A Quantitative Analysis of the Impact of Land use Changes on Floods in the Manafwa River Basin

By

Fidele Bingwa
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Signature of Author: ______________________________
Department of Civil and Environmental Engineering
May 10, 2013

Certified by: ______________________________
Richard Schuhmann, Ph.D.
Senior Lecturer, Department of Civil and Environmental Engineering and Gordon Engineering Leadership Program
Thesis Supervisor

Accepted by: ______________________________
Heidi M. Nepf
Chair
Departmental Committee for Graduate Students

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ABSTRACT

Flood events in the Manafwa watershed, located in eastern Uganda, have increased in frequency in recent years. The risk of flooding is increasing globally due partly to climate change which enhances the number of weather extremes like excessive rainfalls or droughts. This increase in flood events is also a response to land use changes; as more people use the land for agriculture and housing the percentage of less pervious and impervious area increases. Floods in the Manafwa watershed are often deadly and always an economic burden. In eastern Uganda there is little that can be done about climate change but land use changes can be managed. This study analyzed the impact of land use changes on floods in the Manafwa watershed in hopes of informing local leaders regarding future flood risk reduction.

The analysis was conducted using a hydrologic model of the Manafwa watershed. The model had two main components: a meteorological model and a basin model. The meteorological model contained past rainfall data of the watershed and the basin model used the SCS curve number method as its soil water loss method. The curve number determines the percentage of rainfall water that becomes runoff, and is derived empirically from land use or land cover information as well as the soil type. A curve number map of the watershed was created using current land use and soil data; land use changes were modeled by making modifications to the land use map which resulted in changes on the curve number map.

In addition to modeling the current land use condition, three land use changes were simulated and the outflow result showed that land use changes can affect river flow and hence flood events in the Manafwa river basin. The results also show that a land management program like reforestation could decrease the risk of flooding in the watershed.

Thesis Supervisor: Dr. Richard Schuhmann

Title: Senior Lecturer, Department of Civil and Environmental Engineering and Gordon Engineering Leadership Program

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1 Introduction

1.1 Purpose of the Study

The Manafwa River basin in Eastern Uganda is flooded regularly, inundating the downstream plains in the districts of Butaleja, Mbale, and Manafwa, with runoff that originates from rainfall on Mount Elgon. Mount Elgon is a 4300 m high volcano upstream of the Manafwa River in the Bududa district. Because of the socioeconomic burden of floods in the river basin, the Uganda Red Cross society (URCS) would like a rainfall-based flood forecasting system for the Manafwa River basin. The forecasting system can help the Red Cross avoid a humanitarian disaster after a flood; emergency supplies and evacuation plans would be in place before the area is flooded.

The Red Cross asked the Civil and Environmental Engineering department at the Massachusetts Institute of Technology (MIT) to participate in the development of a flood forecasting system. The forecasting system will take as input precipitation forecast and output the probability of flooding and the potential flooded area. The system will use a hydrologic model to relate rainfall with runoff and ultimately river flow. The hydrologic model will also use the river geometry to determine the flood plain from the river flow output.

The increase of flood events in the Manafwa watershed tends to be attributed to climate change, but the nexus between land use and increased surface water runoff suggests that land use changes may also impact floods in the Manafwa River basin. When asked about the cause of the increased frequency of floods in the basin, many local leaders cited global climate change as the main culprit, to which they added bad land management, and the reality that the population has been living and growing crops closer to the river each year hence increasing the socio-economic damages of floods when they do occur.

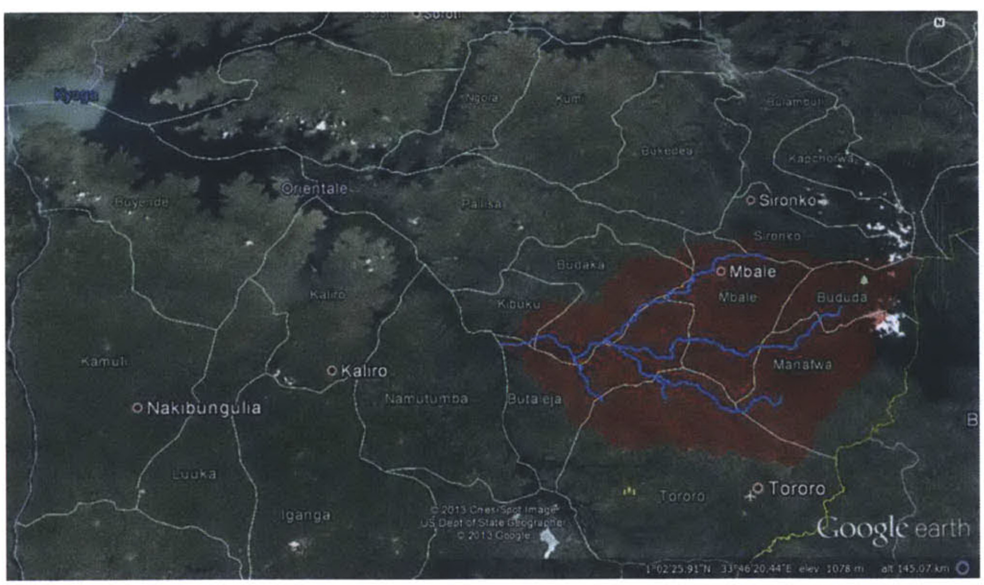
Cecinati, 2013 indicated that the average amount of rainfall during rainy seasons in the Manafwa watershed has decreased but extreme rainfall events have increased which could explain the increased flooding in the region. Having climate change as the only cause of increased flooding is popular because it removes responsibility from locals, local leaders and government officials. Land use management, on the other hand, is an issue that can and should be managed locally. Proper land use and city planning can contribute to mitigating flood risks in the river basin. Local communities and their leaders, if shown the benefits of proper land use practices, can take the necessary steps towards a safer future. The result of this work will showcase how land use changes affect flooding in the Manafwa River watershed.

Using the HEC-HMS software and information on land use changes in the Manafwa River basin, this study will examine the river stage and river flow as a selected output. The study will focus on changes in watershed outflow and river flow due to land use changes. It is expected they will be dependent upon land use changes.

1.2 Study Area

The Manafwa river basin is located in the eastern region of Uganda, near the Kenyan border (Figure 1). Flooding of the Manafwa River affects the livelihood of about 45,000 people in the districts of Manafwa, Butaleja, and Bududa. Bududa district is located upstream of the river, at the foot of Mount Elgon. Bududa is more affected by landslides on Mount Elgon than it is by floods, but floods downstream are usually caused by rainfall in Bududa. Manafwa, Mbale, and Butaleja are downstream of Bududa on the Manafwa River; Butaleja is the furthest downstream of the three and is flooded most often. The three districts are at an altitude ranging from 1000 to 1200 meters above sea level; Butaleja, farthest downstream, is flattest of them.

Figure 1: Manafwa River and Manafwa watershed



1.3 Population in the Manafwa River basin

Sub-Saharan countries have the some of the highest population growth rates in the world. Uganda has a 3.3% population growth rate, 3rd in the world with 34.1 million inhabitants as of 2012 (C.I.A., 2012). Except for Mbale district, all the other districts in the Manafwa watershed have a population growth rate above the country average. The Uganda Bureau of Statistics (UBoS) estimated a population growth rate for the Bududa, Butaleja, and Manafwa districts at 3.99%, 3.52%, and 3.49% respectively.

Figure 2: Uganda population, with a mid-year 2012 projection, UBoS

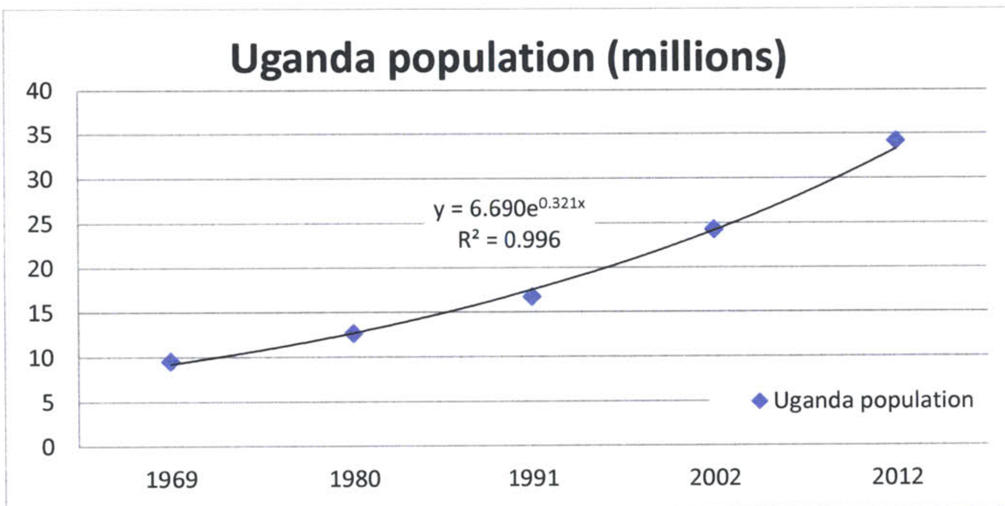
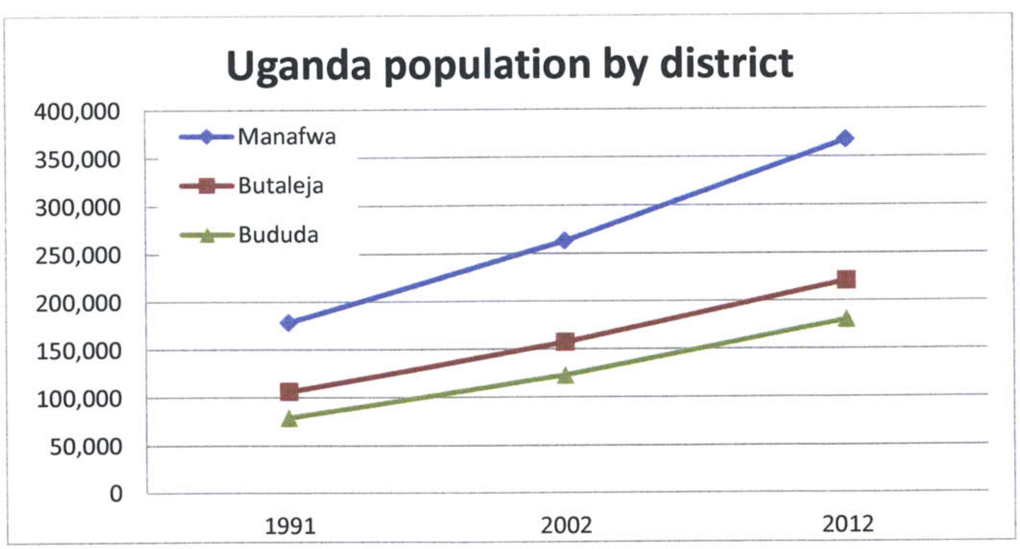


Figure 3: Uganda population, with a mid-year 2012 projection, UBoS



UBoS also estimated the Ugandan urban population to be about 5 million in 2012, about 15% of the total population. Therefore, in the districts of interest, it is assumed that most of the population lives in rural areas with subsistence agriculture as their primary source of food and income; a January 2013 site visit confirmed this assumption. As the population increases more cultivated and built land is needed to satisfy the population's needs.

