the Clear Creek Watershed is Mollisols. This type of soil is key to the productivity of Iowa farming due to its rich nutrient content and high organic matter (Dideriksen et al. 2007). These loess-derived soils are homogenous, which makes them highly erodible. Eighty-four percent of cropland in the upper portion of the watershed is classified as highly erodible (Iowa Watershed Approach 2017). For this reason, among others, proper land use and management practices are key to the protection of soils and retention of sediment.

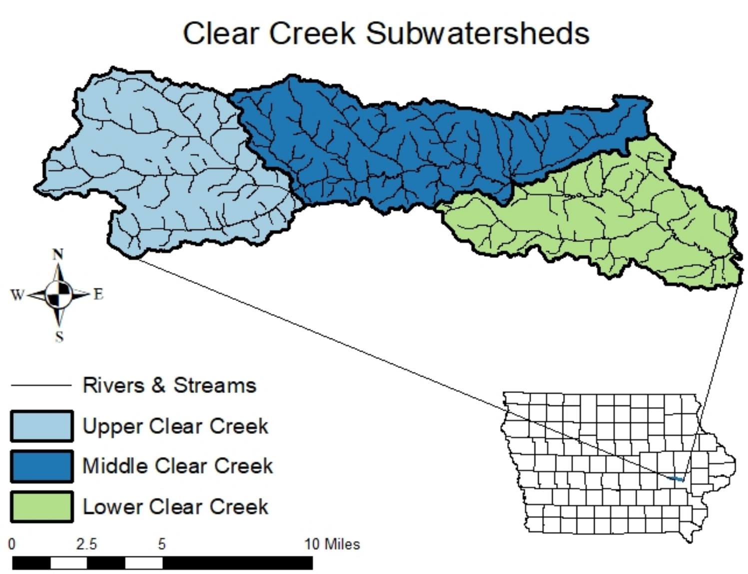

Figure 1. *The Clear Creek Watershed, sub-watersheds, and streams.*

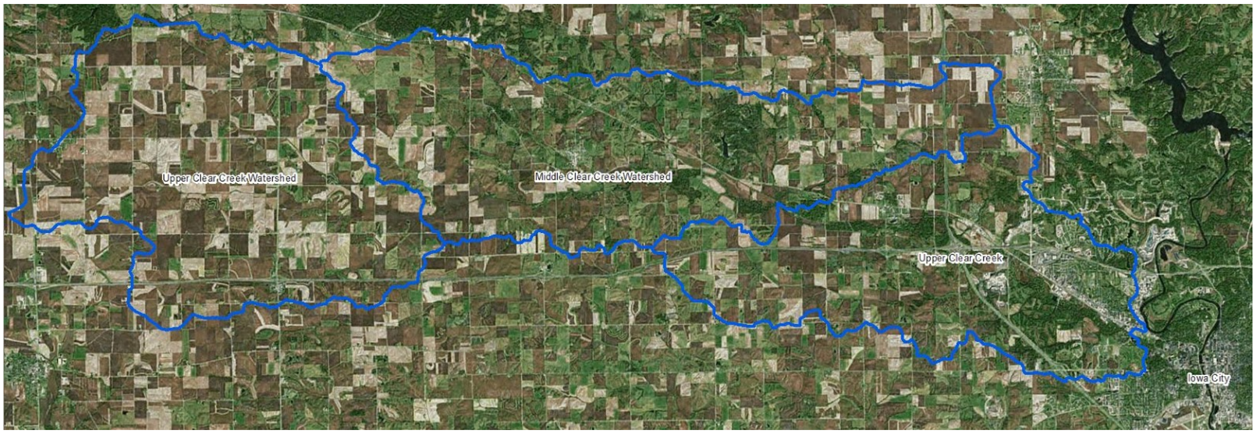

Figure 2. *A satellite image from the National Agriculture Imagery Program (NAIP) showing the land cover of the watershed.*

2 METHODOLOGY

2.1 Model

We used the TerrSet InVEST sediment retention model to explore sediment retention in Clear Creek. This model uses soil properties, topography, vegetation, and human activity, which all affect sediment dynamics, to calculate how much sediment is transported into waterways (Natural Capital Project). Much of this model relies on the revised universal soil loss equation (RUSLE).

