Vegetative Impacts on Flooding in Wildcat Creek Watershed

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Introduction

Wildcat Creek covers 255 km^2 near the city of Manhattan, Kansas. Starting in 2012 there were concerns about flooding after large rain and storm events. With flooding, concerns of people displacement, property damage, and costs of repair come to mind. The City of Manhattan wanted an early warning system and now are looking into how to decrease the effects and damage of flooding. Utilizing a model can help to find a way to slow down the excess water in an environmentally friendly, efficient, low cost, with little to no maintenance. This research looks at the changes of nearby vegetation along with possible urban changes in relation to flooding events and how the vegetation change seasonally.

Background

The Wildcat Creek Watershed is located in Riley County, Kansas as shown in Figure 1, and spans approximately 100 square miles and meets the city limits of Manhattan, Kansas. Over the past decade the watershed has experienced an increase in impervious areas as the city has grown. Increased urbanization of the area has contributed to major flooding events that are adversely affecting residents in the watershed. Impervious cover, reduces infiltration thereby elevating surface water runoff and increasing the volume and velocity of water reaching the stream. These hydrologic alterations cause channel erosion and increase the frequency of flooding.

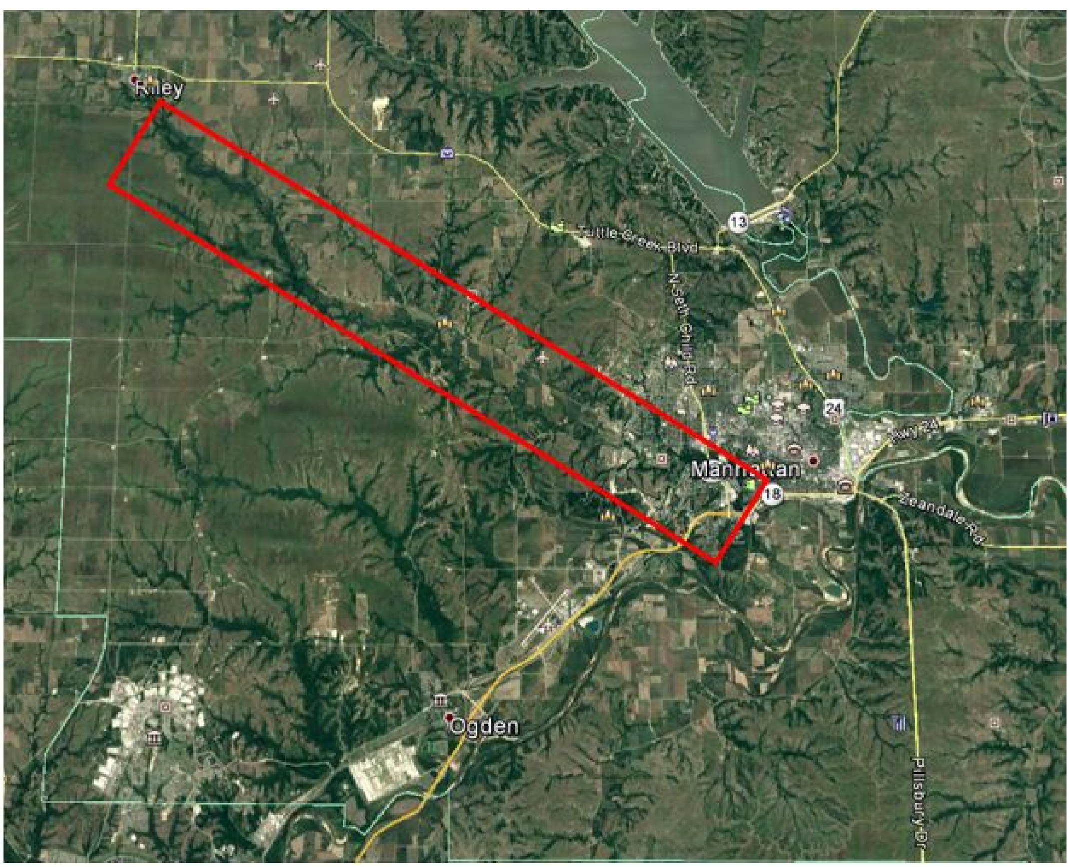

Figure 1. Wildcat Creek Watershed Location

With around 24% of the land area of the Wildcat Creek Watershed being used for production agriculture, it is apparent that discovering the best farming practice for flood control will be beneficial to the watershed as a whole. The two main farming practices that are being used in this region are no-tillage (strip-tillage) with a cover crop, and conventional-tillage. With no-till, the soil has little disruption by the producer. This is done by using implements designed to cut through the crop residue and topsoil. In a no-till system, cover crops are also utilized to hold the top soil in place and to add extra residue on top of the soil. Cover crops are usually drilled in the late fall in place of winter wheat or in the early spring, so that that residue can be used for a fall harvested crop such as corn or soybeans. Another farming practice that producers utilize on their farm ground in the watershed is conventional-tillage. With conventional-till, the farmer prepares the soil and the seedbed with equipment such as a disk, chisel, and cultivator. This is done to break up the topsoil and kill weeds that have sprouted since the last time the ground was turned.

Figure 2. On the left is Strip Till compared to Conventional Till on the right

Figure 2 gives an example of strip till which leaves residue on the soil surface, compared to a conventional till with no residue. Tillage systems expose organic materials and help improve oxidation of soil, which in turn reduces the soil's capacity to absorb rainwater and hold nutrients.

In a 3 year study done by K-State Extension, it shows that in a soybean/grain sorghum rotation in Franklin County, soil/water runoff is decreased by over half by converting to no till. 0.85 tons/acre/year lost with conventional-tillage and 0.275 tons/acre/year lost with no-tillage.