1.4 Floods in the Manafwa River basin

Although there are official records of floods in the study area, only partial records were found. These records are not detailed and only relatively recent and major floods were recorded. The records retrieved are all from international organizations. The Red Cross created a record of floods (Table 1) for post-emergency fundraising purposes. The URCS is currently in the process of generating a more accurate record of floods in the region; it is a tedious and demanding process.

Table 2 represents the data supplied by the URCS. Another source of information on flooding was the International disaster database (EM-DAT) which recorded with more details disasters in the study area (Table 3).

Table 1: Red Cross appeal list of natural disasters in Manafwa River basin

Date	Involved Districts	Type of event	Affected Households
July 2011	Bududa	Landslide	NA
	Butaleja	Flood	231
	Mbale	Flood	45
March 2010	Bududa	Flash Flood, Landslide	206
	Butaleja	Flood	1204
	Mbale	Flood	238
	Manafwa	Flood	56
	Budaka	Flood	211
July-Sep 2007	Bududa	Flash Floods, Landslides	560

Table 2: URCS list of floods in the Manafwa River basin

Year	Parish	Village	No. killed
2007	Bufuja	Nasogo	2

2008	Lubembe	Nandelema	3
2009	Dhoho	Muhuyu	1
2010	Muyago	Wega, Wapala, Namahere, Paya, Leresi and Butesa	6
2010	Dhoho	Kooli	3
2010	Kapisa	Manafa	1
2012	Tindi	Tindi	-
2012	Kanyenya	Kanyenya A	-

Table 3: EM-DAT list of disasters in the Manafwa River basin

Year	Districts	Start month	End month	No. killed	No. affected	No. homeless
1997	Tororo, Mbale	11	11	100	150000	3500
2002	Mbale	4	5	17	760	0
2003	Mbale	7	7	20	700	0
2006	Butaleja	10	12	0	4000	0
2007	Bududa, Mbale, Manafwa	8	10	29	435070	282975
2011	Mbale Butaleja	8	9	27	63075	0

As part of this study, a survey was conducted in five villages of the Butaleja district to gather more information on floods in the watershed from residents. In each village five people who had each lived in the village for more than 15 years were interviewed. The villages were selected by a Red Cross volunteer with a selection criterion that the villages be located near the river. Meetings with villagers were organized Red Cross volunteers. Because of time and resources limitations only five persons were interviewed per village.

The survey sought to determine how often villages were flooded, in which year and month were the worst floods experienced, how high was the water when flooding occurred, and what villagers would do if there was a functioning forecasting system warning them of approaching floods. The answers to when the worst flood occurred were subjective, but facilitated identification of the worst years in terms of flooding.

Table 4: Flood records from a 2013 survey of 5 villages in Butaleja

Tindi Village	Masulula Village	Doho Village	Nahasalagala Village	Wagabono Village
February 2012	April 2012	November 2012	June 2012	2012
April 2012	1997	1997	April 2012	1997
May 2012	1994	1962	1997	1961
April 2011	1960			

Local leaders and Red Cross volunteers were instrumental in the acquisition of information on floods in the region, both in document and survey form. The Red Cross confirmed some of the information gathered from the survey such as the flood frequency and the dates of some of the worst floods each district experienced.

Floods are caused by the storm water runoff which is dependent on rainfall and land use in the watershed. Rainfall dictates the amount of water that falls on the earth's surface, and the land use determines the percentage of the storm water that becomes runoff. The work of this thesis was conducted because understanding the impact of land use changes on storm water runoff will allow local planners to take appropriate actions and decrease the negative consequences of subsequent floods.

2 Literature Review

Since the second half of the 20th century, the alarming increase in urban population and the growing need for natural resources accelerated land use changes and made these changes an important parameter in flood events investigation. Urban areas are notorious for their exposure to flash floods. There is little space for rainwater infiltration in typical urban areas. Without infiltration, most of the rainwater becomes runoff and leads to floods when the rain is excessive. This phenomenon is not limited to urban areas; in rural areas, natural vegetation is being replaced by agricultural fields as the demand of crops increases. Mining activities are similarly responsible for land use changes. Like agriculture, mining activities increase with the growing world population. These anthropogenic activities cause land use changes leading to land cover changes, which cause an increase in runoff and as a result increase the river flow.

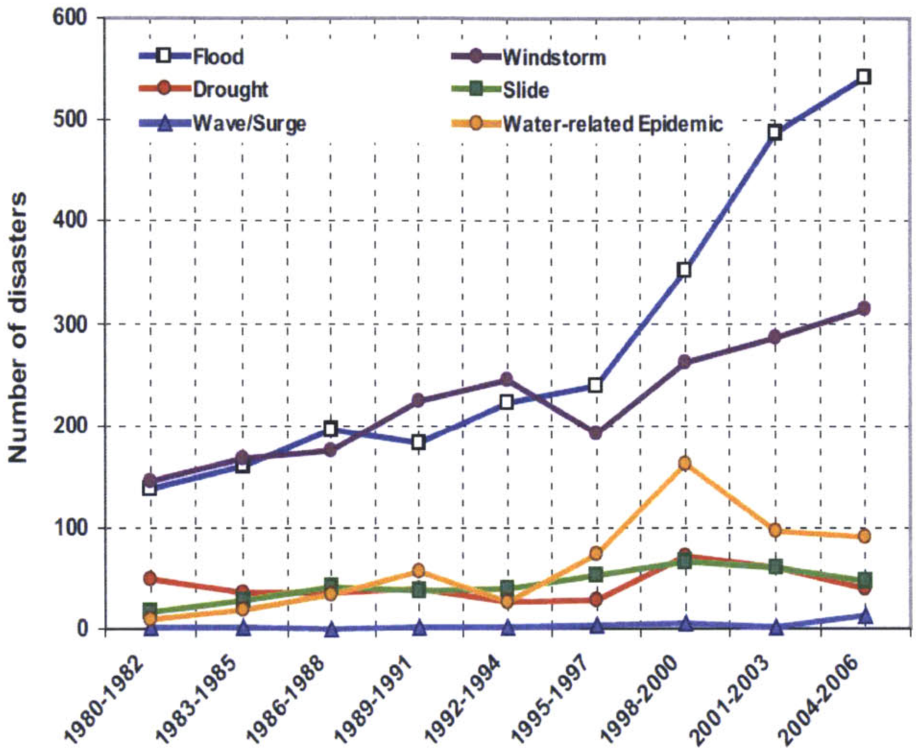
The goal of this study is to quantify the impacts of land use changes on floods in the Manafwa River basin. Therefore, it is important to start by understanding flood events in other regions of the world and how they are linked to their respective local land use changes.

2.1 Floods in the world

A flood is an overflow of water past its natural or designed confinement to cover a normally dry land. There are different types of floods: some occur slowly due to long rainfall events and others occur in a few minutes with no apparent local rainfall; some cover small areas like neighborhoods or village and others cover large areas like cities; some are caused by natural events like rainfall and glacier melt, and others are caused by engineering defects like dam or levee failure. Floods are hazards, but without humans living in the flood plain they would be a simple water overflow. When the flood plain is inhabited, its population is vulnerable to flooding. When a population doesn't adequately prepare to manage flooding, the simple water overflow becomes a disaster.

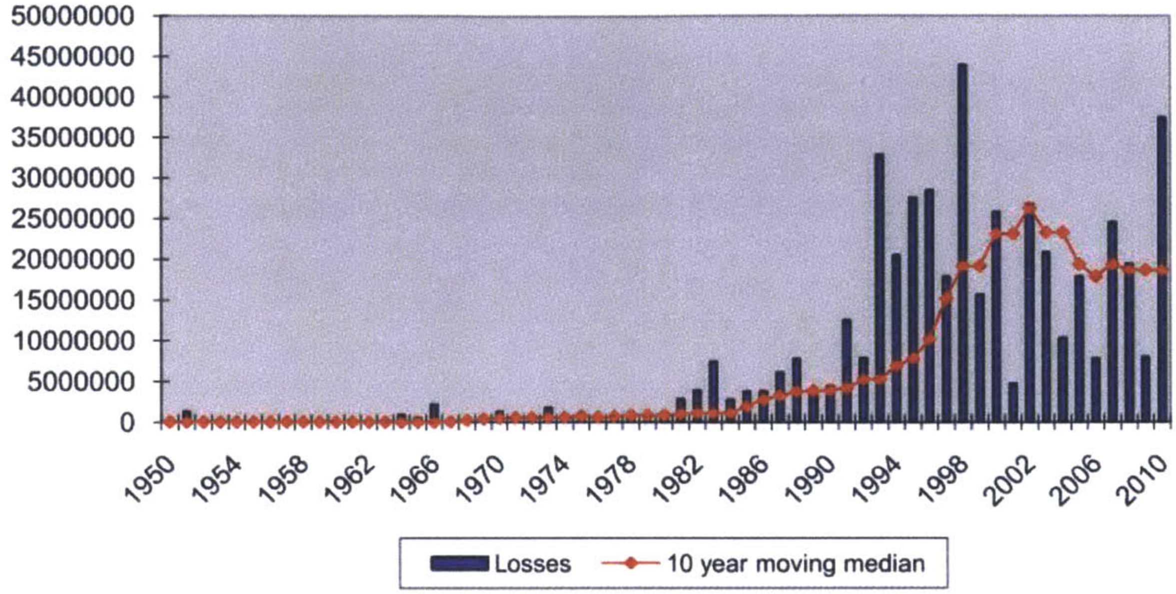
The United Nations World Water Assessment Program reported that between 1900 and 2006 about 30% of natural disasters were floods, and these floods affected about 48% of the people affected by natural disasters (Adikari & Yoshitani, 2009). Of all water-related natural disasters, floods seem to be increasing in frequency (Jha et al., 2011). Figure 4shows that the number of recorded floods has more than doubled in the last twenty years, which is uncharacteristic of other water-related disasters.