The model itself uses images of watershed boundaries, a digital elevation model, a land cover model, several soil property images, a CSV file that relate land cover sensitivity to erosion, and a CSV file on the maximum sediment delivery ratio possible to create the outputs (Natural Capital Project).

The model calculates the amount of annual sediment export for each pixel by calculating how much sediment is eroded annually per ton per hectare and the sediment delivery ratio. The annual soil loss is calculated by multiplying several soil erosion related variables such as rainfall erosivity and the slope length-gradient factor. The sediment delivery ratio is calculated by creating a ratio between the upslope and downslope components of the landscape. It is defined as the proportion of soil loss that actually reaches the catchment outlet (Natural Capital Project). Figure 3, below, helps illustrate how the sediment retention model works.

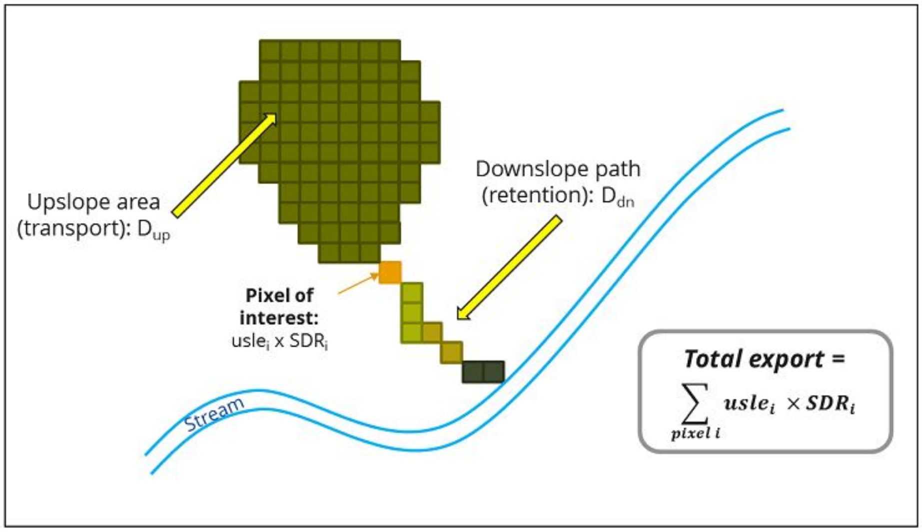

Figure 3. *An illustration of the general way in which the sediment retention model works. From the National Capital Project.*

2.2 Data and Inputs

The raster data used in the model came primarily from the USDA/ARS Agricultural Conservation and Planning Framework (ACPF), a watershed planning tool that provides a comprehensive geodatabase of soil types, field boundaries, watershed boundaries, and land use (ACPF 2017). The land cover shapefile from ACPF comes from the USDA National Agricultural Statistics Service Cropland Data Layer (CDL). This data layer was produced using satellite imagery, mostly from Landsat 8, and has a ground resolution of 30 meters. *Figure 4*, below, shows the land cover raster for 2008, 2012, and 2016, all years we analyzed.

The soil erodibility data, or K-factor, is from the National Cooperative Soil Survey's Soil Survey Geographic Database (SSURGO), and the watershed and field boundaries shapefiles were developed by ACPF using crop data information and aerial imagery. The DEM is from the National Resource Geographic Information System for the state of Iowa (NRGIS). The R-factor, or erosivity index, is from the National Oceanic and Atmospheric Administration (NOAA). *Figure 5* shows a visualization of the different raster data inputs.