Project Methodology

Stream Gauge Data

In 2012, after large rain and storm events, the City of Manhattan, Kansas implemented a stream gage data collection located on Wildcat Creek at the intersection of Wildcat Creek and Scenic Drive, as an early warning detection system for flooding. This data allows observers to know how much water is being discharged from Wildcat Creek at a given time. A gauge depth of the creek is measured every 15 minutes giving the ability to observe the data as it changes throughout the day, month, and year to provide warnings of any potential flooding that may begin to occur. This data is important in determining the relationship of the creek depth with time and how it varies seasonally. It also provides a realistic data set to compare to a model, observing the results of various scenarios can influence later decisions to improve flood control.

Precipitation and Evapotranspiration

When analyzing flooding events one of the main contributing factors is precipitation. When utilizing a model it is important to look at real world data as a comparison. The data can also be used to find the best days to use for large rain events to be inputted into the model for simulation purposes. Over a six-year period beginning in January of 2012, average monthly measurements of water in inches were taken by Kansas Mesonet. Records show the precipitation and reference evapotranspiration (ET) levels of water from plants at Wildcat Creek watershed. Trends show that flooding occurs when there is excess rainfall/precipitation that plants cannot take up for use as evapotranspiration. The most rainfall is around March, April, and May when evapotranspiration is not as high. Overall, plants are not getting enough water, but graphs show that there can be significant flooding mostly in the late spring.

Model Methodology

Computer modeling and simulations is one of the best ways to evaluate the effectiveness of proposed methods. For this research the i-Tree Model was chosen (USDA Forest Service, 2006). This model is able to analyze changing vegetation and cover land of an area in relation to permeability. Data layers on elevation, land cover, and area of Wildcat Creek were implemented from GIS into the i-Tree Model. Within the model, weather data from a local weather station and precipitation data were used.

The i-Tree Model was used to investigate the changes in total and impervious flow during a heavy rainfall event on June 13, 2010 between 2 a.m. and 11 a.m. by considering the following scenarios based on a calibrated base condition from 2012: an increasing urban scenario, a cover crop versus conventional till scenario and an increasing tree cover scenario. To calibrate the 2012 base condition, the existing land cover from the National Land Cover Database was inputted into the model. 8.4% of the land cover was assumed to be tree cover, 63.8% was herbaceous cover, 0.5% was water cover, 3.1% was impervious cover and 24.2% was soil cover. The land cover percentages were based on the different land covers shown in Figure 3. In addition, the streamflow and weather data were were taken from the nearest stream and weather gauges to Manhattan.

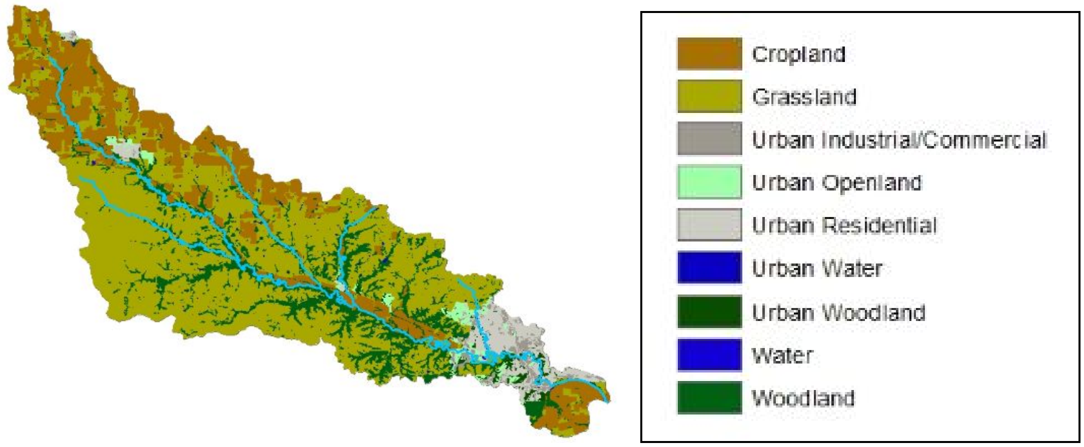

Figure 3. Wildcat Creek Watershed Land Cover Map

Once the i-Tree model was calibrated, the existing land cover percentages were changed to resemble each of the scenarios for 2010. The year 2010 was chosen because it was a wet year with multiple heavy rainfall events and recorded flooding. For the first scenario, the impervious cover was steadily increased from 25% to 95% to simulate an increase in urbanization around the area. Simultaneously, the herbaceous and soil cover were decreased. For the cover crop versus conventional till scenario, the cover crop was increased from 0% to 100% based on the whole watershed area. Finally, the tree cover was increased from 25% to 97% and the herbaceous cover and impervious cover were reduced for the increasing tree cover scenario. Appendix A displays the impervious and total flow results from each scenario for both the calibrated base condition and the alternative cases.

Finally, the depth of flow per hour based on the time of day was graphed for each scenario and compared to realistic streamflow data, precipitation and evapotranspiration data, and crop system information.

Results

Increase in Impervious area

Increased impervious surfaces impacts infiltration, stormwater runoff and groundwater recharge. When the water runs off urban impervious surfaces it can pick up sediment, oils, debris, nutrients, chemicals and bacteria. The runoff is then discharged into surface water without treatment. Not only is water quality compromised, but loss of riparian vegetation and ecological habitats are affected by urbanization. Warmer temperature runoff water also impacts the temperature of the body of water it flows into and the surrounding ecosystem. Runoff greatly influences groundwater and impacts recharge and infiltration rates. The increased volume and velocity of the storm water damages stream channels due to erosion causing channel widening and streambeds to be altered. The i-Tree model as seen in Figure 4, showed that when the impervious area was increased to 95 % the impervious flow increased significantly with an average increase of 65% from the base flow at 2am to 11am on June 13th, 2010. When the impervious area was increased to 65% the impervious flow increased with an average increase of 18% from the base flow at 2am to 11am on June 13th, 2010. An increase of 25% impervious area lead to an average increase of 2% impervious flow.

