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Impacts of Remotely Sensed Land Use Data on Watershed Hydrologic Change Assessment

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Impacts of Remotely Sensed Land Use Data on Watershed Hydrologic Change Assessment

Abstract
Urbanization affects the stream system of a watershed. Increased urbanization alters the land cover and surface characteristics, the stream channel characteristics, and pollutant load of a stream system by increasing the amount of impervious surface. Once rural, forest, or wetland areas are changed to streets, highways, parking lots, sidewalks, and building rooftops. This results in large volumes of runoff being generated for an intense storm over a relatively short time period. As a result, sensitive ecosystems are likely to be damaged by increased urbanization.

Projecting the impact of land use changes on a watershed scale often requires the use of remote sensing data to derive the required inputs on land cover and the related amount of impervious surface. Such forecasts are then used to devise alternative land use and stormwater control policies. One critical question that arises then is the impact of land use/land cover (LULC) mapping error on the resulting hydrologic model projections. In this research, we developed a methodology to assess those impacts. The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model was used to estimate the peak hydrograph for a baseline land use condition and then used to estimate the impact of LULC mapping accuracy levels on those forecasts. The Big Darby Creek Watershed located near Columbus, Ohio, which is experiencing increased urbanization, was selected to map LULC, calibrate a hydrologic model, and assess the hydrologic change due to LULC mapping error. The resulting analysis showed that modest changes in land cover classification did not produce significant impacts on the hydrologic modeling results in rural basins. However, the hydrologic changes are noticeable in urbanizing watersheds. The framework developed in this paper can be used for future modeling efforts to understand the hydrological impact of LULC change in a watershed at a large scale.

Keywords
Urbanization, land use/land cover (LULC), hydrologic modeling, HEC-HMS

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1. INTRODUCTION

Urbanization creates development pressures on suburban and exurban areas. Once rural, forest, or wetland areas are changed to streets, highways, parking lots, sidewalks, and building rooftops, the hydrologic runoff conditions change. The increase in impervious surface results in large volumes of runoff being generated for an intense storm over a relatively short time period. Land use change is a primary factor that influences surface hydrology by human activity (Booth and Jackson 1997, Brabec et al. 2002). To quantify the effect of urbanization in terms of surface runoff, hydrologic modeling has been performed by several researchers (Booth & Jackson 1997, Du et al. 2012, Viessman et al. 1989, Weng 2001). Surface water hydrologic modeling is the realization of surface runoff for a given rainfall time series in a simplified land characterization within a watershed. In order to simulate hydrologic response to urbanization, land cover information is critical (Miller et al. 2007). Forecasts of increases in the amount of runoff are crucial to avoiding an increase in the frequency of local flooding and to conform to local stormwater control policies to avoid flooding and the deterioration of aquatic ecosystems through the implementation of Best Management Practices (Center for Watershed Protection 2003).

Remote sensing has been a primary source of creating Land Use/Land Cover (LULC) data. There have been many studies on developing hydrologic models using a current LULC condition (Ahn 2007, Weng 2001), hydrologic impact by change in LULC (McColl and Aggett 2007), or assessing hydrologic conditions by future development scenarios (Hu et al. 2006). In order to understand the effect of hydrologic response by land cover change, a complex interaction between land cover and precipitation needs to be modeled, which requires a distributed hydrologic model (Yeo et al. 2007). A few studies have addressed the hydrologic influences by the accuracy of LULC data (Eckhard et al. 2003, Hundecha and Bardossy 2004, DeFries and Eshleman 2004, Miller et al. 2007). Miller et al. (2007) assessed the uncertainty in hydrologic runoff due to land cover error using 100 systematically generated land cover maps that were spatially varied, but retained the original land cover's error matrix within a 1% threshold. The land cover classification error was found to be directly related to watershed scale and inversely related to rainfall magnitude. Also, they reported that urban misclassification created the largest runoff error. Land cover data used for input to hydrologic modeling can have various land cover error matrices, with some land cover classes having fewer classification errors than others.

Since shifts toward more urban lands and higher levels of impervious surface cause the most significant changes in the hydrology of urbanizing watersheds, it is critical to understand the impact that misclassification of urban uses have on the predicted hydrographs. Using two different representations of possible errors in impervious surface estimation from remote sensing, this paper quantifies their impacts on the predicted hydrographs for an urbanizing watershed in Ohio.

2. STUDY AREA

The study area is the Big Darby Creek Watershed, a rapidly urbanizing watershed located in the western part of the Columbus metropolitan area, Ohio (Figure 1). The watershed includes parts of six counties. The study watershed is primarily an agricultural watershed with a small amount of forest with increasing areas of residential and commercial land uses. The watershed drains about 1,450 km^2. The watershed is characterized by flat terrain with soils with low infiltration rates. Because of its unique biological diversity, the accurate prediction of changes in imperviousness is critical to its long-term ecological health.