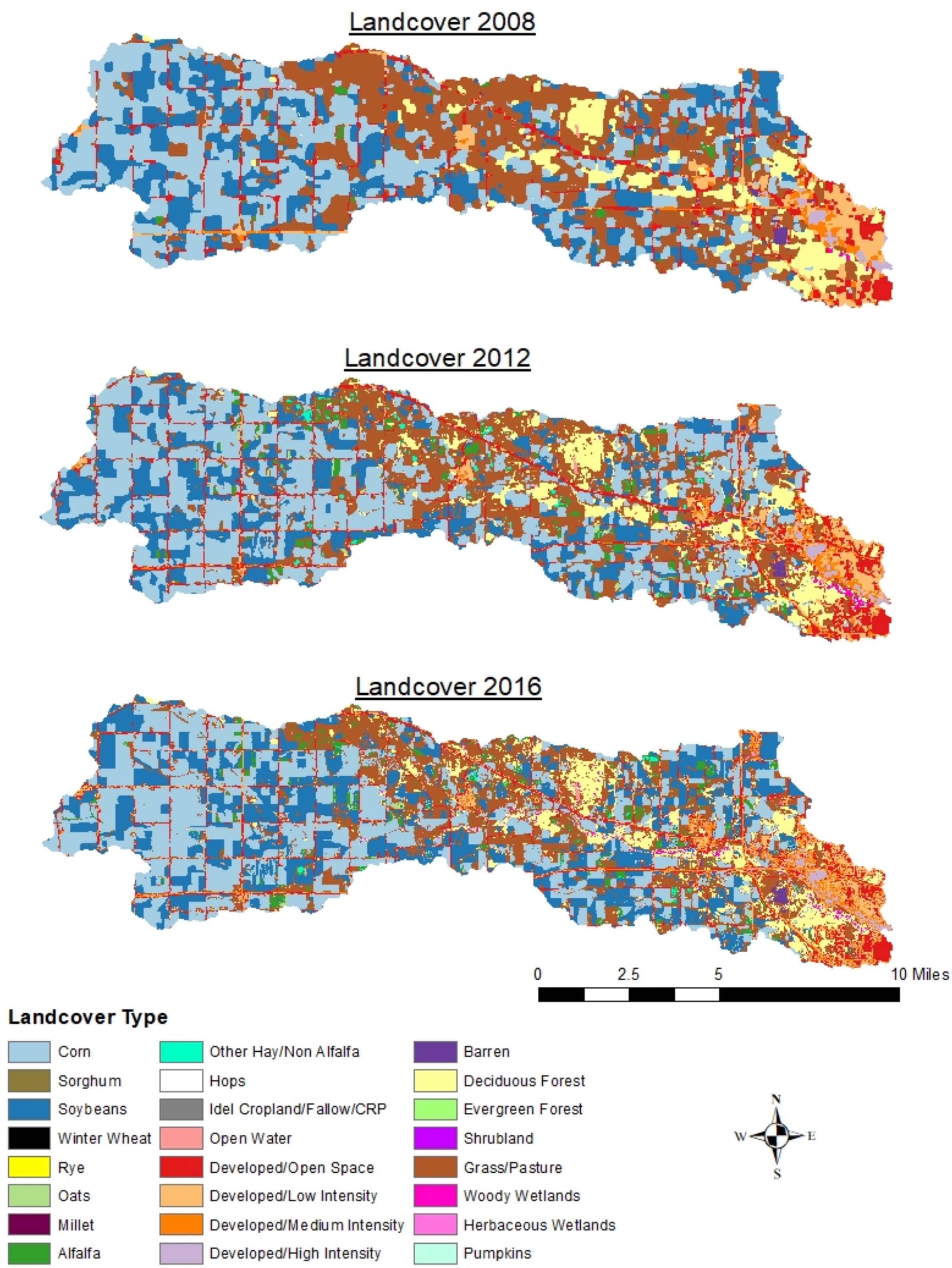

Figure 4. *The three different land cover images used in our project. Created using data provided by ACPF.*

