The Effect of Land-cover Changes on Lag Time in the Banklick Creek Watershed, KY

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Introduction

Urbanization in a watershed is known to affect the entire balance of the water network, often resulting in more frequent and severe flooding. In a natural environment, precipitation is: intercepted by vegetation and evapotranspired back into the atmosphere, stored in the soil, transported as overland flow to low order streams, or percolated down to the water table (Yang et al., 2009). The prevalence of impervious surfaces in urban areas retards penetration and infiltration and reduces friction and meandering, drastically increasing flow velocity and erosive force. The result is an increased amount of runoff, moving faster, meaning a shorter lag time to discharge, manifesting in less groundwater recharge and higher flood peaks (Wheater and Evans, 2009). Another result of urban development is the destruction of first and second order streams, which also contributes to flooding (Brilly et al. 2006).

The effects of urbanization on flooding have been widely investigated in the scientific community because in an urban environment, flooding is a threat to citizens and infrastructure (Yang et al. 2010). In a 2010 study, a team from Purdue University led by Gouxian Yang investigated the response of watersheds to urbanization in the White River Basin, Indiana. They made land use classes using unsupervised classification of Landsat thematic mapper (TM) and used them in an altered Anderson level-2 classification scheme. They estimated high density urban pixels as 90 percent impervious area, and 35 percent low density. These are according to the Environmental Protection Agency (EPA)'s definition, that 80-100% of highly urbanized areas are impervious, and 20-49% of low-density urbanization is impervious (Yang et al. 2010). This helps account for the error introduced from a large pixel size, which may capture mixed land-cover types.

Methodology

a.) Study Area

The Banklick Creek watershed is a 58-square mile basin covering much of Kenton County and a small portion of Boone County, Kentucky. The creek itself is 19.2 miles long and drains northeast into the

Licking River. It has six main tributaries including: Brushy Fork, Bullock Pen Creek, Fowler Creek, Holds Branch, Horse Branch, and Wolf Pen Branch. An active USGS gauging station, number 03254550, is present on the stream in the city of Erlanger, capturing 58% of the drainage area (Limnotech 2009).

b.) Data

Discharge data from USGS station # 03254550 dates back to 1999, and was obtained in fifteen-minute increments for a ten-year study period from 2000 to 2010. Precipitation data was received from the National Climatic Data Center (NCDC) for station number 151855, the Covington, KY station at the Greater Cincinnati Airport, located approximately 3.5 miles from the Banklick Creek basin. The precipitation data from 2000 til May of 2010 was obtained. Since there was not a full year's record for 2010, the decision was made to narrow the study period into four year increments, with study years of 2001, 2005, and 2009 to capture the trend of the 2000 decade. The three largest discharge events in each study year were identified and averaged into hourly records so that the two data types were in equal units.

To quantify the urban growth in the Banklick Creek watershed over the last ten years, Landsat 4-5 Thematic Mapper (TM) images were obtained from 2000 to 2010 and classified. All images were taken in August and September. This ensures consistency of season, but also allows for enough selection for high-quality images (ranked 9 by NASA) with low (less than 30 %) cloud cover. The images were ordered using the United States Geological Survey (USGS) Global Visualizer (GloVis). Landsat bands 1 through 5 were stacked in ENVI+IDL by date and loaded into an RGB display using bands 4, 3, 2, creating a false-color image. The displays were then enhanced by using a Gaussian stretch tool to apply a normal distribution to the pixel values. This minimizes the possibility of variation between the images due to variations in the image capture, such as time of day, etc.

An unsupervised iterative self-organizing data analysis (ISODATA) classification was run to gain basic knowledge of the land cover classes in the study area. A maximum likelihood supervised classification was then performed in ENVI 4.8 to create major land cover classes in the area. Six classes were used, including forest, agriculture/grass, highly impervious, partial impervious, water, and bare ground. The forest class captures bushy dense vegetation and the agriculture class includes not only cropland but all low-lying less dense vegetation, such as lawns. Highly impervious areas are areas of definite impermeability, such as warehouses, city centers, and airports. The “partial impervious” class includes areas of mixed pixel values characteristic of suburban development, a mix of impermeability and grass. The water class was needed to capture water bodies in the area. “Bare Ground” is a necessary class due to its unique reflectance; it is important to define it separately from impervious surfaces. Pixel values between years may fluctuate between agriculture and bare ground due to weather conditions.