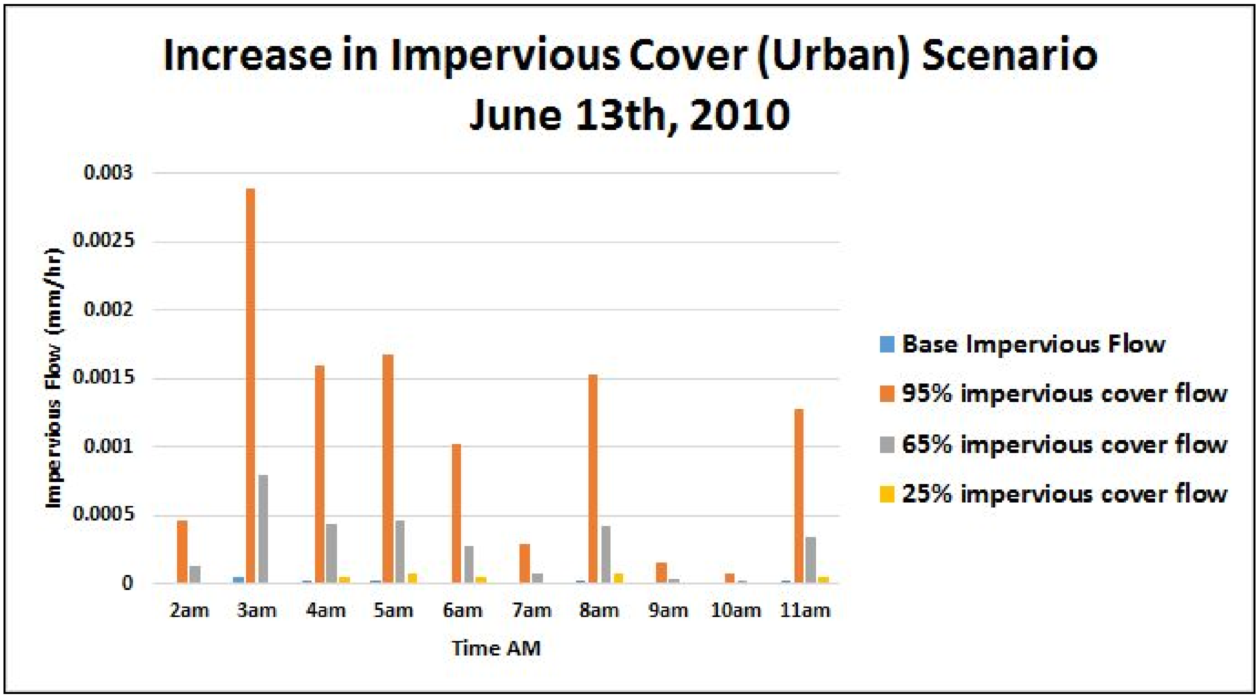

Figure 4. Changes in impervious cover modeled in i-Tree

Cover Crop versus Conventional Till

The two main farming practices that are being used in this region are no-tillage (strip-tillage) with a cover crop, and conventional-tillage. The cover crop indicates that the soil is left undisturbed so that the topsoil will add extra residue for the crops. With conventional till, the farmer prepares the soil and the seedbed with equipment such as a disk, chisel, and cultivator before planting the crops. The base condition of the i-Tree model represented approximately 24% of the watershed and was modeled as conventional till. As shown in Figure 5, the model shows a decrease in streamflow as the cover crop was increased from 0% to 50% to 100%, which indicates that more water is being stored in the soil. As the soil became saturated with heavier rainfall between 6 and 8 a.m., the results show that there is not a difference between the base condition and the increasing cover crop scenarios. Moreover, between 9 and 10 a.m., the rainfall concentration decreased and as indicated, at 11 a.m., the 100% cover crop soil scenario could hold more water compared to the base condition. In summary, the model indicates that farmers should utilize the cover crop practice compared to the conventional till practice to decrease the total water flow in the Wildcat Creek Watershed and prevent potential flooding issues within the area.