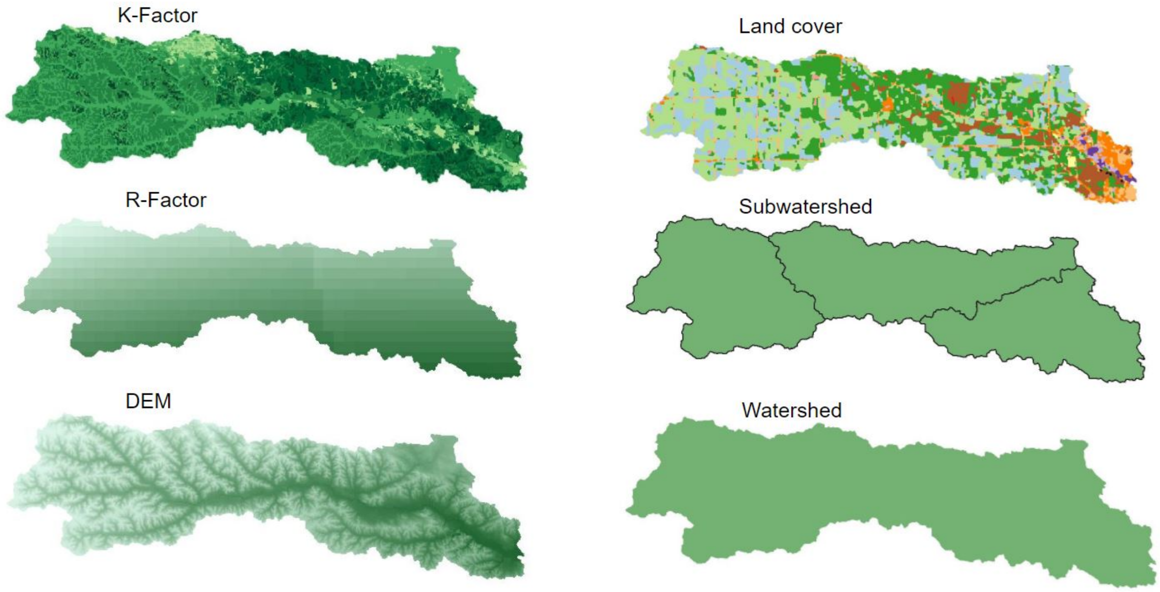

Figure 5. *Raster data used as inputs for the sediment retention model, created using data published by ACPF, NOAA, and NRGIS.*

The data in the CSV files needed for the model came from a variety of sources. The first file, a biophysical table, included a land use code, c-factor, and p-factor. The land use code is nothing more than an identifying number relating land use in the raster image to other information in the biophysical table. The c-factor is the cover management factor and the p-factor is the support practice factor. We used data provided to us by Dr. Dave Bennett to fill in these values (Bennett, pers. com.). For the second CSV file, a sediment threshold table, we used the same values as those used in the TerrSet training data.

2.3 Methods

All raster data was processed in Esri's ArcMAP before it was used in the TerrSet InVEST sediment retention model. The data were all made to have the same resolution of 30 meters, the same extent, and no null values. The land cover rasters were created by merging the three separate sub-watershed rasters provided by ACPF. This was done for 2008, 2012, and 2016 land cover data. A sub-watershed raster was created, with values 1, 2, and 3 used to identify the different sub-watersheds. A constant value raster of the entire watershed was also created, in order to identify the watershed extent in the model. The biophysical table and sediment threshold table were filled in using information provided primarily by Dr. Bennett and the training data.

Once all of these inputs were pre-processed, and after solving a handful of different problems error messages, we successfully ran the model. The first set of runs was done to look at the impact of land cover on sediment retention. For this we used middle-of-range c and p-factors, to simulate medium conservation practices. We kept all inputs the exact same throughout the runs, except the land cover raster. By using the land cover raster provided by ACPF for 2008, 2012, and 2016, respectively, as the independent variable, the model returned outputs that allowed us to explore the effects of land cover on sediment retention.

After running the model to focus on addressing our first hypothesis, that land cover significantly affects sediment retention, we ran the model to focus on addressing our second hypothesis, that sediment retention increases as conservation practices increase. To achieve results that would allow us to address our hypothesis, we ran the model with all of the same inputs except the c and p-factors in the biophysical table. To test the model as representing high conservation land management practices, we adjusted the c-factor and p-factor to match those values associated with no-till land management. To test the model as representing low conservation land management practices, we adjusted the c-factor and p-factor to match those values associated with traditional till land management. This distinction – that of representing different levels of conservation by only changing c-factor and p-factor values – is imperative to note.

3 RESULTS

3.1 Land Cover and Sediment Retention

The results of the sediment retention model are shown in *Figure 6*. This compares sediment retention over the years, with only land cover changing between the three. Middle Clear Creek seems to have more pixels of higher sediment retention compared to the Upper and Lower Clear Creek sub-watersheds. This is logical, since Middle Clear Creek includes more forested and naturally vegetated area than the other sub-watersheds. While the difference between the sub-watersheds in noticeable, the difference in sediment retention across the entire watershed between the years is difficult to see.