Figure 4: Water-related disaster events recorded globally, 1980 to 2006 (Adikari & Yoshitani, 2009)



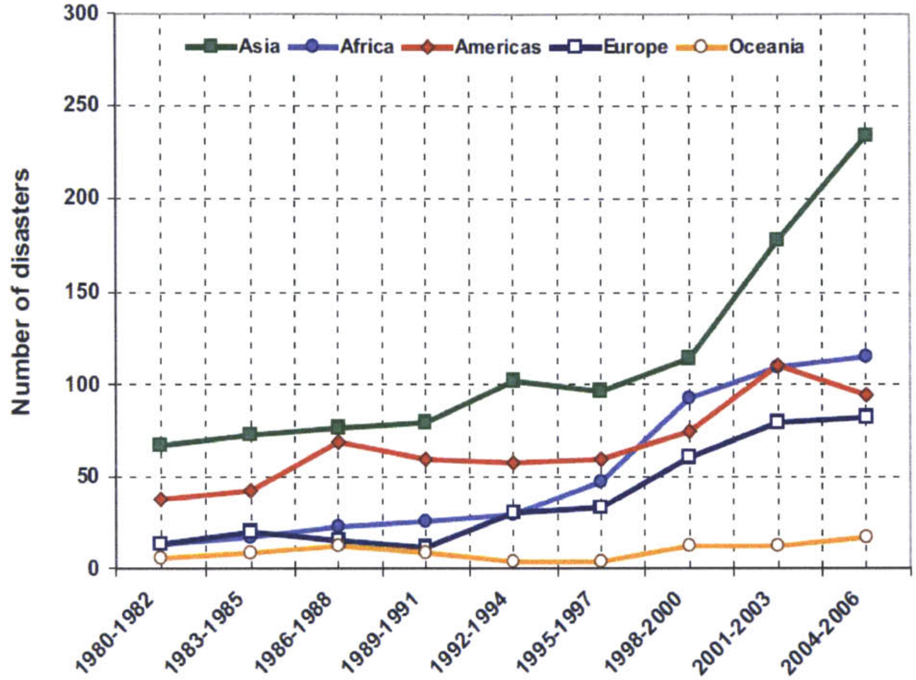
The socioeconomic impact of floods has also increased over the years; as seen in Figure 5, the cost of floods has increased dramatically during the last two decades. This data only considers damages to physical properties, but the consequences of floods are normally worsened by the health toll on the population affected. Diseases and malnourishment are more frequent; hospitals and health centers often cannot handle all cases. Floods are frequent and devastating enough that many countries have invested heavily in flood forecasting systems and have implemented evacuation plans as well as emergency measures that mitigate the impact of floods.

Figure 5: Global Losses due to flooding (Jha et al., 2011)



A 2011 World Bank report on flooding in cities (Five feet high and rising: Cities and flooding in the 21st Century) noted that the number of deaths due to flooding in the 2000-2010 decade had decreased significantly compared to the previous decade (Jha et al., 2011). This decrease is partly because of advanced warning systems and effective evacuation plans. However, these technological and organizational advances are primarily found in developed countries. Developing countries do not have the combination of advanced warning and flooding preparedness that might result in a decrease of their vulnerability to floods. As shown by the Adikara and Yoshitani, flood events increased primarily in Asia and Africa, where most of the developing countries are located (Figure 6).

Figure 6: Recorded number of floods by region, 1980 to 2006 (Adikari & Yoshitani, 2009)



Floods, like all natural disasters, have always been hard to document. Sometimes floods happen on a small scale and are judged not worthy of reporting, or they happen in remote areas where people have to see fleeing survivors to know about their occurrence. Some of the increase in the number of floods can be attributed to the advancement of communication, as it is now easier to record flooding events that occur anywhere in the world. Nowadays, news of a flood happening miles away can be transmitted via cellphone; hence more floods and their casualties are recorded. Yet, technology cannot be the only reason the number of floods has increased over the years.

Rapid urbanization can increase the frequency of small floods up to ten times (Jha et al., 2011). In many areas, the infrastructure and urban planning haven't kept up with the increasing urban population, which has led to the establishment of slums in areas that were deemed unsuitable for construction when the cities were first developed. Many slums around the world are built on flood plains without any infrastructure protecting them against floods. Jha et al. (2011) indicate that the urban population is growing faster than the world's population. This is accentuated in developing countries, where urban growth rates of 3.3% in the Middle East and Africa, and 2.7%

in Asia-Pacific, are higher than the 2.1% total growth rate of the world's population (Jha et al., 2011). This makes flood forecasting and management a growing concern for many countries.

The situation in the districts affected by the floods from the Manafwa River is consistent with these global trends. The population in Butaleja, Bududa, Manafwa, and Mbale district is increasing at a combined growth rate of about 3.3%. The city of Mbale is the only urban area in the region and its population is growing. The population in the other districts lives in rural areas where subsistence agriculture and cattle rearing are the main sources of income. The increasing population requires more land in order for it to be fed; this increased use of land is enhanced by inefficient agricultural practices. Expanding agriculture has led to the encroachment of the National Park on top of Mount Elgon, upstream of the Manafwa River, and the wetlands located downstream. These virgin soils are very fertile, which attracts the growing population. Like most parts of the world, the Manafwa River basin is likely to experience more floods, and they will be increasingly damaging as the population and infrastructure accrue in the flood plain.

2.2 Land use monitoring

Urbanization and other anthropogenic activities change the land cover and land use, and these changes subsequently affect river flow; therefore, understanding the impact of land use changes on floods is imperative given the increasing frequency of flood events. Land use and land cover are often used interchangeably, but since this analysis is focused on land use changes it is important to distinguish the two terms and explain how they relate to one another. Chandra P.Giri (2012) defines land cover as the observed biotic and abiotic assemblage of the earth's surface and immediate subsurface and land use as the function that humans have given to an area of the land. Land cover is the physical cover of the earth's surface such as forests, water bodies, grasslands, savannas, urban areas, and permafrost. Land use is the function given to a parcel of land; it can be used for agriculture, it can be turned into an urban area, or it can become a protected forest or park (Giri, 2012). A particular land cover can have different land uses. For example, an urban area land cover can be residential or commercial, just as forest land cover can be a protected park or a wood production resource. Usually land cover changes are due to land use changes; the city of Las Vegas changed the land cover of the area from a desert to an urban area.

Land cover and land use data is collected using satellite images, aerial photographs, and in situ surveys. Amongst these sources of data, satellite images are used more often and are easily accessible. Land use is not easily deciphered from satellite images; sometimes, additional information from parties involved in the land function is needed. On the other hand, land cover can be easily determined from satellite images and there are standard processes used to determine land cover types. Land cover data was first collected when city planners attempted to manage urban resources like water and land. The data collection started with simple mapping and evolved to the satellite images that are currently used. Satellite images came to prominence in the 1970s as NASA and other agencies had a growing interest in remote sensing data acquisition (Loveland, 2012). During the 1980s, launches of Landsat 4 and 5, the Thematic Mapper (TM), a new sensor with improved spatial and multispectral capabilities, and the French Satellite Pour l'Observation de la Terre (SPOT) mission led to the availability of high resolution land cover data. In spite of the success and popularity of Landsat and SPOT, Tucker et al. (1985) demonstrated the value of coarse-resolution space-based imagery with their use of advanced very high resolution radiometer (AVHRR) data to map Africa's land cover (Loveland, 2012). The success of AVHRR led to nation scales land cover mapping during the 1990s, and ultimately, the creation of AFRICOVER; the United Nations Food and Agriculture Organization (FAO) project that provided consistent, high-resolution land cover for all areas of Africa. The data was manually interpreted from Landsat and other similar resolution data, and country maps were developed using in-country teams (Loveland, 2012). The Africover project started the Land-Cover Classification System (LCCS), a land cover legend that allowed for consistency in land cover data. This study uses an Africover map of the watershed in its analysis of land use change impact on floods.

3 The Manafwa Watershed Hydrologic Model

In order to quantify the impact of land use changes in the Manafwa River basin, land use, land cover, and population data must be inputted in the hydrologic model of the Manafwa watershed. The hydrology of the Manafwa watershed was simulated using a model built with the Hydrologic Engineering Center Hydrologic Model Simulation (HEC-HMS) software developed by the United States Army Corps of Engineers (USACE).

3.1 HEC-HMS

Hydrologic models relate rainfall to runoff and thus river flow. A flood warning system based on precipitation data cannot work without a component relating precipitation to river flow, which is what a hydrologic model does. For this study, HEC-HMS was chosen as the software with which the static hydrologic model of the Manafwa watershed was to be developed. HEC-HMS was chosen because of its simple interface and its ability to handle continuous modeling and assessment, which will be used in the future as part of the flood forecasting system. Additionally, HEC-HMS is able to perform a hydrologic analysis of the Manafwa river basin with a few parameter inputs; a valued fact considering the lack of reliable data for this region.

HEC-HMS models the hydrology of a watershed by using two sub-models: a basin model to represent the physical characteristics of the watershed and a meteorological model to represent the meteorology of the watershed, which incorporates precipitation. The basin model incorporates methods that simulate infiltration rate of water into the soil, transformation of excess rainfall into runoff, contribution of base-flow to river flow, and runoff flow through open channels. Each of these simulations in the basin model has multiple options that could be used for modeling purposes. The options that were selected for the Manafwa watershed hydrologic model are: (1) the SCS curve number method as its infiltration method; (2) the SCS unit hydrograph as the transform method; (3) the lag method as its routing method. These methods were specified for each sub basin in the watershed.

The core physical characteristic of the Manafwa watershed is contained within the infiltration simulation, making the SCS curve number method an important part of the model. The SCS Curve Number method was developed by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS); the NRCS was formerly known as the Soil Conservation Service (SCS), in 1954. The method was initially designed to predict runoff from agricultural fields after rainfall and its use has not expanded to urban hydrology (NRCS, 1986). The SCS option only requires two input parameters, the curve number of each sub basin and the percentage of impervious area in the sub basin:

- The runoff curve number also known as the SCS Curve Number or simply curve number is used in hydrology to determine the amount runoff or infiltration after a rainfall event. The Curve Number (CN) is an empirical parameter calculated from the soil's hydrologic group, the land use, and hydrologic conditions. The CN is reflective of the fraction of the total precipitation that becomes runoff; consequently, the higher the CN, the greater the runoff fraction. The runoff equation is:

Equation 1: The runoff equation (NRCS, 1986)

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}$$

Where Q is the runoff [L]

P is the rainfall [L]

S is the potential maximum soil moisture retention after runoff begins [L],

$$S = \frac{1000}{CN} - 10$$

I_a is the initial abstraction [L] = 0.2S

- The percent impervious surface represents the fraction of the watershed's surface that is impervious to rainfall water. Population growth leads to land use and land cover changes and it also impacts the impervious surface percentage. For example, in rural areas, when the population increases it increases the demand of houses which in turn lead to an increase of the number of houses. Population increase can also lead to an increase of the urban area and its surrounding slums. These examples lead to an increase of impervious surface.