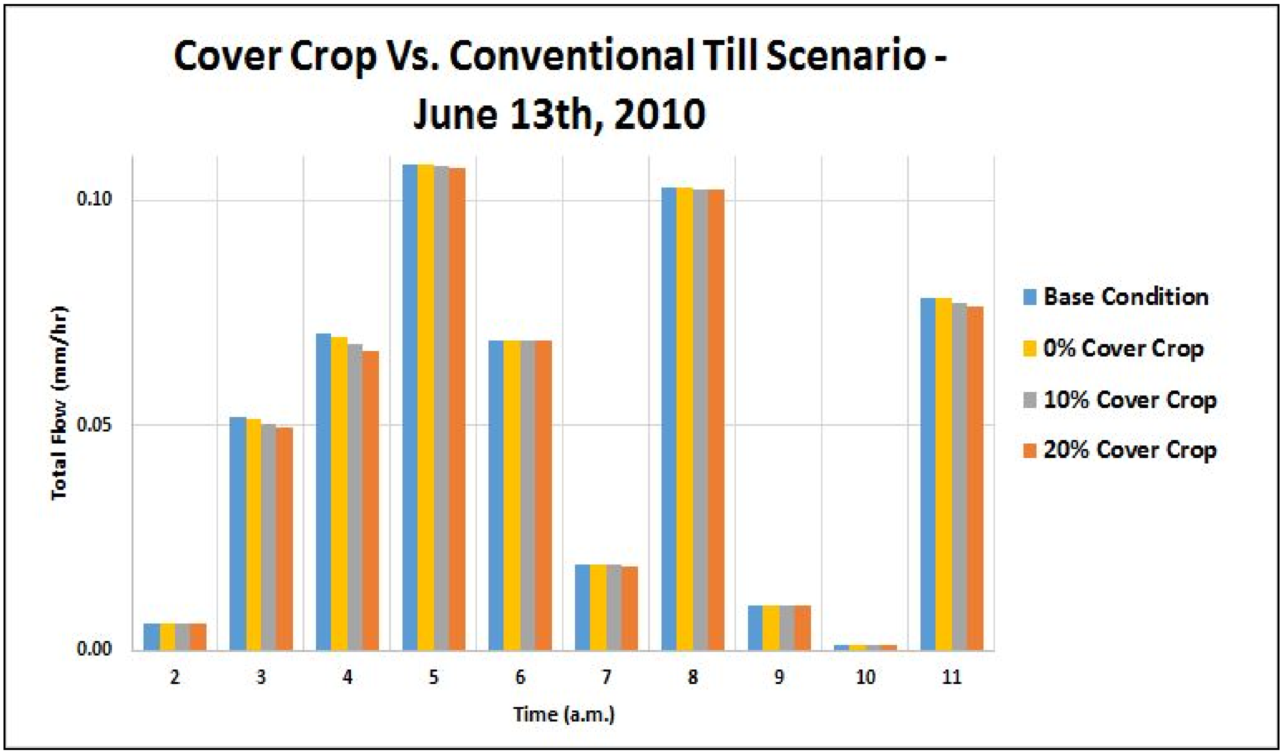

Figure 5. Cover Crops vs. Conventional till modeled in i-Tree

Increase in Tree Cover

With an increase in tree cover it is to be expected to see less streamflow. Trees pull water from the soil and in some species the stream itself. Trees are a great tool to help with limiting streamflow due to their ability to lower the water table and block the sun. With the sunlight not being able to reach the ground it will lower the amount of ground cover vegetation, thus creating a bare soil that is completely saturated with the water from the stream. This means that any additional water that reaches the ground will immediately run off into the stream system and contribute to the discharge. The tree cover model originally comprised of 8% in the base condition and as the tree cover was increased, eventually the impervious flow peaked at the 50% tree cover scenario. As shown the 75% tree cover and 97% tree cover scenarios decrease in impervious flow. With increased tree cover, the canopy area is increased, which captures more rainfall. Consequently, the rainfall evaporates before reaching the ground surface and lowers the total impervious flow within the watershed.

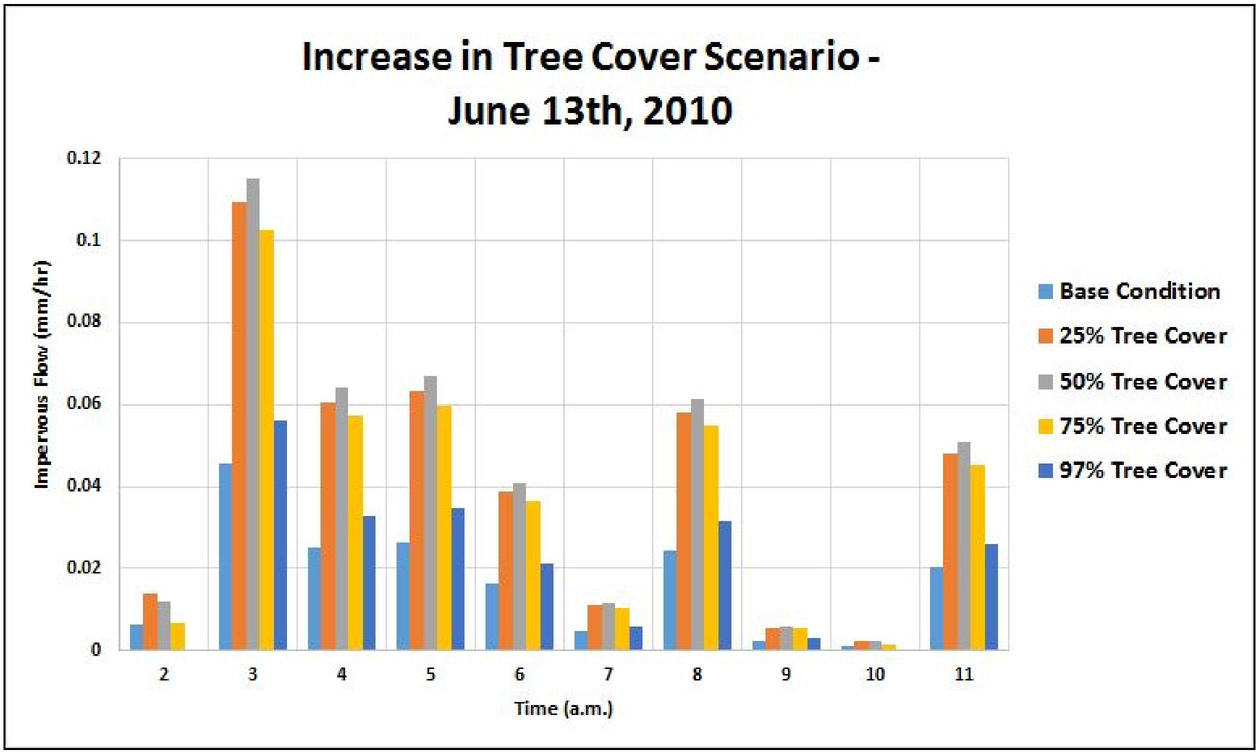

Figure 6. Changes in tree cover modeled in i-Tree

Stream Gauge Data

The stream gauge data collected from the USGS website provides information for Wildcat Creek. This information is vital because it can be used as an early warning system for rising water levels.