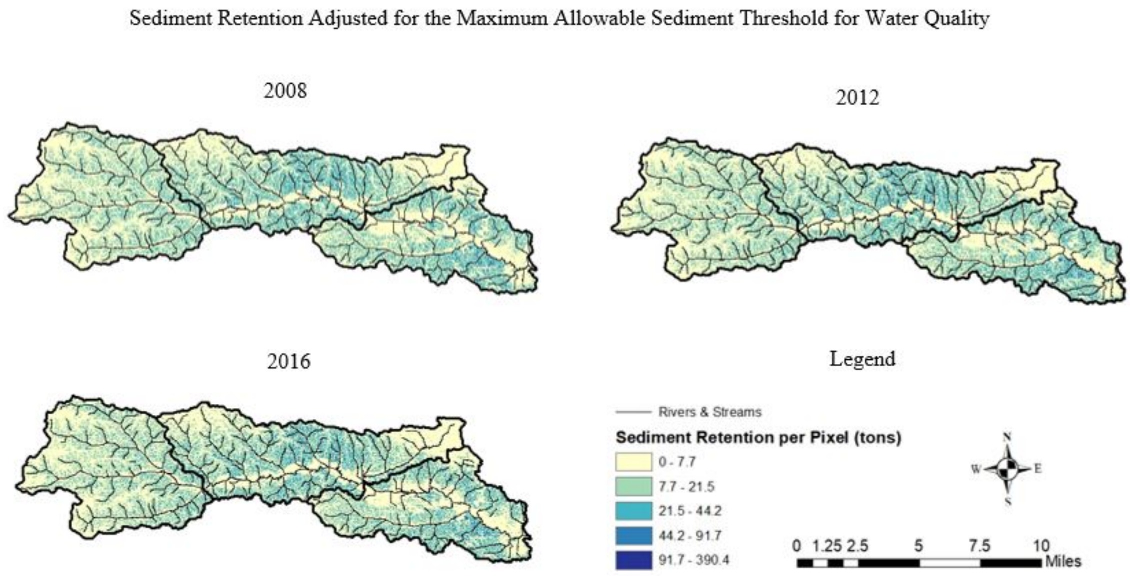

Figure 6. *Maps made from the outputs of the sediment retention model.*

Table 1 illustrates the differences more clearly. Here, the data show that sediment retention increases in two of the three watersheds from 2008 to 2012, and increases significantly in all three watersheds from 2008 to 2016. Sediment retention adjusted for maximum allowable sediment threshold for water quality increases by nearly four thousand tons in Upper Clear Creek, over sixteen thousand tons in Middle Clear Creek, and three and a half thousand tons in Lower Clear Creek.

Table 1. *Annual sediment retention values per sub-watershed. Calculated from model outputs.*

Sediment Retention Adjusted for Maximum Allowable Sediment Threshold for Water Quality

Sub-watershed	2008	2012	2016
Upper Clear Creek	1,804,435.125	1,803,949.625	1,808,303.25
Middle Clear Creek	2,417,290	2,417,413	2,433,472
Lower Clear Creek	1,891,716.875	1,891,093.75	1,895,148.375

*All values in tons

Another useful way to look at the results is by field boundary. This is shown in *Figure 7*, where the fields in black represent those where sediment retention decreased from 2012 to 2016, and fields in white are those that saw an increase in sediment retention from 2012 to 2016. The second image, *Figure 8*, is of the same information but categorized into different data classes which enable you to see more variation between the high and low values.

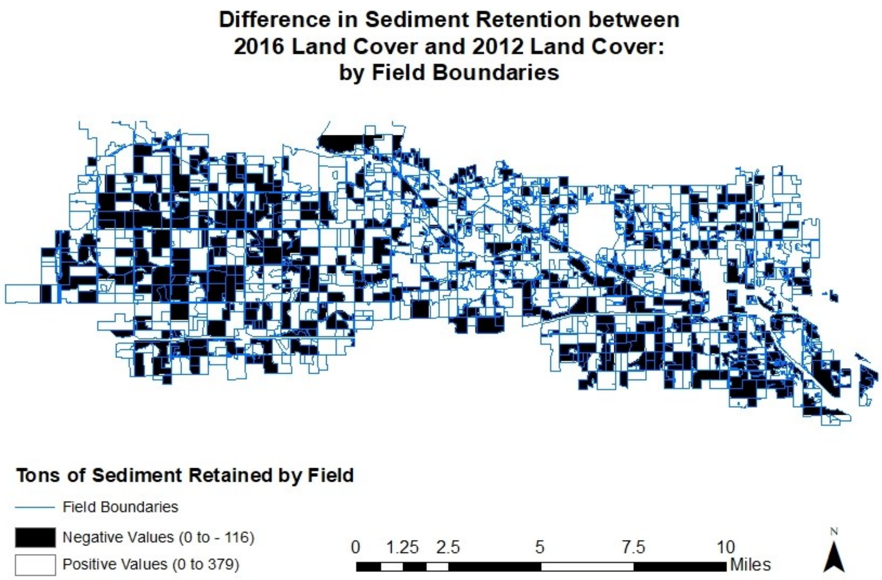

Figure 7. *Sediment retention between different land covers, created from model outputs.*