3.2 Precipitation in the Manafwa watershed

Precipitation data from the Tropical Rainfall Measuring Mission (TRMM) was used as input for the meteorological sub-model of the hydrologic model. The TRMM is a joint mission by the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA). Its goal is to monitor and study tropical rainfall. TRMM data is available online at no cost. TRMM data is widely used, has been validated, and out of the possible sources of remote sensed precipitation data it was the best fit for the Manafwa watershed (Cecinati, 2013). The TRMM data was processed using MATLAB, averaged on each sub basin, calibrated, and finally converted to a format that HEC-HMS could read. For more information on the processing of the rainfall data, refer to (Cecinati, 2013).

3.3 Calibration of the Manafwa hydrologic model

The hydrograph output from HEC-HMS must be calibrated using measured data. The Manafwa Watershed Hydrologic Model (MWHM) outputs total runoff leading into the Manafwa River. Historic Manafwa river level data were collected by a river gauge located near a bridge on the Butaleja-Mbale road in Busiu. The river gauge is not in the middle of the river and no river cross section data is available for that specific location. Therefore, river flow rate values were estimated from the water levels by using an estimated cross section area –calculated using available cross section data of the river –and the Gauckler-Manning formula (Equation 2).

Figure 7: Manafwa River Cross section

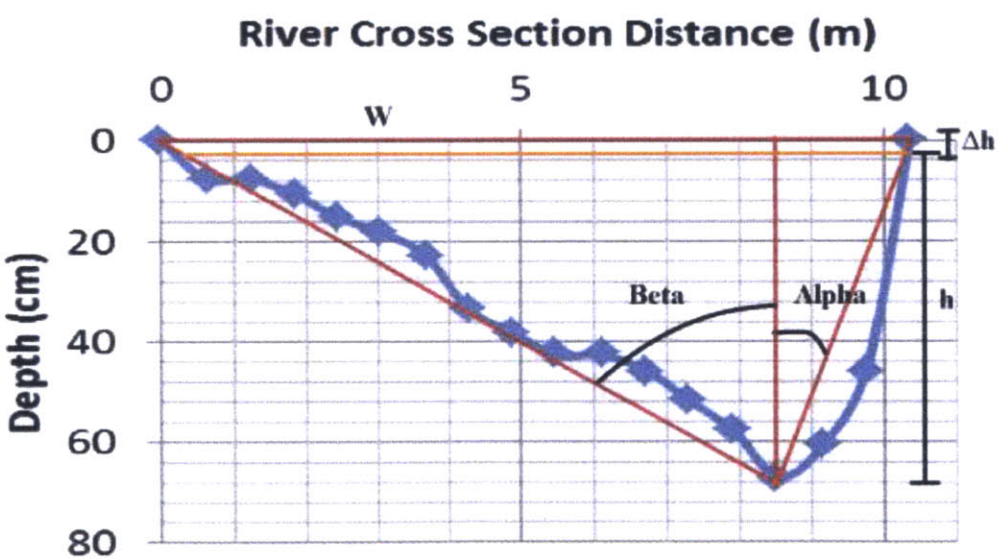


Figure 7 shows a cross section of the Manafwa River taken further downstream of the river gauge location. This cross section was approximated to a triangle in order to facilitate calculations of the cross sectional area. The following is the derivation of the relationship between the river flow rate and the river level:

$$\alpha = tan^{-1}\left(\frac{1.5}{H}\right) \qquad \beta = tan^{-1}\left(\frac{8.5}{H}\right)$$

$$W = H[\tan(\alpha) + \tan(\beta)]$$

$$P_h = H\left(\frac{1}{\mathrm{Cos}(\alpha)} + \frac{1}{Cos(\beta)}\right)$$

$$R_h = \frac{A}{P_h}$$

Where

$H = h + \Delta h$; h is depth from the deepest point of the river and the bottom of the river gauge and Δh is the river level measured by Manafwa river gauge.

P_h is the wetted perimeter

A is the cross sectional area

R_h is the hydraulic radius

Equation 2: Gauckel-Manning equation:

$$V = \frac{k}{n} \times R_h^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

$$A = \frac{W * H}{2}$$

$$Q = A * V$$

Where

k is a conversion factor

n is the Manning coefficient

V is the river flow velocity

W is the river width

S is the river slope

Equation 3: Manafwa River Flow rate (Q) as a function of water level

$$Q = \frac{H^{8/3}}{2^{5/3}} \times \frac{[\tan(\alpha) + \tan(\beta)]^{5/3}}{[\frac{1}{Cos(\alpha)} + \frac{1}{Cos(\beta)}]^{2/3}} \times S^{1/2} \times \frac{k}{n}$$

Where

H = 0.7m + measured river level

α = 85.3 degrees

β= 65 degrees

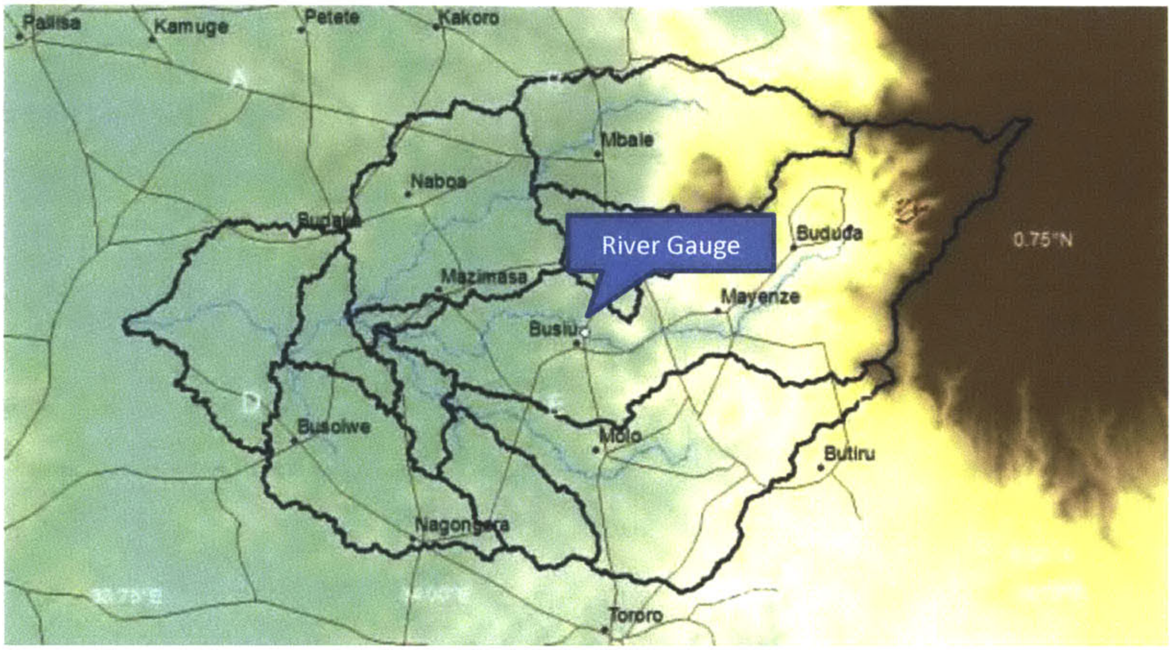
S = 3.86×10^{-5}

k = 1

n = 0.04

The river flow rate calculated from Equation 3 was used to calibrate the flow rate values of the model. As seen from Figure 8, the river gauge doesn't capture the outflow of the entire watershed; it can only be used to calibrate the outflow of the sub basin in which the river gauge is located.

Figure 8: River gauge location in the watershed



3.4 Land Use in HEC-HMS

Land use and land cover are physical characteristics of the watershed; hence, they are parameters that must be inputted in the MWHM. Information provided by land use and land cover maps was inputted in the MWHM as a curve number and percent impervious surface. Land use, land cover, and soil data of a surface area can be used to determine a curve number for that area. The curve number, as previously mentioned, is reflective of the proportion of rainfall that becomes runoff; the greater the curve number, the greater the runoff. All the curve numbers found in a sub basin were averaged as a function of land area and this average became the curve number input of that sub basin. The impervious area can be estimated and later calibrated if necessary. In this study, impervious area was estimated by using population data. This was done with the purpose of capturing the change of impervious surface due to population increase.

3.5 Land use change in HEC-HMS

Because land use and land cover information is all contained in the curve number inputted in each sub basin, land use change was modeled in HEC-HMS by changing the curve number value for that sub basin. If a growing urban area is located in a sub basin, the curve number value for that sub basin will increase in time.

4 Methodology

4.1 Population and Impervious surface

As noted earlier, the districts of Bududa, Butaleja, Manafwa, and Mbale have a high population growth rate. For most of the people in these districts, subsistence agriculture is the main source of food and revenue. An increasing population in these districts can only expand the areas in which subsistence agriculture is practiced. The land demand will decrease the natural or indigenous vegetation and increase the instances of encroachment upon wetlands and forests.

For this analysis, population data was used to estimate the percent impervious surface in the watershed. Because houses decrease the amount of infiltration of rainfall water, it was logical to use population data to determine the trends in impervious surface percentage in the watershed. Not all houses in the watershed have steel sheet roofs; they are ubiquitous in the city of Mbale but not in the rural areas and other districts, where some of the houses are roofed with grass. However, most of the houses have plots covered by a hard compact surface composed of well-trodden dry clay which is fairly impervious. For these calculations, the impervious surface considered was the plot area and it was estimated to be 150m^2. Using this dimension for all houses in the Manafwa watershed, the number of inhabitants by districts, the size of households, and the population growth rate, the percent impervious surface area and its variation with time was calculated using Equation 4.

Equation 4: percent impervious surface

$$\begin{aligned}&\%\ Impervious\ Surface\\&= area\ of\ 1\ House * \left(\frac{number\ of\ inhabitants}{Average\ size\ of\ Household}\right) * \frac{100}{District\ Area}\end{aligned}$$

Population growth rate was used to estimate and project past and future population numbers. Using these estimates and projections in Equation 4, the change of percent impervious surface over time was calculated.