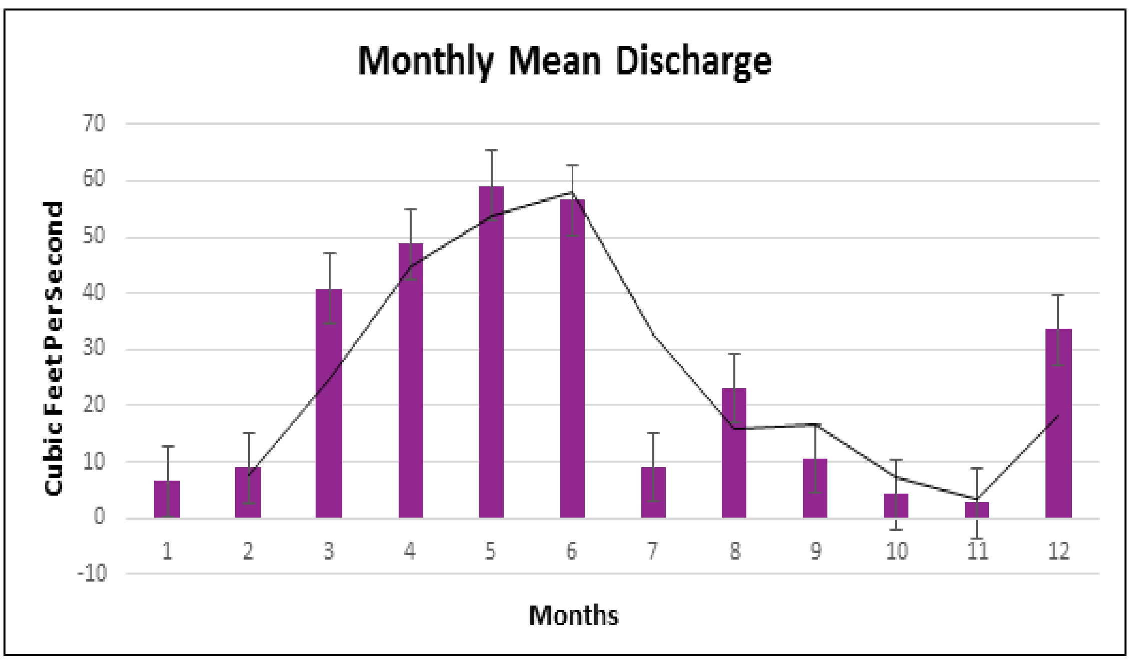

Figure 7. Wildcat Creek mean monthly stream discharge. Data collected from USGS website

This graph was made from data taken from the USGS website, (see Appendix B) with the months ordered starting from January. This stream water data gauge is located at the intersection of Wildcat Creek and Scenic Drive. When looking at the data taken from Wildcat Creek it can be used as a real life reference to many of the models ran. The data shows that spring and early summer are the most active times for the stream. There is a spike in December most likely due to the snow melt that will be experienced on a warm day in the month. Looking at the graph, if the creek were to flood there is a high probability it will flood in May or June given the steady rise in stream discharge over a four month period. However, these numbers can vary any year and certain years may have more water over all as shown in the following graph.