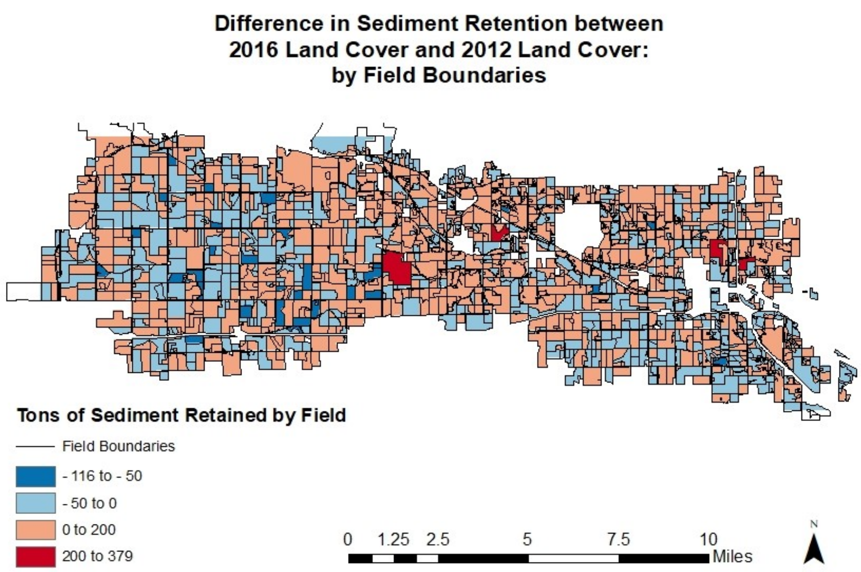

Figure 8. *Sediment retention between different land covers, with a diverging data classification.*

3.2 Conservation Practices and Sediment Retention

The results of the runs focused on comparing sediment retention by different levels of conservation are shown in *Figure 9*. This map was created by subtracting the raster output of sediment retention for low conservation values from the raster output of sediment retention for high conservation values. Negative values, values that correspond to a decrease in sediment retention when going from low conservation to high conservation, are shown in orange. Positive values, those values that correspond to an increase in sediment retention when going from low conservation practices to high conservation practices, are shown in a green/blue. Areas where there is no change are shown in white. The result clearly shows a positive change in sediment retention, as more pixels appear blue/green than white or orange.

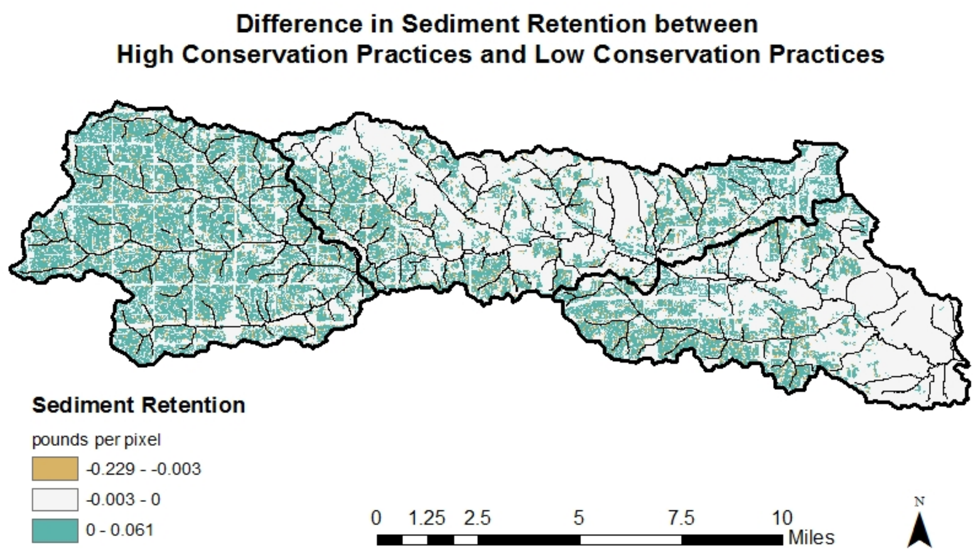

Figure 9. *Map created by calculating a difference raster between high conservation and low conservation model output.*