Figure 9 shows the population of each district in the watershed. UBoS reports population growth rates of 3.52%, 3.99%, 3.49%, and 2.93% for Butaleja, Bududa, Manafwa, and Mbale respectively. Additionally, in the 2009-2010 Household Survey report, UBoS reports that average household size in the Eastern region hasn't changed since the 2005 survey (Uganda Bureau of Statistics, 2010). The 2002 census data shows that the household size in the Eastern region was about the same as that reported in 2005. Therefore, it appears safe to assume that the average household size didn't vary significantly over the years, and the same values can be used for every year. UBoS, in an October 2012 Mbale district socio-economic report, estimated the average size of a household to be roughly 6 inhabitants (Uganda Bureau of Statistics, 2012). Because Mbale has the lowest population growth rate amongst the other districts in the watershed, a household size of 6 was used for the watershed instead of the regional average

Mbale town, because of its level of urbanization, has a higher impervious surface value than rural area. The town center has many commercial buildings, and they buildings were not included in these calculations since their owners seldom live in them. Because these calculations are based on household numbers, commercial buildings will not be taken into account which will make our calculations an underestimate of the impervious area.

Figure 9: Eastern region population by district, UBOS

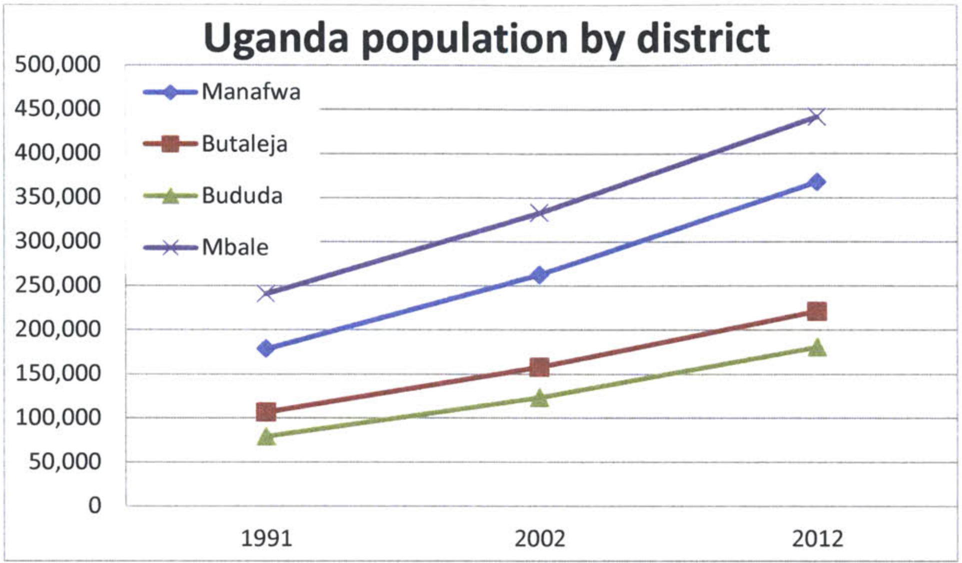


Table 5: Impervious Surface change over time

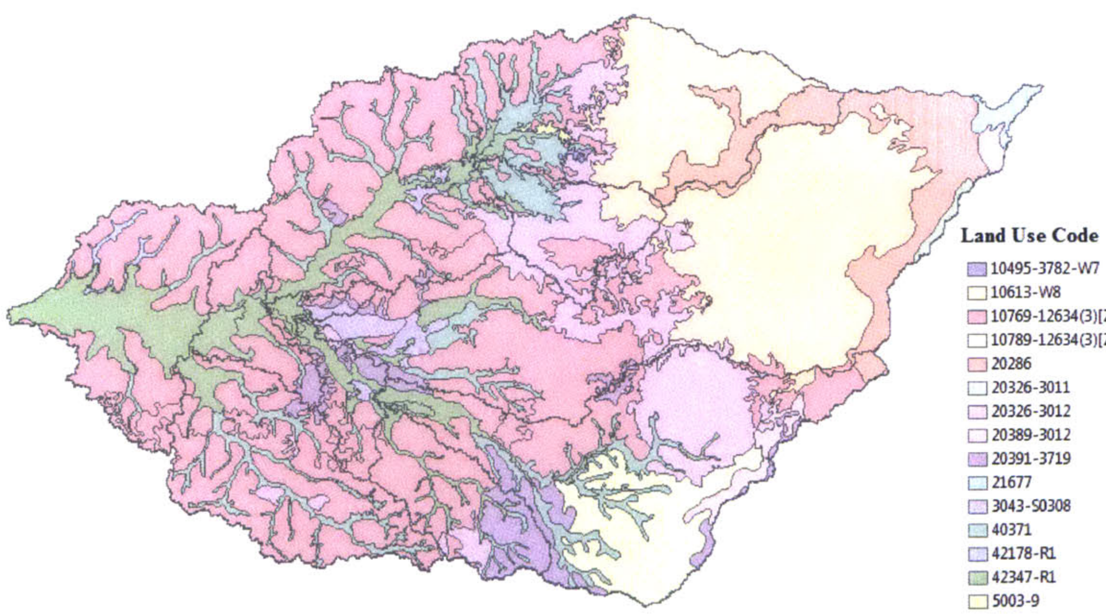
	Mbale		Manafwa		Bududa		Butaleja	
year	population	% imp. Surf.	population	% imp. Surf.	population	% imp. Surf.	population	% imp. Surf.
1970	132405	**0.64**	85785	**0.36**	34271	**0.34**	50938	**0.19**
1980	179194	**0.86**	121613	**0.50**	51075	**0.51**	72430	**0.28**
1991	240929	**1.16**	178528	**0.74**	79218	**0.79**	106678	**0.41**
2002	332571	**1.60**	262566	**1.09**	123103	**1.23**	157489	**0.60**
2012	441300	**2.13**	367500	**1.53**	180600	**1.80**	221100	**0.85**
2022	601165	**2.90**	526708	**2.19**	272899	**2.72**	317671	**1.22**
2032	**813600**	**3.92**	**746687**	**3.10**	**406711**	**4.05**	**451699**	**1.73**

4.2 Land use data processing

This study used two main data sources for the development of a curve number map of the Manafwa watershed: (1) a digital land use map from the AFRICOVER program and (2) a digital soil map from the Harmonized World Soil Database collected global soil data (HWSD).

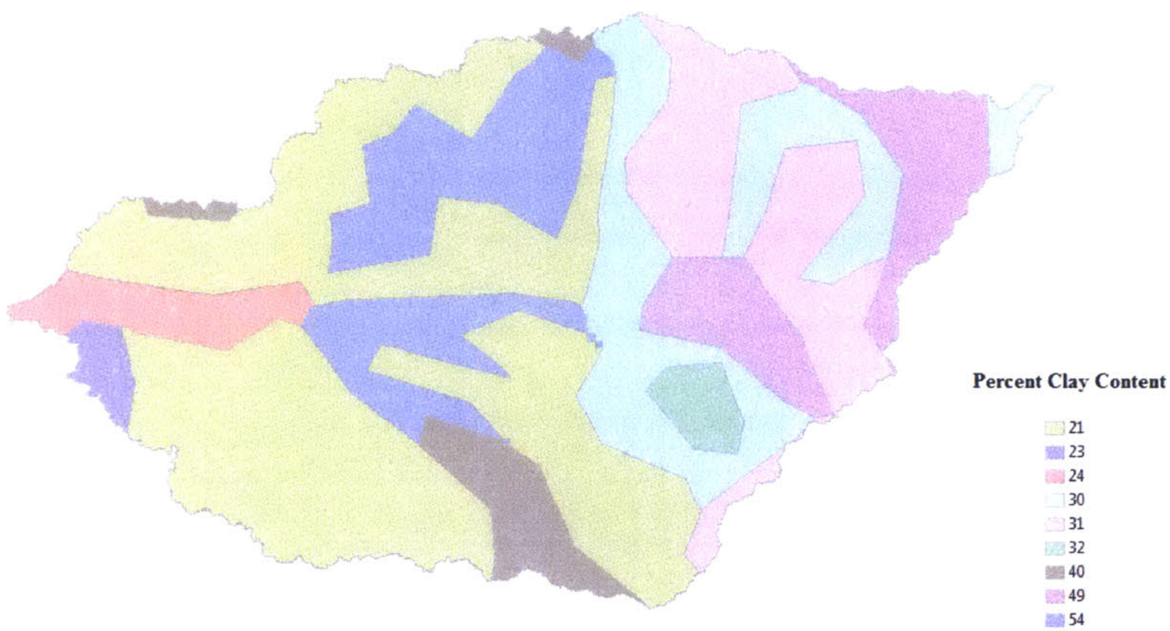
The FAO AFRICOVER program developed a land use map for the African continent. A 2001 AFRICOVER land use map of Uganda was used in this study in order to create a land use map of the Manafwa watershed. This map was used as representative of the current land use state of the watershed, and all the land use changes were modeled using it as reference. Assuming that land use hasn't changed in the past decade since 2001 may not be a strong assumption, but no recent and processed land use maps were found for the Manafwa watershed. Because this study is an analysis the impact of land use changes on river flow (i.e. difference in flow as a function of difference in land use), using a 2001 map is not inappropriate. Using ArcGIS, the land cover classification (LCC) was single out from the data contained in the AFRICOVER land use map (Figure 10) and used to determine the curve number of the different land uses found in the watershed.

Figure 10: Manafwa Watershed Land Use Map, ("Spatially Aggregated Multipurpose Landcover Database for Uganda - AFRICOVER," 2003)



The FAO's HWSD is an online resource that provides worldwide soil information. Part of the information it provides is the clay content of the soil, which was used to determine curve number values for each land use of the Manafwa region. The curve number depends on the hydrologic soil type of the soil on which the land use or land cover rests. The clay content of a soil can be used to determine its hydrologic soil group. Therefore, using ArcGIS, the percent clay content of the dominant topsoil in the watershed was extracted from the HWSD data and a map of percent clay content was created (Figure 11).