3. METHODOLOGY

In order to test the sensitivity of runoff projections from a regional hydrologic model, we used the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS 3.1.0) model to estimate the peak hydrographs for various accuracy levels of LULC data. There were four major steps to this procedure:

1. Collect the required input data to estimate and test the basic model for an actual storm in the study area.
2. Establish a statistical relationship between the land use categories, the soil hydrologic characteristics, and the Curve Number (CN) used in the model to represent imperviousness. This allowed us to use alternative impervious surface values and translate them into the CN number required to perform a model run.
3. Create input data change scenarios. The first focuses on possible data errors throughout the watershed, regardless of land use type. The second focuses on errors in the highest intensity urban categories, where errors in impervious surface estimation are most likely.
4. Make multiple runs of the model to measure the sensitivity of the forecasts in stormwater to systematic errors in impervious surface estimation.

HEC-HMS was developed by the U.S. Army Corps of Engineers as a successor of HEC-1. HEC-HMS has the capability to simulate a large river basin, climate change (Beighley et al 2003), water supply, flood hydrology (McLin et al. 2001), and small urban and natural watershed runoff (Boggs et al. 2004). Successful application areas using HEC-HMS include water availability, urban drainage, flow forecasting, future urbanization impacts, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation (Knebel et al. 2005). In addition, HEC-HMS is equipped with a distributed modeling approach to simulate the precipitation-runoff model using the ModClark method. Also, HEC-HMS facilitates many currently available hydrologic modeling algorithms. Parameters in HEC-HMS can be efficiently prepared by the use of GIS tools, such as the HEC-GeoHMS (Fleming and Doan 2010), in a semi-automated process.

3.1 INPUT DATA

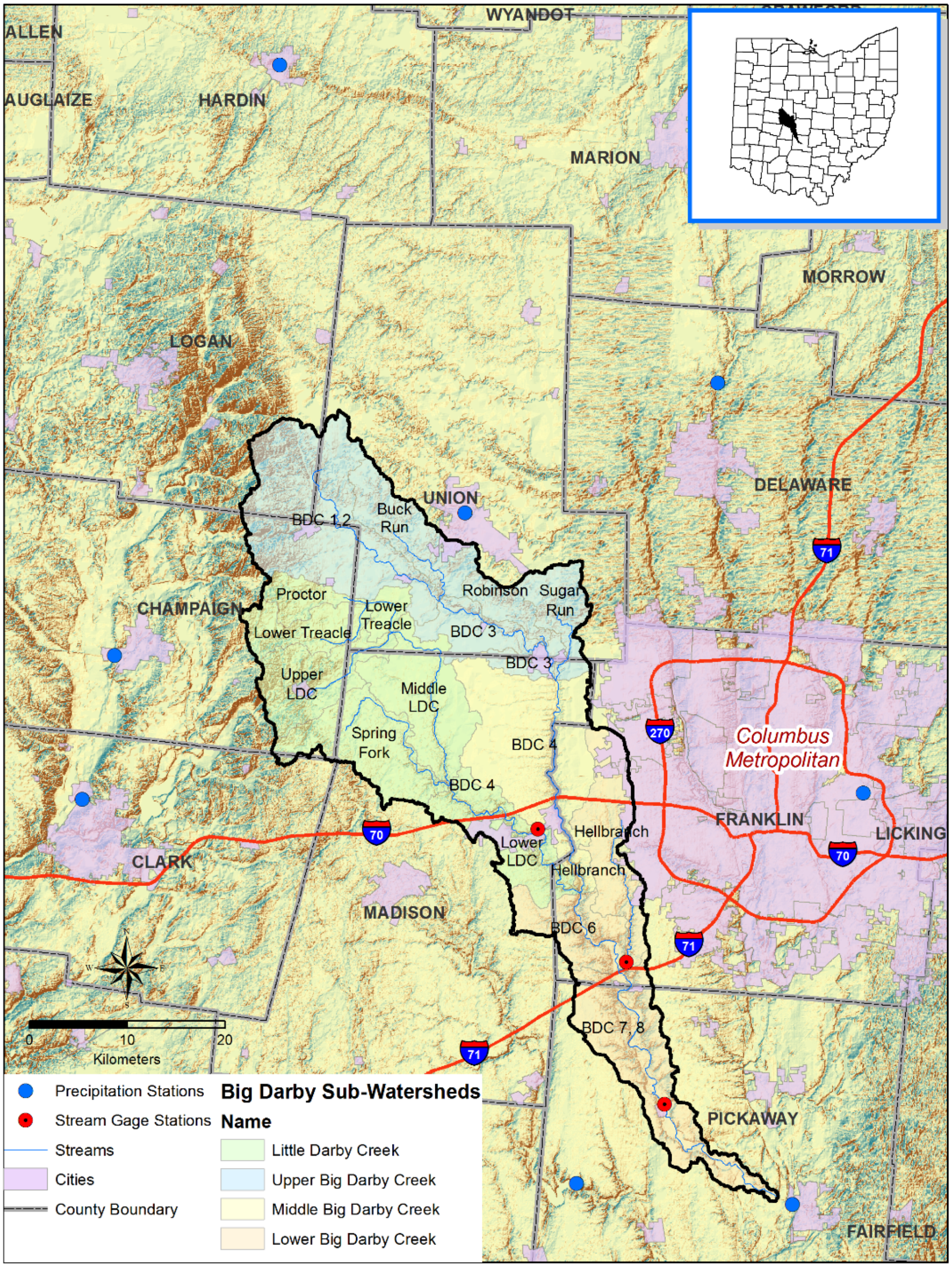


Figure 1. Location map of the Big Darby Creek Watershed overlying a hillshaded DEM.