Of the three sub-watersheds, Upper Clear Creek has the most pixels of increased sediment retention when going from low to high conservation practices. The large areas of white, or no change, in Middle Clear Creek and Lower Clear Creek are areas that are primarily natural vegetation and urban landscape, respectively. The same results are shown in *Figure 10*, but visualized by field boundary. When shown by field boundary, the results appear more evenly spread across the three sub-watersheds, as compared to *Figure 9* where sediment retention is shown at the pixel level.

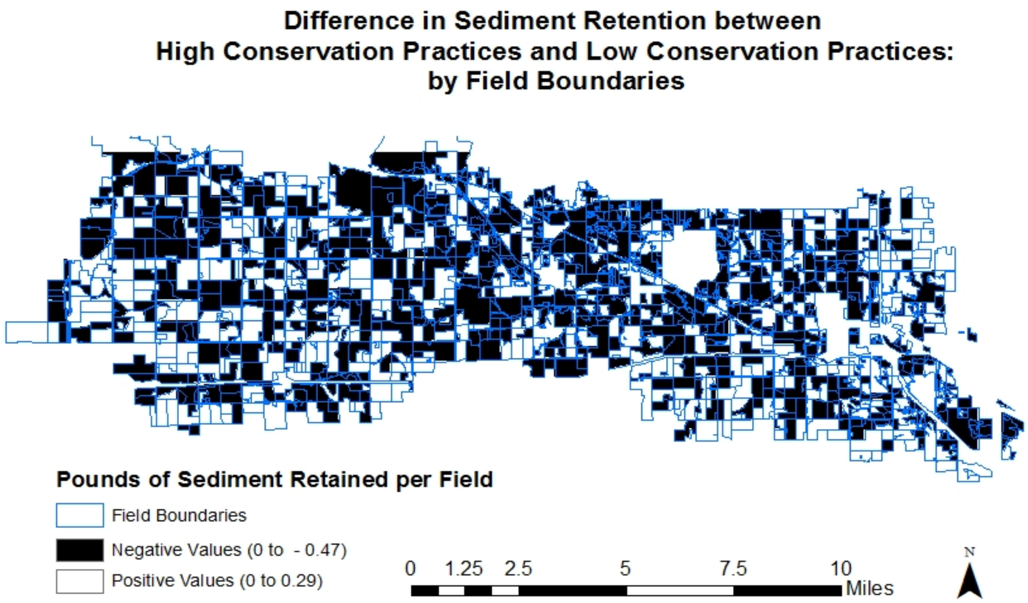

***Figure 10**. Map showing positive and negative changes to sediment retention when subtracting low conservation model output from a high conservation model output.*

Though high conservation practices, when compared to low conservation practices, increase sediment retention across more land area than changes in land cover do, the actual amount of increased sediment retention by improving conservation practices is dwarfed by increased sediment retention due to changes in land cover. Changing land cover results in sediment retention changes by tons, while changing conservation practices only changes sediment retention by pounds.

4 DISCUSSION

As we can see from the results, land cover change has a greater influence on sediment retention in the Clear Creek Watershed than conservation practices. The changes in sediment retention due to land cover change range from 50 to 100 tons per pixel (negative 100,000 to 200,000 pounds), while the changes in sediment retention due to conservation practices range from -0.2 to 0.06 pounds per pixel.

The large change in sediment retention due to land cover supports our first hypothesis, that land cover has a significant effect on sediment retention. The slight change in sediment retention due to conservation practices provides support for our second hypothesis, that sediment retention increases as conservation practices increase, though these results are not as convincing and obvious as those supporting the land cover hypothesis. A future study with a focus on the statistical significance of conservation practices could be beneficial in better understanding the effects of conservation practices on sediment retention.

Our study is clear in its finding that land cover significantly affects sediment retention in Clear Creek watershed. Small changes in land cover were responsible for thousands of tons of difference in sediment retained, as illustrated in *Table 1*, *Figure 7, and Figure 8*. These changes dwarfed any difference that resulted from conservation practices. Perhaps as time goes on and agriculture continues to remain a part of the Midwestern United States' DNA, more focus should be put on conservation practices that inherently change land cover.