Figure 11: Percent clay content, from HWSD database

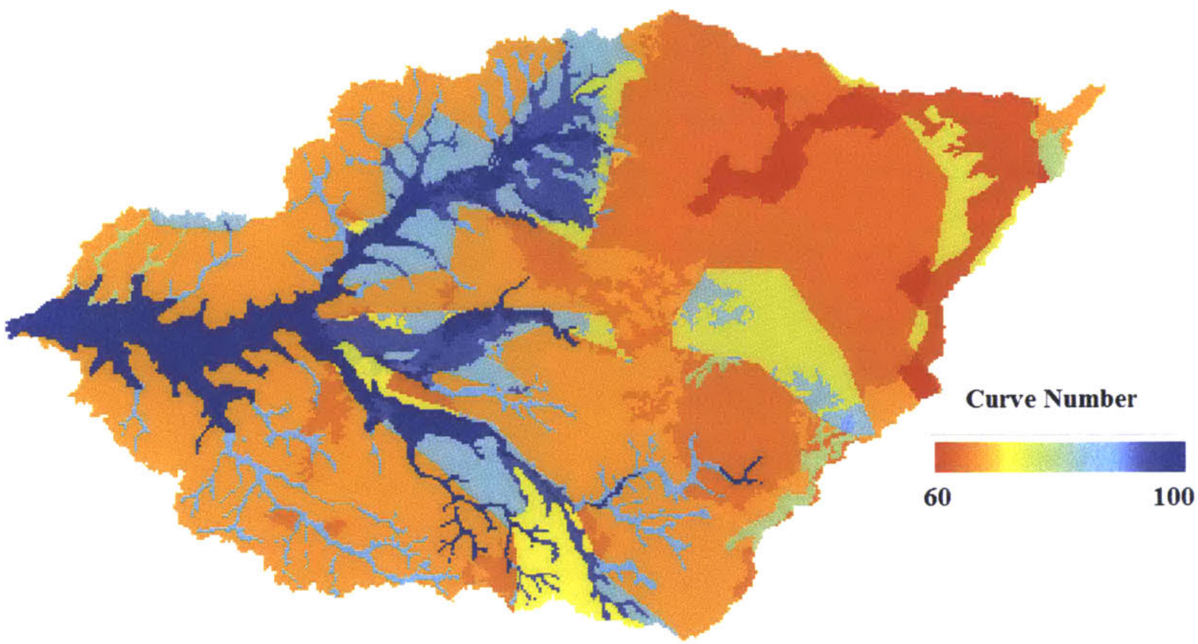


After the LCC and percent clay content data were secured, the LCC legend (Appendix 1) was used to interpret the LCC codes on the map. The LCC legend and the runoff CN table – a table developed by the NCRS that assigns a CN to various land covers and land uses (NRCS, 1986) – were used to assign curve number values to the different land use types found in the Manafwa watershed; Appendix 4 is the result of this process. Only the hydrologic soil types C and D were included in the table because they are the only soil types found in the watershed.

The CN of each land cover type in the Manafwa watershed was determined by using the percent soil clay content map, the land use map, and the NCRS CN table mentioned earlier. They were converted to matrices and processed with a MATLAB function (Appendix 3) that determines a

CN for an area based on its land cover type and percent clay content. The result was a CN map of the Manafwa watershed, Figure 12.

Figure 12: Curve Number map of the Manafwa watershed



4.3 Land use in HEC-HMS

In HEC-HMS the separation of runoff volume from precipitation volume is done using one of the seven loss methods incorporated in HEC-HMS: (1) Green & Ampt, (2) Initial/Constant, (3) SCS Curve Number, (4) Gridded SCS Curve Number, (5) Deficit/Constant, (6) Soil Moisture Accounting (SMA), and (7) the Gridded SMA. As noted earlier, this study uses SCS Curve Number method as the infiltration method because of the relative accessibility of the data it uses as input parameters, curve number and percent impervious surface.

The NCRS, which developed the SCS Curve Number method, developed a table of CN values for particular land cover, land use, and hydrologic soil groups. This study relies on the NCRS table to estimate curve number values for the different combinations of soil type, land use, and land cover found in the watershed.

HEC-HMS models the watershed as a group of connected sub basins. Therefore, data inputted in the model must to be defined on a sub basin scale. The Manafwa watershed has 11 sub basins (Figure 13), and each sub basin has respective land use, land cover, soil data, and precipitation data inputted. As mentioned earlier, land use, land cover, and soil data is combined into one input, the curve number, which is the average of all the CN found in a sub basin. The sub basin average CN is calculated by a statistics function in ArcMap 10.1 and its results are shown in Table 6.

Figure 13: Manafwa watershed Sub basins

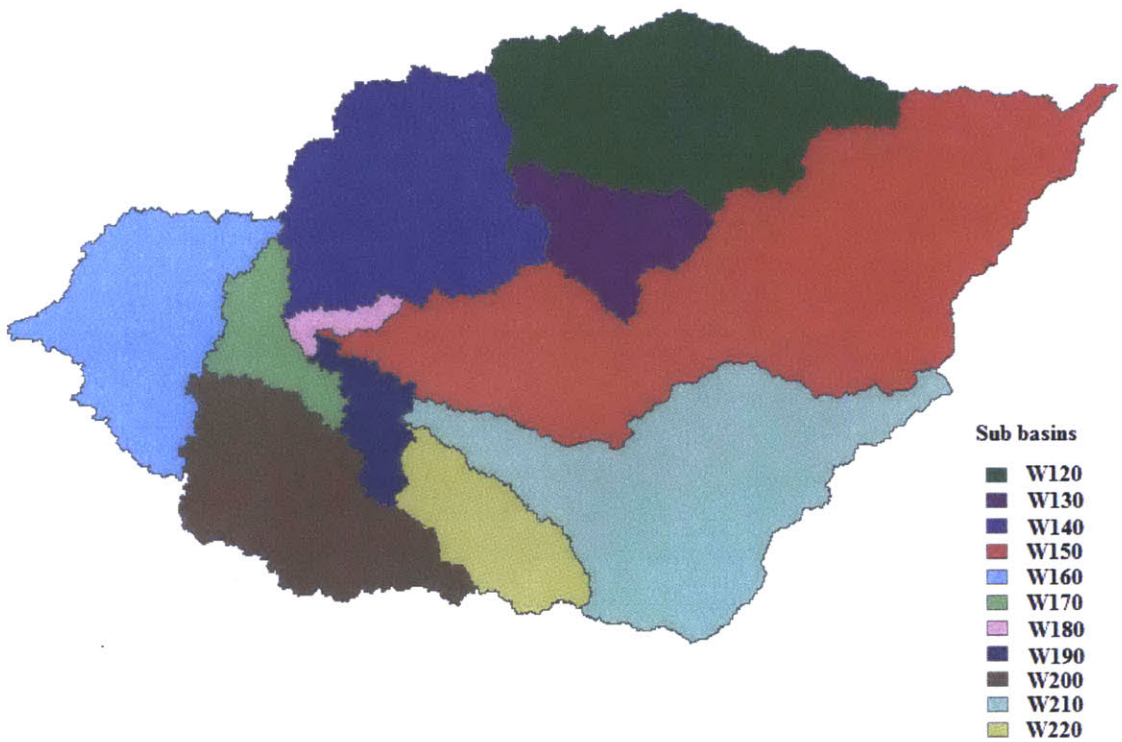


Table 6: Mean CN values per Sub basin

Sub basin	Mean CN
W120	75.6
W130	78
W140	81.4

W150	75.3
W160	83.2
W170	82.4
W180	86.4
W190	82.2
W200	74.4
W210	77.7
W220	80.2

4.4 Modeling land use changes

The goal of this study is to quantify the impacts of land use changes on flood events in the Manafwa river basin by using the Manafwa watershed hydrologic model (MWHM) to study how land use changes affect the Manafwa river flow.

For this study, land use changes were modeled by assuming that only the current land uses found in the watershed could either replace another land use or be replaced by one. This is a safe assumption to make because agriculture is the major source of income in the region, which implies that the main land use changes anticipated in the near future are increase of cultivated lands. Given that cultivated lands are already represented in the current land use map, this assumption in not far from what is observed in the watershed. This assumption allowed, through a series of MATLAB functions and MATLAB scripts (Appendix 5), to model particular land use changes and their extent. The functions and scripts take as inputs the new land use code, the old land use code, and the desired percent change as inputs and ultimately outputs a CN map representative of the watershed land use after land use changes.

There are many land uses changes that could be analyzed in terms of their impact on river flow, but this study was limited to 4 scenarios that answer the following questions: (1) Have land use changes affected floods in the Manafwa River basin? (2) Is there a positive land use change that could alleviate flooding of the Manafwa River?

To answer these questions several land use changes scenarios were used to simulate rainfall and runoff in the Manafwa watershed using the hydrologic model. The river flow was then analyzed for each of the land use changes scenarios. The following detailed descriptions of the land use changes scenarios modeled:

Scenario 1: Current land use

This is the base case scenario with which all the others will be compared. It represents the current land use state of the watershed. As stated earlier, the curve number map for this scenario was developed using a 2001 AFRICOVER land use map of Uganda. The actual land use of the Manafwa watershed is different from the one of the AFRICOVER map, but the map served the purpose of this study because the study analyzed the effects of land use changes on flow. The accuracy of changes made to the current land use map was more important than the accuracy of the current land use map. Table 6 shows the mean CN values per sub basin for this scenario.

Scenario 2: Decrease of cultivated area by half

In order to know if historic land use changes have affected flood events in the Manafwa watershed, a watershed land use map with less cultivated area was created. Most of the crops in the watershed are rain-fed which means that more land is needed to produce more food. With the prominence of erosion, the land is less fertile also leading to the need for more land. Decreasing the area of cultivated area enables the analysis of the watershed's hydrology before the anthropogenic impact became as severe as present. As shown in Figure 14 cultivated areas more than doubled between 1995 and 2006; therefore this scenario will help determine if land use changes have affected flooding events in the watershed.

The land use map of the watershed shows four major cultivated areas: land use codes 10613-S0604W8, 10769-12634(3)[Z10], 3043-S0308, and 10789-12634(3)[Z10] (see Figure 10). These land uses/covers were replaced by forest and woodland, codes 20268 and 20326-3012 respectively. Table 7 shows the CN of each sub basin after the discussed land use changes have been made.

Table 7: Mean CN values per sub basin after decreasing the cultivated area of the of the Manafwa watershed

Sub basin	CN
W120	74.5
W130	77.6

W140	80.2
W150	70.8
W160	83.2
W170	82.4
W180	84.8
W190	81.9
W200	77.3
W210	77.27
W220	80

Scenario 3: Deforestation

A tropical high forest covers Mount Elgon, where the Manafwa River originates. Tropical high forest covered 12.7% of Uganda's land area at the beginning of the 20th century, but because of deforestation and poor land management forests only covered 3% of Uganda at the end of the century (Kamanyire, 2000). More specifically, Mugagga,et al., 2012, show that on Mount Elgon woodland and forest land have decreased by 58% and 34% respectively between 1995 and 2006. Figure 14 shows that this decreased of forest and woodland occurred concurrently with a 241% increase in cultivated land. The high population growth rate in the region suggests that this trend is likely to continue, which is why this scenario was modeled as a possible land use and land cover of the watershed. The future increase in urban area was only considered for Mbale Town because it was assumed Mbale Town would be the main urban area of the region in the next decade.