Change detection was then run in four-year increments, 2001-2005, and 2005 to 2010. Unfortunately, every Landsat image taken of the study area for the summer months in 2009 has detrimental cloud cover, making accurate analysis difficult. The decision was made to use 2010 imagery instead. This allows for capture of the land-cover change, although impervious surface values may be slightly over-estimated because of this.

Next, a watershed boundary shapefile was imported into ENVI 4.8 to limit analysis to the study area alone. Change detection statistics in ENVI 4.8 were then run to provide a detailed summary of the changes of land cover classes between each set of images, showing the changes from each class to another. In accordance with EPA guidelines, anything classified as “highly impervious” in this study is considered 95% impervious cover and “partially impervious” is considered 40% impervious.

Results

		Peak Precipitation	Peak Discharge	Lag Time
	#1- 3870 cfs	10/24/01 3:00	10/24/01 7:00	4 hrs
2001 Events	#2- 2650 cfs	7/18/01 0:00	7/18/01 4:00	4 hrs
	#3- 2100 cfs	6/6/01 15:00	6/6/01 18:00	3 hrs
	#1- 5360 cfs	3/28/05 3:00	3/28/05 4:00	1 hr
2005 Events	#2- 5010 cfs	11/15/05 4:00	11/15/05 7:00	3 hrs
	#3- 3830 cfs	1/3/05 9:00	1/3/05 11:00	2 hrs
	#1- 9490 cfs	7/30/09 22:00	7/31/09 2:00	4 hrs
2009 Events	#2- 1860 cfs	10/9/09 0:00	10/9/09 6:00	6 hrs
	#3- 1810 cfs	2/27/09 3:00	2/27/09 7:00	4 hrs

Table 1. Precipitation, Discharge, and Lag Time, Top 3 discharge events for 2001, 2005, and 2009

Image Classification Results:

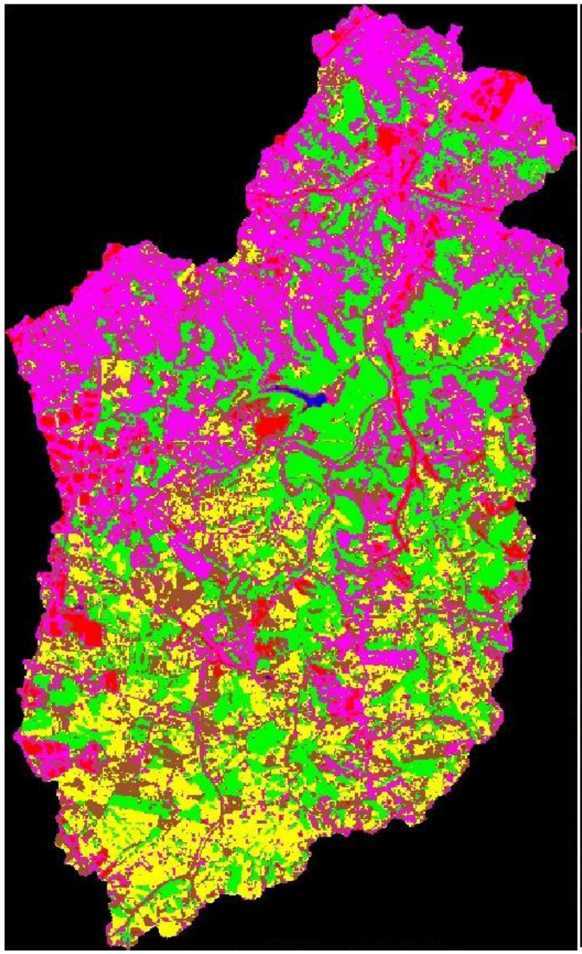

Figure 1. August 2001 Classified Image

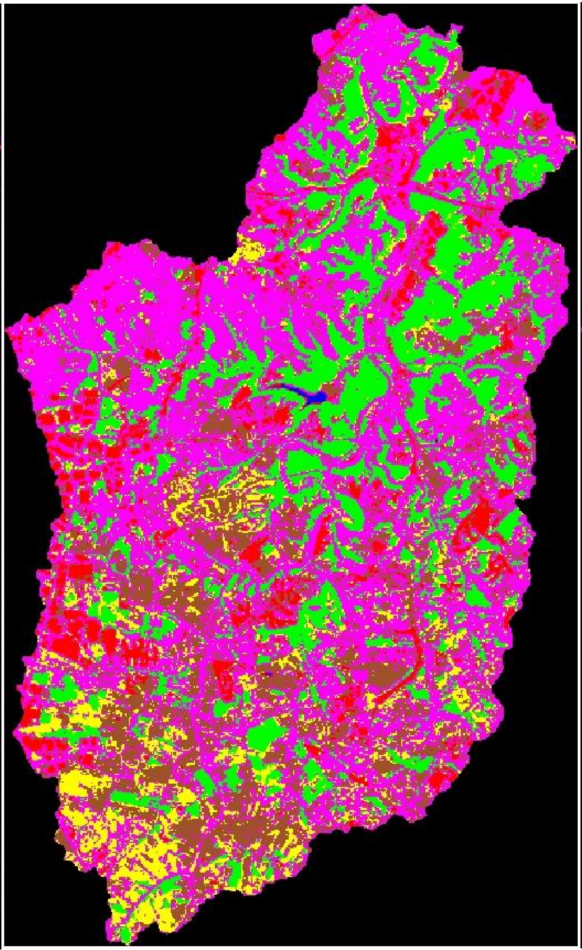

Figure 2. August 2005 Classified Image

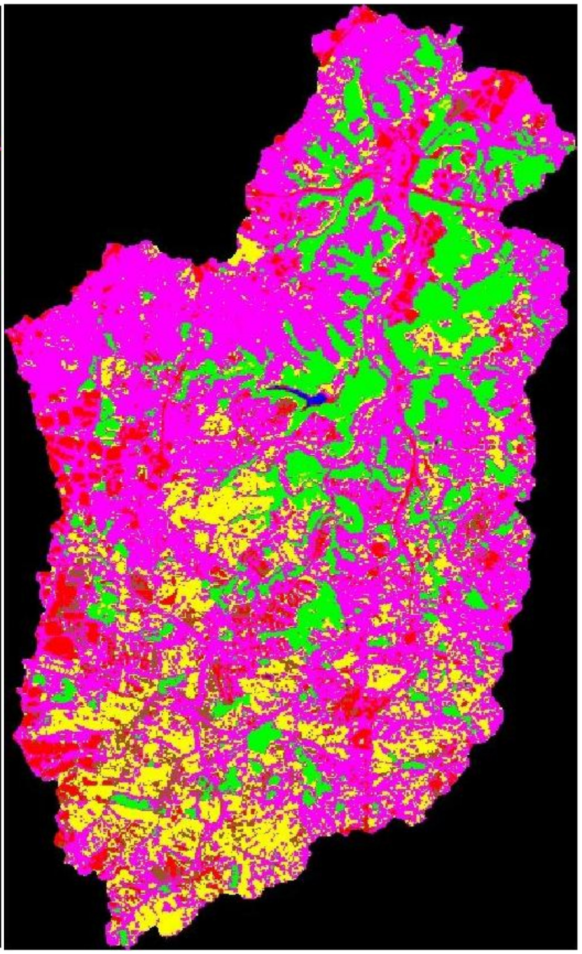

Figure 3. September 2010 Classified Image

Area (Square Meters) Change from 2001 to 2005				
	Forest [Green] 2779 points	Highly Impervious [Red] 2248 points	Partial Impervious [Magenta] 2475 points	Water [Blue] 2077 points
Unclassified	0	0	0	0
Forest [Green] 2678 points	25577100	9900	2870100	0
Highly Impervious [Red] 2163 points	942300	4554000	2322900	54900
Water [Blue] 2718 points	0	9000	900	124200
Agriculture/Grass [Yellow] 3243 points	1571400	59400	1233900	900
Bare Ground [Sienna] 330 points	486000	379800	3604500	0
Suburban [Magenta] 2084 points	7304400	2130300	35753400	2700
Class Total;	35881200	7142400	45785700	182700
Class Changes:	10304100	2588400	10032300	58500
Image Difference:	-5145300	3815100	25101000	-47700