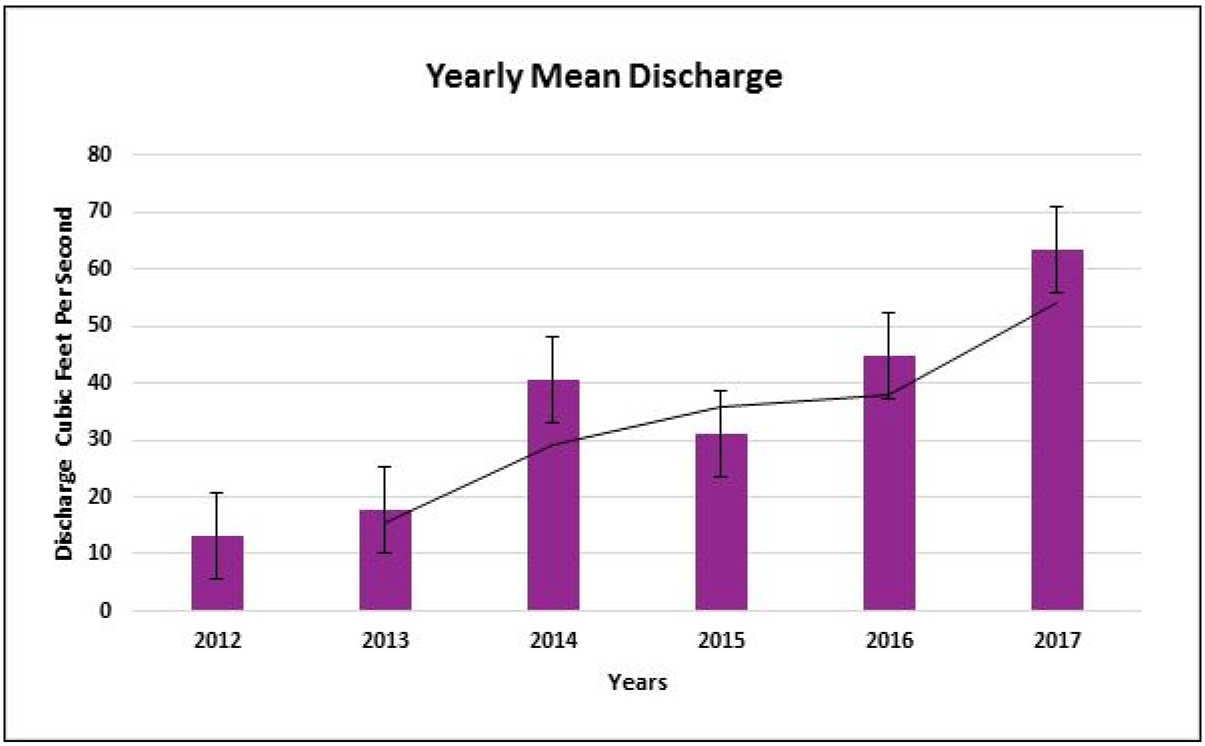

Figure 8. Wildcat Creek mean monthly stream discharge

Figure 8 was created using information provided by the USGS website, the graph shows stream discharge data relating to Wildcat Creek from 2012-2017. The data was taken over a six year period and shows a variety of results. While there is a steady rise in streamflow it is not enough information to tell if it will fluctuate, stabilize or continue to rise. It is very possible that the stream will be in constant flux due to its small size. The biggest influences of streamflow is the intensity and amount of rainfall in the area. With more rainfall in a given year the stream will collected larger quantities of water moving at a faster velocity resulting in a higher rate of discharge.

Precipitation and Evapotranspiration

Measurements taken by Kansas Mesonet at the Manhattan location were averaged monthly over a six-year period starting in January 2012. They determine the precipitation and reference evapotranspiration (ET) levels by inches of water from a range of plants at Wildcat Creek watershed. Plants are having a higher evapotranspiration rate than the amount of precipitation occurring within the month, meaning they are not getting the amount of water they need. Evapotranspiration is not as high in the spring when there is the most rainfall. Results show that for the most part, plants are not getting enough water except a few months of significant precipitation throughout the year.

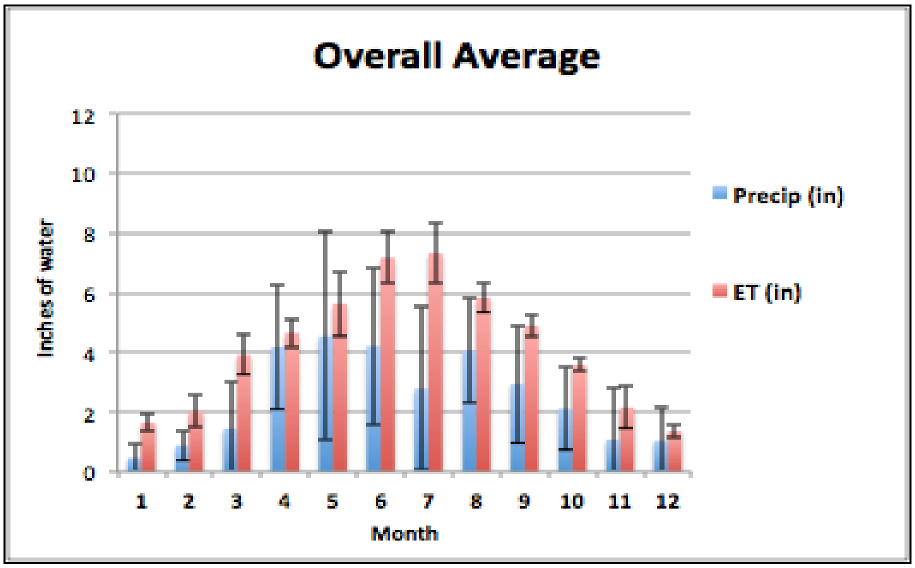

Figure 9. Overall average precipitation and ET levels from Kansas Mesonet

Evapotranspiration levels rise and fall steadily with the changing of the seasons with rainfall far more sporadic and extreme. Error bars show this in the spring months of April and May and signify standard deviation of levels.

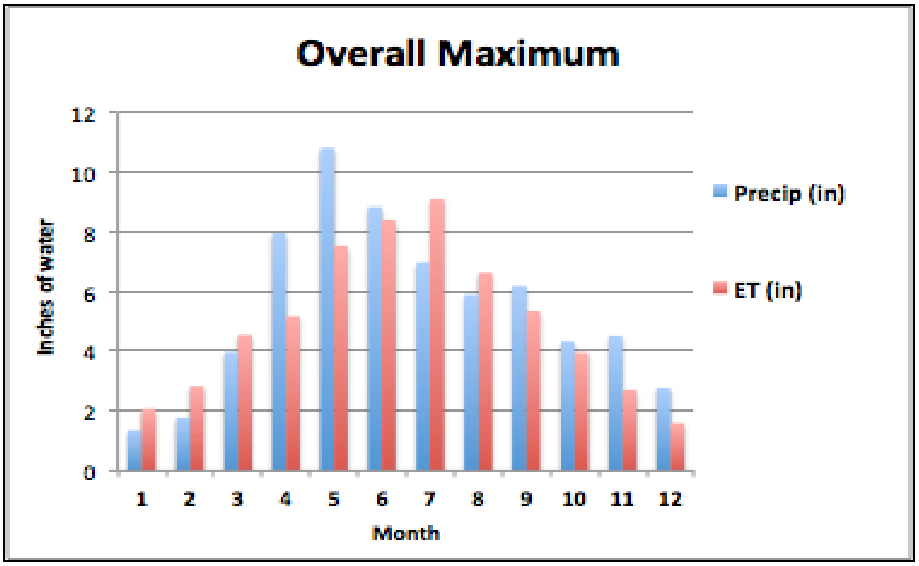

Figure 10. Overall maximum precipitation and ET levels from Kansas Mesonet

Figure 10 shows that May has the highest maximum precipitation of 11 inches of water. The Evapotranspiration has a maximum of 9 inches of water evaporating in July which is likely cause from the increased exposure to sun and higher temperatures.