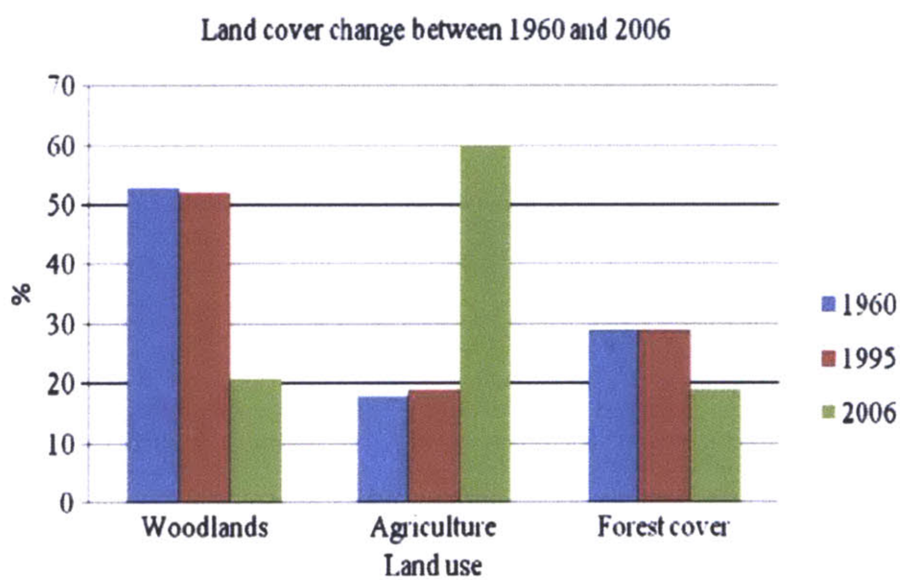
Also considered in this scenario was an increase of the rice field size. An irrigation system and reservoir were built to complement rice fields in Butaleja suggesting that the rice fields could increase in size as demand increases, which may happen given the increasing population. The rice fields were not the only cultivated areas increased downstream of the Manafwa River. It was also assumed that other cultivated areas would increase in time and lead to a reduction of the area occupied by natural vegetation.

For this scenario, most of the area covered by woodland and forest was replaced by cultivated areas. In terms of land use codes changed on the land use map, for this scenario it was the inverse of the changes made in the previous scenario. Table 8 shows the effects of these land use changes on the CN of each sub basin.

Table 8:Mean CN values per sub basin after Deforestation of the Manafwa watershed

Sub basin	CN
W120	77.6
W130	78.9
W140	81.5
W150	77.5
W160	83.2
W170	82.3
W180	86.4
W190	82.54
W200	77.5
W210	78.1
W220	80.3

Figure 14: Trend in Land use Change in Manafwa district (Mugagga et al., 2012)



Scenario 4: Reforestation

Also considered, was a scenario in which better land management plans were implemented in the region. These plans would involve activities such as reforestation, better protection of wetlands and forests. For this scenario it was assumed that the restoration of forest and woodlands in the watershed were completed and that the areas they each covered were double what they are at the present time. Table 9 shows what sub basin CN values would become after the scenario's land use changes were implemented.

Table 9: Mean CN values per sub basin after Reforestation of the Manafwa watershed

Sub basin	CN
W120	75.5
W130	77.9
W140	81.4
W150	72.5
W160	83
W170	82
W180	85
W190	82
W200	77.4
W210	77.3
W220	80.2

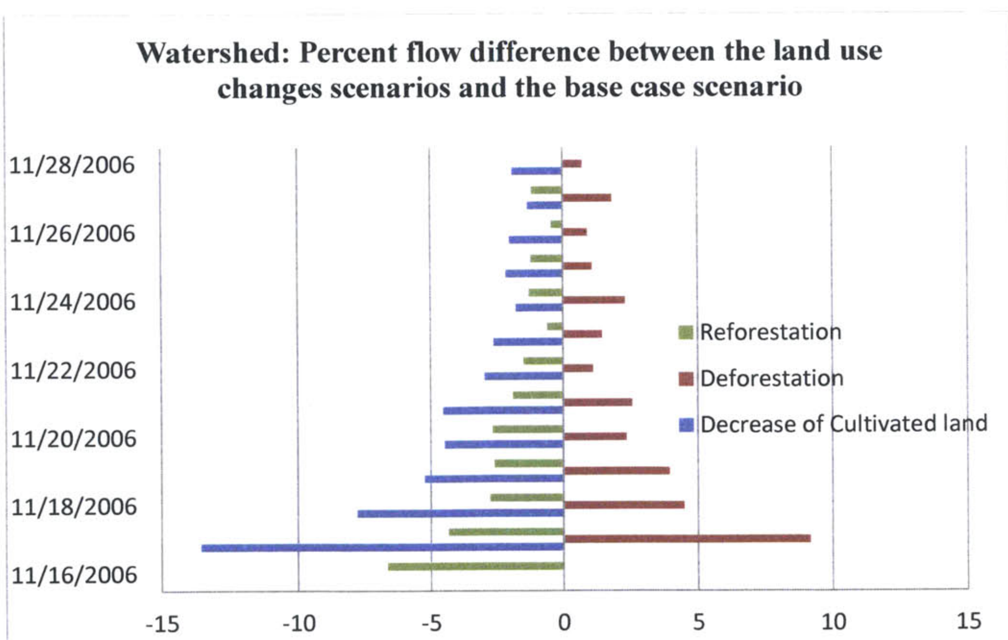
5 Results

5.1 Land use change impact on floods

This study used HEC-HMS to quantitatively observe the relative effects of land use changes in the Manfwa River watershed on runoff rates. Because calculations in this study were performed prior to model calibration, discrete runoff quantification was not possible; instead, a relative runoff comparison was conducted for a limited period of time. The hydrologic model of the Manafwa watershed was used to simulate rainfall and runoff during a fourteen-day period in November 2006 for the four land use changes scenarios discussed earlier. These fourteen days were selected because the Manafwa River levels measured near Busiu showed a spike during that time period. Additionally, impervious surface variations were not considered in the scenarios because the impervious surface is negligible in the Manafwa watershed (Table 5).

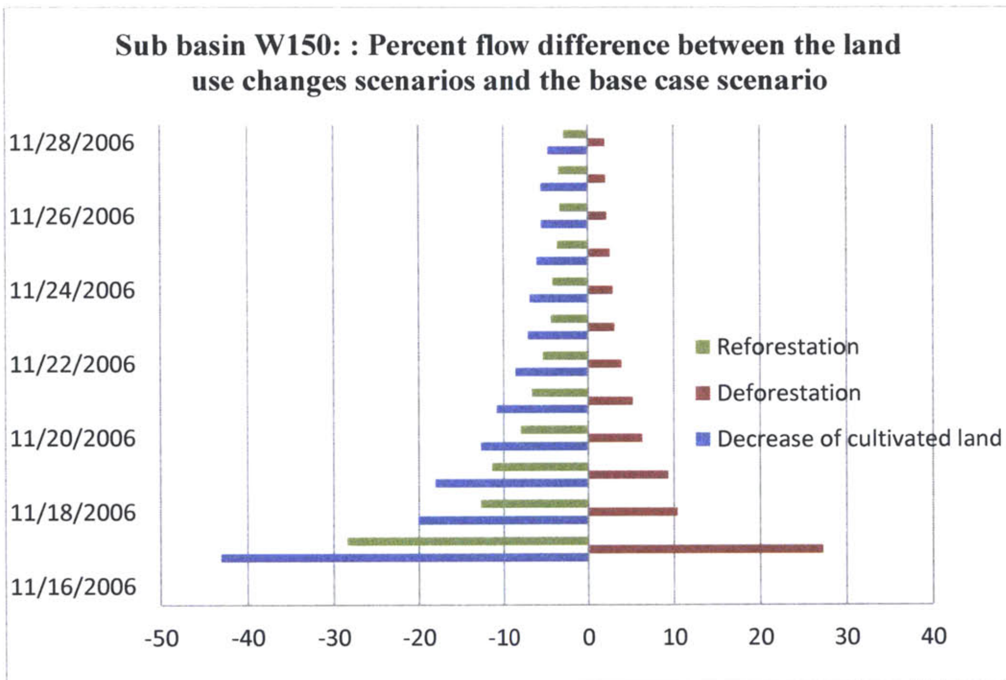
Comparison of the base case land use scenario outflow and the outflows of other scenarios show variations greater than 10% in some cases; this illustrates the magnitude of the nexus between land use changes and flooding (Figure 15).

Figure 15: Percent difference of flow between land use change scenarios at the Watershed's outlet



Focusing on sub basin W150, where Bududa, Butaleja, Manafwa, and Mbale districts are located and where most of the land use changes occurred, the flow differences between the land use changes scenarios and the base case scenario is more significant (Figure 16). This indicates that river flow is very sensitive to land use changes in these districts; watershed outflow increased from the base case by almost 50% due to current agricultural activities in the region.

Figure 16: Percent difference of flow between land use change scenarios at sub basin W150 outlet



5.2 Possible solutions to the issue

Floods are devastating, it's important to mitigate flood risk when possible. One of the actions that could decrease flood risk in the Manafwa watershed is a reforestation program. It is readily assumed that reforestation will diminish the amount of runoff; this study modeled the reforestation program that would double the size of the current forest. The results in Figure 15 and Figure 16 show that watershed and sub basin outflow reduction is possible through a reforestation program. Such a reduction of outflow would result in lowered river levels, which would decrease flooding risks.

6 Conclusion

This study started by highlighting the increase of flood events in the world and stating that evidence shows that global flood events are likely to increase in the near future. This is due to a combination of various factors but mainly climate change and population increase which influences land use changes. This study focused on the Manafwa watershed to analyze the impact of land use changes on flood events.

The land use's role in hydrology is to dictate the amount of water that will infiltrate the soil. If the land is used as an urban area, only minimal infiltration is possible which creates high amounts of runoff. If the land is used for agriculture or as a park, then there is less runoff after a rainfall because more water infiltrates the soil. Given land use's impact on runoff, drastic changes such as the ones that occurred in the Manafwa watershed are expected to affect river flow in watersheds and thereby flood event frequency.

The Manafwa watershed has experienced major land use changes during the last two decades; its fast growing population destroyed forests, woodlands, and wetlands in the search of land to cultivate on which has led to an increase in flood events. Some of the changes on land use and land cover can be reversed by better land management which could alleviate flood risk. These management practices are usually not implemented until it is proven that they will be effective.