We represented variations in conservation levels by using c-factors and p-factors associated with different tilling practices, practices that do not fundamentally change land cover. While this provided useful information, it did not include any conservation practices that change land cover. In reality many conservation practices implemented in the Midwest are considered conservation practices *because* they fundamentally change land cover. Take, for example, buffer strips. This popular edge-of-field practice changes land cover. As our results have shown, this change in land cover could dramatically change sediment retention. Buffer strips, then, are not just a conservation practice and are not just a change to land cover. The categories are not mutually exclusive. Buffer strips are **both** a conservation practice and a land cover change. The latter, in this case, defining the former.

This topic of conservation practices that fundamentally change land cover is one area that could be researched more in the future. While the effectiveness of edge-of-field practices, like buffer strips, in reducing water runoff is still up for debate, it is generally accepted, and further supported in this study, that vegetated land significantly decreases soil erosion when compared to land covered by crops.

5 CONCLUSION

Iowa is likely to remain “The King of Corn” in coming decades. Its already intensive agricultural practices will be compounded by the inevitable growth in population, leading to higher demands of Iowa’s agricultural sector. How Iowa chooses to handle this new challenge will have serious implications for long-term land productivity, sediment retention, and water quality.

Our results show that land cover has a significant impact on sediment retention in the Clear Creek watershed, while conservation practices, when independent of land cover change, also have an impact on sediment retention in the watershed, though less so than land cover. While the results of this project provide a foundation for understanding how land cover and certain conservation practices affect sediment retention, there is much more that still needs to be researched, tested, and understood.

ACKNOWLEDGEMENTS

We would like to extend our most sincere thanks to Dr. Heather Sander, without whom this project would not have been possible. We would like to thank Dr. Sander specifically for providing us with the necessary foundation needed to understand the complexities of ecosystem services, for guiding us to professors and graduates who had useful data and information, and for helping us work through the problems we encountered during this project.

We would also like to thank Dr. Dave Bennett for providing us with data and suggestions. His advice helped us overcome challenges in data acquisition and data processing.

Finally, we would like to thank our classmates, Brianna, Mike, Ben, and Lauren, who encouraged us along the way and provided much needed comedic relief during late nights in the GIS lab.

WORKS CITED

Abaci, Ozan, and A. N. Thanos Papanicolaou. 2009. “Long-Term effects of management practices on water-Driven soil erosion in an intense agricultural sub-Watershed: monitoring and modelling.” *Hydrological Processes*, Vol. 23, Pp. 2818–2837

Bennett, D. (November 2017). Personal communication and data acquisition.

“Clear Creek Watershed”. *Iowa Watershed Approach. 2017*.

Dideriksen, R.O., M.R. LaVan, K.K. Norwood, S.R. Steckly, and J.E. Steele. 2007. Soil survey of Iowa County, Iowa. USDA-NRCS.

Environmental Protection Agency. *“*What is Sediment Pollution?” Mid-American Regional Council (MARC) for US Environmental Protection Agency. *2005*.

Keestra, S., Pereira, P., Novara, A., Brevik, E.C., Azorin-Molina, C., Parras-Alcantara, L., Jordan, A., Cerda, A. 2016. “Effects of soil management techniques on soil water erosion in apricot orchards”. *Science of the Total Environment,* Vol. 551-552, Pp. 357-366.

National Agriculture Imagery Program (NAIP). 2015. *USDA, USGS.*

Natural Capital Project. 2017. “Sediment Delivery Ratio Model.” *Natural Capital Project*.

Natural Resources Geographic Information Systems (NRGISL). 2014. *Iowa DNR*.

R-Factor for the Coterminous United States. 2013. *Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National OCeanic Services (NOS), Office for Coastal Management (OCM).*

Rayburn, A.P. and Schulte, L.A. 2009. *Landscape change in an agricultural watershed in the US*

Midwest. Landscape and Urban Planning. Vol. 23, Pp. 123–141.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at *https://websoilsurvey.nrcs.usda.gov/.*

TerrSet Geospatial Monitoring and Modeling Software. 2015. *Clark Labs*.

The Agricultural Conservation Planning Framework (ACPF). 2017. *USDA*.