	Agriculture/Grass [Yellow] 2074 points	Bare Ground [Sienna] 1473 points	Row Total	Class Total
Unclassified	0	0	0	83781000
Forest [Green] 2678 points	318600	1960200	30735900	30735900
Highly Impervious [Red] 2163 points	1416600	1666800	10957500	10957500
Water [Blue] 2718 points	0	900	135000	135000
Agriculture/Grass [Yellow] 3243 points	8680500	3979800	15525900	15525900
Bare Ground [Sienna] 330 points	10481400	7772400	22724100	22724100
Suburban [Magenta] 2084 points	6384600	19311300	70886700	70886700
Class Total;	27281700	34691400	0	0
Class Changes:	18601200	26919000	0	0
Image Difference:	-11755800	-11967300	0	0

Table 2. Change Detection Results from 2001 and 2005 images, square meters

Area (Square Meters) Change from 2005 to 2010

	Forest [Green] 2678 points	Highly Impervious [Red] 2163 points	Partial Impervious [Magenta] 2084 points	Water [Blue] 2718 points
Forest [Green] 2198 points	20844900	4500	2707200	0
Water [Blue] 2027 points	0	24300	0	124200
Highly Impervious [Red] 2154 points	393300	6645600	3361500	8100
Partial Impervious [Magenta] 2087 points	8272800	3031200	57904200	2700
Agricultural [Yellow] 2234 points	1062900	345600	5649300	0
Bare Ground [Sienna] 2575 points	162000	906300	1264500	0
Class Total	30735900	10957500	70886700	135000
Class Changes	9891000	4311900	12982500	10800
Image Difference	-6540300	1720800	9758700	14400

	Agriculture/Grass [Yellow] 3243 points	Bare Ground [Sienna] 330 points	Row Total	Class Total
Forest [Green] 2198 points	623700	15300	24195600	24195600
Water [Blue] 2027 points	900	0	149400	149400
Highly Impervious [Red] 2154 points	919800	1350000	12678300	12678300
Partial Impervious [Magenta] 2087 points	4982400	6452100	80645400	80645400
Agricultural [Yellow] 2234 points	8385300	12610800	28053900	28053900
Bare Ground [Sienna] 2575 points	613800	2295900	5242500	5242500
Class Total	15525900	22724100	0	0
Class Changes	7140600	20428200	0	0
Image Difference	12528000	-17481600	0	0

Table 3. Change Detection Results from 2005 and 2010 images, square meters

Lag time was measured as clearly increasing between 2001 and 2005 (Table 1), which shows the effect of urban development in the headwaters seen in the Figure 3, and not Figure 2. There is a 13,664,745 m^2 increase in impervious surface area measured in this time. This area is calculated by multiplying the highly impervious surface area by 95% and adding it with 40% of the partially impervious area in Table 2. The increases in impervious land cover types are accompanied by a decrease in forest and agriculture or bare ground, which further confirms the development trends.

In 2005, many neighborhoods were under construction. These areas of packed ground and gravel were classified as highly impervious (red). Much of these clusters are then classified as partially impervious in the 2010 image (Figure 3). After construction, these sites were regraded and seeded, and lawns and vegetation were established. This is why even though there is still an increase in impervious surface area from 2005 to 2010 of 5,538,240 m^2, lag time is seen to go back up. The results suggest that even though there is significant development between 2001 and 2009, since the land has had time to allow growth of vegetation, the water is slowed back down to a longer lag time between precipitation peaks and discharge peaks. The 2005 image had a much larger “bare ground” class due to a drought that year, with the area only receiving 38.8 inches of precipitation. This creates a false increase in agriculture between 2005 and 2010 with the decrease in bare ground as the vegetation in these areas was reinstated.

Conclusions

The results of this study clearly show the effect that land cover has on lag time between precipitation and discharge peaks. Urbanization reduces infiltration and speeds up runoff, effectively reducing lag time, increasing the frequency and magnitude of flooding. The later results, however, show how with some time for vegetation to develop, lag time can be brought back up. Further studies beneficial to the understanding of this watershed could include higher resolution data, both in imagery and shorter-increment precipitation and discharge data. Hydrologic modeling such as HEC-HMS or the EPA's SWMM model could also be used to project future and model past conditions.

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