This study, using satellite precipitation data, land use maps, a hydrologic model of the Manafwa watershed, and different land use changes scenarios, simulated what would happen to the watershed flow if the land use was changed. The results show that land use changes affect river flow and thus are partly responsible for the increased flood events frequency in the Manafwa watershed. The results also show that better land management can decrease river flow and mitigate flooding risks. Therefore, it might be in the local government's best interest to reinforce forest and woodland protection laws, promote better agricultural practices, and when possible relocate the population out of the flood plain.

6.1 Recommendations

The curve number values were determined using a curve number table developed for North American land uses and land covers. A more accurate outcome could be achieved by using curve number values derived for African land uses and land covers.

A more recent land use map of the watershed needs to be created; it would help with further analyses of the watershed's hydrology.

A calibrated model of the watershed would give more reliable outputs even though the conclusion will likely be the same as the one seen in this work. It is still important for future projects to have a calibrated model to continue further studies in the watershed.

It is in the best interest of the local population and local leaders to start land conservation and restoration projects as they would have a positive impact river flow.

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Appendix

Appendix 1: Manafwa watershed Land Cover Legend

LC	LCCCode	LCCOwnDescription	LCCLabel
1Tree Crops	10495-3782-W7	Large Tree Plantations Rainfed	Permanently Cropped Area With Rainfed Broadleaved Tree Crop(s) Crop Cover: (Plantation(s))
3Herbaceous Crops	10769-12634(3)[Z10]	Small Herbaceous Fields With One Additional Crop and Sparse Tree Crops - Rainfed	Permanently Cropped Area With Small Sized Field(s) Of Herbaceous Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop Sequentially).
9Mixed Class	10789-12634(3)[Z10]	Clustered Small Herbaceous Fields With One Additional Crop and Sparse Tree Crops Rainfed	Scattered Clustered Permanently Cropped Area With Small Sized Field(s) Of Herbaceous Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop Sequentially) .
1Forest	20268	Closed woody with sparse trees	Closed Woody Vegetation With Emergents
2Woodland	20326-3011	Open trees with open shrubs	((70-60) - 40%) Woodland With Open Shrubs
2Woodland	20326-3012	Very open trees with closed to open shrubs	(40 - (20-10)%) Woodland With Shrubs
9Mixed Class	20389-3012 // 21463	Very open shrubs with closed to open herbaceous OR Closed to very open grassland	(40 - (20-10)%) Shrubland with Herbaceous // Continuous Closed to Open Grassland
4Shrubland	20391-3719	Very open shrubs with closed to open herbaceous and sparse trees	(40 - (20-10)%) Medium To High Shrubland With Medium to Tall Herbaceous And Emergents

1Aquatic Or Regularly Flooded Graminoid Crops	3043-S0308	Small Fields Rice	Continuous Small Sized Field(s) Of Graminoid Crops On Permanently Flooded Land Dominant Crop: Cereals-Rice (Oryza spp.)
Error	42347-R1	Closed to Open Herbaceous On Permanently Flooded Land	Closed to Open Herbaceous Vegetation On Permanently Flooded Land Water Quality: Fresh Water
4Open Shrubs	40371	Open general shrubs with closed to open herbaceous on temporarily flooded land	Open Shrubs With Herbaceous Vegetation On Temporarily Flooded Land
Error	21677	Closed to very open grassland with sparse trees and sparse shrubs	Closed To Very Open Grassland with Trees and Shrubs
Error	42178-R1	Closed to very open herbaceous with sparse shrubs on temporarily flooded land - fresh water	Closed to Very Open Herbaceous Vegetation With Sparse Shrubs On Temporarily Flooded Land. Water Quality: Fresh Water
1Built Up Areas	5003-9	Urban areas	Urban Area(s)
2Shrub Crops	10613-S0604W8	Rainfed Shrub Crop, Small Fields - Banana	Permanently Cropped Area With Small Sized Field(s) Of Rainfed Shrub Crop(s). Dominant Crop: Fruits & Nuts - Banana (Musa spp.) Crop Cover: Orchard(s)

Appendix 2: Land use change MATLAB function

```
function L = LanduseChangeOld( landuseMap,NewLandU,OldLandU,Percentchange )
% simulates land use changes, replacing old with new only when they are
% next to each other. change is limited to the percent change inputted.
% This function takes the percent decrease of a land use and starts the
% iteration from the right towards the left of the Map.
n=NewLandU;
m=OldLandU;
L= landuseMap;
s=size(landuseMap);
change=0;
T= changem(L,m+1,m);
T= T-L;
Change=round((Percentchange/100)*sum(T(:)));
for J=1:s(2)
  j=s(2)+1-J;
  if change==Change
    break;
  else
    for i= 1:s(1)
      if change==Change
        break;
      elseif i==1&&j==1&&L(i,j)==n
        M=L(i:i+1,j:j+1);
        N=changem(M,n+1,m);
        M=changem(M,n,m);
        N=N-M;
        change=change+sum(N(:));
        L(i:i+1,j:j+1)=M;
      elseif i==1 &&j==s(2)&&L(i,j)==n
        M=L(i:i+1,j-1:j);
        N=changem(M,n+1,m);
        M=changem(M,n,m);
        N=N-M;
        change=change+sum(N(:));
        L(i:i+1,j-1:j)=M;
      elseif i==s(1)&&j==1&&L(i,j)==n
        M=L(i-1:i,j:j+1);
        N=changem(M,n+1,m);
        M=changem(M,n,m);
        N=N-M;
        change=change+sum(N(:));
        L(i-1:i,j:j+1)=M;
      elseif i==s(1)&&j==s(2)&&L(i,j)==n
        M=L(i-1:i,j-1:j);
        N=changem(M,n+1,m);
```

```
            M=changem(M,n,m);
            N=N-M;
            change=change+sum(N(:));
            L(i-1:i,j-1:j)=M;
        elseif i==1 && L(i,j)==n
            M=L(i:i+1,j-1:j+1);
            N=changem(M,n+1,m);
            M=changem(M,n,m);
            N=N-M;
            change=change+sum(N(:));
            L(i:i+1,j-1:j+1)=M;
        elseif i==s(1)&& L(i,j)==n
            M=L(i-1:i,j-1:j+1);
            N=changem(M,n+1,m);
            M=changem(M,n,m);
            N=N-M;
            change=change+sum(N(:));
            L(i-1:i,j-1:j+1)=M;
        elseif j==1 && L(i,j)==n
            M=L(i-1:i+1,j:j+1);
            N=changem(M,n+1,m);
            M=changem(M,n,m);
            N=N-M;
            change=change+sum(N(:));
            L(i-1:i+1,j:j+1)=M;
        elseif j==s(2) && L(i,j)==n
            M=L(i-1:i+1,j-1:j);
            N=changem(M,n+1,m);
            M=changem(M,n,m);
            N=N-M;
            change=change+sum(N(:));
            L(i-1:i+1,j-1:j)=M;
        elseif L(i,j)==n
            M=L(i-1:i+1,j-1:j+1);
            N=changem(M,n+1,m);
            M=changem(M,n,m);
            N=N-M;
            change=change+sum(N(:));
            L(i-1:i+1,j-1:j+1)=M;
        end
      end
   end
end

end
```

Appendix 3: function creating a curve number map from land use and percent clay maps

```
function C = CurveNumberMap( clay,landuse,CN )
%Maps are represented in MATLAB as matrices and numbers in the matrices are
%values corresponding to each cell of the map.
%Using a percent clay soil map,a land use map, and a CN table, this
%function determines the curve number of each cell of the map thus creating
%a curve number map.
s=size(clay);
C=zeros(s(1),s(2));
n=s(2);
m=s(1);
for i=1:m
    for j=1:n
        if clay(i,j)== -9999
            C(i,j)= -9999;
        else
            if clay(i,j)<40
                C(i,j)=CN(landuse(i,j),2);
            else
                C(i,j)=CN(landuse(i,j),3);
            end
        end
    end
end
end
```

Appendix 4: Manafwa watershed LCC codes and their corresponding CN values

LCCCode	Land Cover	Ascii value	LCCOwnDescr	CN table look up	CN_C	CN_D
10495-3782-W7	Tree crops	**11**	Large Tree Plantations Rainfed	woods-grass combination(orchard or tree farm)/Fair	76	82
10769-12634(3)[Z10]	herbaciou s crops	**4**	Small Herbaceous Fields With One Additional Crop and Sparse Tree Crops - Rainfed	Herbaceous-mixture of grass, weeds, and low-growing brush, with bruch the minor element/good	74	85
10789-12634(3)[Z10]	Mixed class	**15**	Clustered Small Herbaceous Fields With One Additional Crop and Sparse Tree Crops Rainfed	Herbaceous-mixture of grass, weeds, and low-growing brush, with bruch the minor element/good	74	85
20268	Forest	**2**	Closed woody with sparse trees	Open Forest	60	64
20326-	woodland	**13**	Open trees with open	woods/fair	73	79

3011			shrubs			
20326-3012	woodland	**9**	Very open trees with closed to open shrubs	woods/fair	73	79
20389-3012 // 21463	Mixed class	**8**	Very open shrubs with closed to open herbaceous OR Closed to very open grassland	Herbaceous-mixture of grass, weeds, and low-growing brush, with bruch the minor element/fair	81	89
20391-3719	shrubland	7	Very open shrubs with closed to open herbaceous and sparse trees	Shrubland	73	78
3043-S0308	aquatic or regularly flooded	**12**	Small Fields Rice	small grain/straight row+CR/good + Wetland	90	92
42347-R1	error	**1**	Closed to Open Herbaceous On Permanently Flooded Land	wetland	100	100
40371	open shrubs	**6**	Open general shrubs with closed to open herbaceous on temporarily flooded land	Herbaceous-mixture of grass, weeds, and low-growing brush, with bruch the minor element/good + wetland	87	92
21677	error	**5**	Closed to very open grassland with sparse trees and sparse shrubs	Pasture, grassland, or range-continous forage for grazing/Good	74	80
42178-R1	error	**14**	Closed to very open herbaceous with sparse shrubs on temporarily flooded land - fresh water	'Herbaceous-mixture of grass, weeds, and low-growing brush, with bruch the minor element/fair	81	89
5003-9	built up areas	**10**	Urban areas	developing urban areas	91	94
10613-S0604W8	shrub crops	**3**	Rainfed Shrub Crop, Small Fields - Banana	woods/fair	73	79

Appendix 5: Land use change simulation script

```
% Land use change in a watershed
% land use and percent clay maps must have the same size

A= landuseascii;
B= clayclipascii;
```

```
C= curvenumber;
n= 2;
o= 3;
p= 100;
D= LanduseChange(A,n,o,p);
n2=12;
o2=1;
A= D;
D= LanduseChange(A,n,o2,p);
PastLand= CurveNumberMap(B,D,C)
```