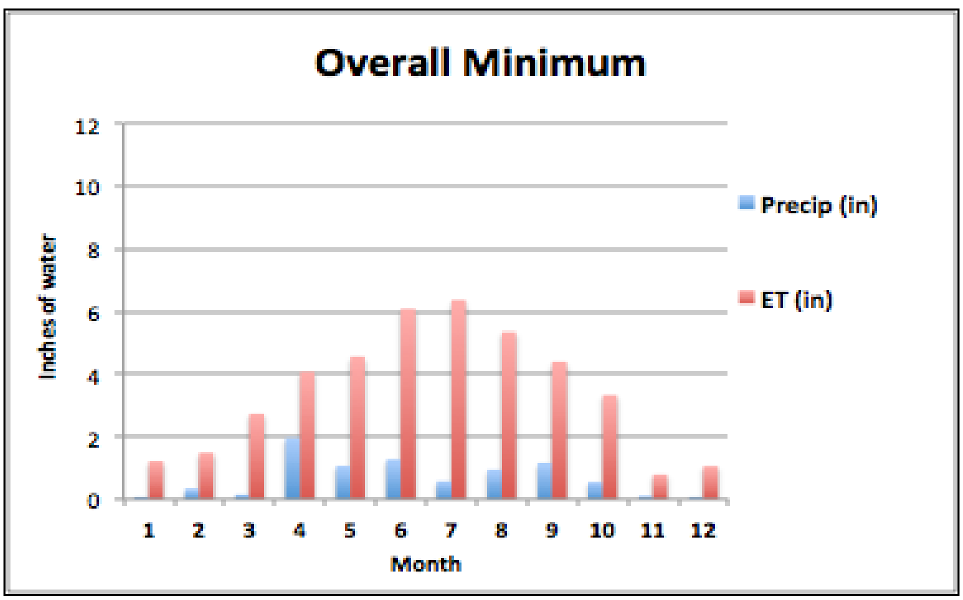

Figure 11. Overall minimum precipitation and ET levels from Kansas Mesonet

Figure 11 illustrated low or no precipitation in the winter months of November to January. The evaporation rates are also minimized in the winter months most likely due to decreased exposure to the sun.

Discussion

The i-Tree model results produced much larger water volumes when compared to the USGS data however the models still show similar trends and can be referenced and used as potential land management strategies for the region. The model results for the increasing impervious cover scenario reflect the results of a similar study performed by the Department of Agricultural Engineering at the University of Agricultural Sciences in India. Choodegowda, Murukannappa and Chalapathi investigated the influence of land use changes on flooding in the Wildcat Creek Watershed and concluded that a 20% increase in impervious cover in Manhattan resulted in an increase in water depth within the Wildcat Creek, which was assumed to cause potential flooding issues (Choodegowda et al., 2015). For the Manhattan area it would be recommended to limit the amount of impervious area through policy. By incorporating more green infrastructure, water runoff can be decreased and overall flooding can be reduced. From the cover crop versus conventional till scenario, the model indicates that cover crops can hold more water and reduce total flow compared to conventional till practices. Nonetheless, the difference between cover crop total flows and conventional crop total flows are nearly insignificant; however, if the entire region surrounding the Wildcat Creek utilized cover crop farming practices, it would be assumed that the cover crop total flows would decrease significantly compared to the conventional till total flows and potentially reduce flooding in the future.

The scenario that increased the total tree cover area for the region showed that when the trees were increased by 50% there was the highest impervious flow because trees have deep root systems that use water from deeper beneath the surface. During extreme events the soil will become saturated and the trees will not adsorb the surface water at fast enough rates. The base flow had the lowest impervious flow because trees only accounted for 8% of the land cover meaning grasses and shrubs would be more prevalent. The higher percentage of grasses and shrubs will absorb more surface water due to their shorter root systems that are in closer proximity to the surface water. When the tree cover increases beyond 50% the surface water is decreased due to canopy cover preventing rainfall from hitting the ground surface. For the Wildcat Creek region it would be recommended to keep the tree cover below 50% since the area has been historically prairie land containing lots of grasses which lowers the impervious flow.

Conclusion

As Wildcat Creek Watershed changes due to land cover and the climate continues to change, the region will experience more extreme weather events and cause more severe flooding. The USGS stream data showed that flooding in the Manhattan area is most likely to occur in the Spring months, the greatest amount of precipitation will also occur in the spring months whereas the highest rates of evapotranspiration were seen in the summer months as expected based on traditional seasonal changes. The no till method resulted in less water runoff into the stream system, the cover crop model showed that more water is retained by the soil as the cover crop was increased. The watershed was modeled and found that as impervious area was increased the impervious flow also increased. The impervious flow increased with increased tree cover until total tree cover reached 50% where the impervious flow began to decrease again. Overall, the modeling and USGS data showed that vegetation does impact flooding in the Wildcat Creek Watershed.

Acknowledgment

This study of Wildcat Creek is completed, in part, to meet the requirements of the Natural Resources and Environmental Sciences senior capstone project at Kansas State University. The lead instructor for the course and director of the NRES Secondary Major is Dr. Shawn Hutchinson and the project team advisor is Dr. Trisha Moore from the department of Biological and Agricultural Engineering.

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Appendix A
i-Tree Model Results

Table A.1. Increase in Impervious Cover (Urban) Scenario

Date & Time	Rainfall (mm/h)	Base Condition Impervious Flow (mm/hr)	25% Impervious Cover Alternative Total Flow (mm/hr)	65% Impervious Cover Alternative Total Flow (mm/hr)	95% Impervious Cover Alternative Total Flow (mm/hr)
06/13/2010 2:00:00	1.524	6.17686E-06	0	0.000124549	0.000457732
06/13/2010 3:00:00	3.302	0.000045846	1.2155E-05	0.000794607	0.002896618
06/13/2010 4:00:00	1.524	2.53893E-05	4.85612E-05	0.000439104	0.001600485
06/13/2010 5:00:00	1.778	2.65371E-05	7.59054E-05	0.000458933	0.00167276
06/13/2010 6:00:00	1.016	1.6235E-05	4.81157E-05	0.000280784	0.001023425
06/13/2010 7:00:00	0.254	4.66946E-06	1.31322E-05	8.09142E-05	0.000294958
06/13/2010 8:00:00	1.778	2.43149E-05	7.16497E-05	0.000420662	0.001533294
06/13/2010 9:00:00	0	2.39525E-06	7.06305E-06	4.14384E-05	0.000151041
06/13/2010 10:00:00	0.254	1.04143E-06	1.78413E-07	1.96364E-05	7.19179E-05
06/13/2010 11:00:00	1.524	2.02201E-05	5.30449E-05	0.000350346	0.001277116

Table A.2. Cover Crop vs. Conventional Till Scenario

Date & Time (a.m.)	Rainfall (mm/h)	Base Condition Total Flow (mm/h)	0% Cover Crop Alternative Total Flow (mm/h)	10% Cover Crop Alternative Total Flow (mm/h)	20% Cover Crop Alternative Total Flow (mm/h)
06/13/2010 02:00:00	1.524	6.18E-06	6.18E-06	6.18E-06	6.18E-06
06/13/2010 03:00:00	3.302	5.18E-05	4.94E-05	5.04E-05	5.14E-05
06/13/2010 04:00:00	1.524	7.05E-05	6.66E-05	6.83E-05	6.99E-05
06/13/2010 05:00:00	1.778	1.08E-04	1.07E-04	1.08E-04	1.08E-04
06/13/2010 06:00:00	1.016	6.88E-05	6.87E-05	6.88E-05	6.88E-05
06/13/2010 07:00:00	0.254	1.91E-05	1.89E-05	1.90E-05	1.90E-05
06/13/2010 08:00:00	1.778	1.03E-04	1.03E-04	1.03E-04	1.03E-04
06/13/2010 09:00:00	0	1.01E-05	1.01E-05	1.01E-05	1.01E-05
06/13/2010 10:00:00	0.254	1.24E-06	1.24E-06	1.24E-06	1.24E-06
06/13/2010 11:00:00	1.524	7.86E-05	7.64E-05	7.73E-05	7.82E-05

Table A.3. Increase in Tree Cover Scenario

Date & Time (a.m.)	Rainfall (mm/h)	Base Condition Impervious Flow (mm/h)	25% Tree Cover Alternative Impervious Flow (mm/h)	50% Tree Cover Alternative Impervious Flow (mm/h)	75% Tree Cover Alternative Impervious Flow (mm/h)	97% Tree Cover Alternative Impervious Flow (mm/h)
06/13/2010 02:00:00	1.524	6.18E-03	1.41E-02	1.18E-02	6.69E-03	0
06/13/2010 03:00:00	3.302	4.58E-02	1.09E-01	1.15E-01	1.03E-01	5.63E-02
06/13/2010 04:00:00	1.524	2.54E-02	6.06E-02	6.40E-02	5.73E-02	3.30E-02
06/13/2010 05:00:00	1.778	2.65E-02	6.34E-02	6.69E-02	5.99E-02	3.48E-02
06/13/2010 06:00:00	1.016	1.62E-02	3.88E-02	4.09E-02	3.66E-02	2.13E-02
06/13/2010 07:00:00	0.254	4.67E-03	1.11E-02	1.17E-02	1.05E-02	6.02E-03
06/13/2010 08:00:00	1.778	2.43E-02	5.81E-02	6.13E-02	5.48E-02	3.18E-02
06/13/2010 09:00:00	0	2.40E-03	5.72E-03	6.04E-03	5.40E-03	3.13E-03
06/13/2010 10:00:00	0.254	1.04E-03	2.43E-03	2.28E-03	1.68E-03	3.46E-04
06/13/2010 11:00:00	1.524	2.02E-02	4.83E-02	5.08E-02	4.53E-02	2.61E-02

Appendix B
USGS Monthly and Annual Stream Data

Table B.1. Monthly Stream Discharge Data

YEAR	00060, Discharge, cubic feet per second, Monthly mean in ft3/s (Calculation Period: 2012-02-01 -> 2017-06-30)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012		11.6	21.6	43.1	6.75	10.4	1.01	1.04	0.473	0.517	0.586	0.653
2013	0.881	1.57	1.34	39.1	33.4	17.8	15.9	55.2	7.26	5.98	4.93	5.33
2014	5.9	25.7	11.6	22.7	16.3	146.3	8.18	3.51	2.01	1.94	1.75	2.17
2015	1.93	2.77	2.02	1.95	54.9	81.2	17.3	7.03	3.21	1.23	3.19	78.4
2016	15.6	14.7	9.7	98.8	153.5	34.3	24.5	29.9	26.2	10.6	7.52	7.24
2017	13.2	7.94	107.6	130.4	120.7	22.6						
Mean of monthly Discharge	7.5	11	26	56	64	52	13	19	7.8	4.1	3.6	19

Table B.2. Annual Stream Discharge Data

Water Year	00060, Discharge, cubic feet per second
2012	11.3
2013	14.6
2014	21.3
2015	14.9
2016	41
2017	46.3