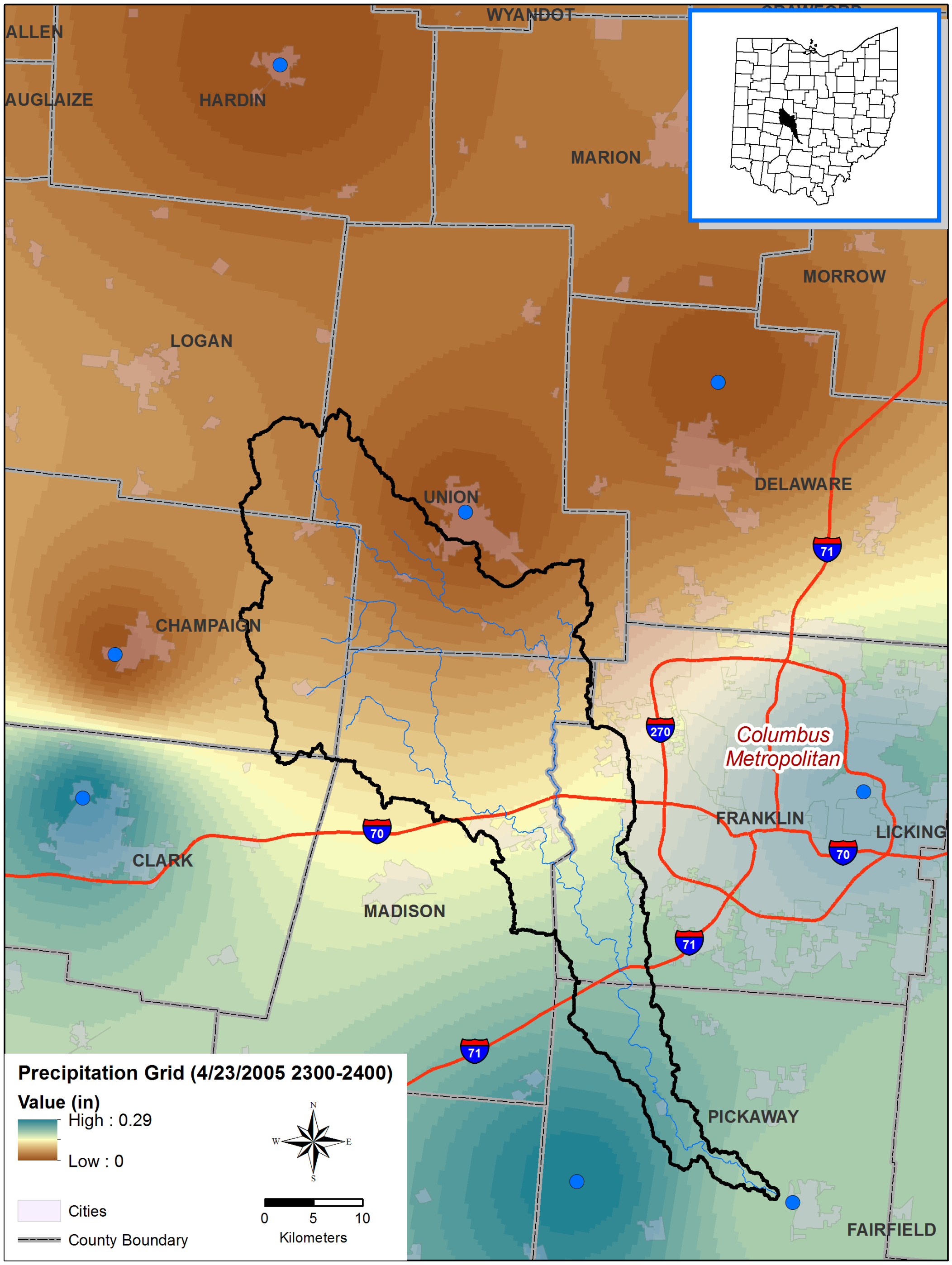


Figure 2. Snapshot of a 3-D precipitation map of the Big Darby Creek Watershed using the precipitation record collected on April 23, 2005 at 11PM to 12AM. The eight blue dots represent the precipitation gages used for the interpolation.

Various input data were processed in order to prepare the HEC-HMS hydrologic model input parameters for the basic model. For rainfall, hourly precipitation gaging station data were obtained from NCDC (National Climatic Data Center) and a 13-day precipitation record during spring rain events recorded from April 18, 2005 to April 30, 2005 were employed. To acquire 3-D precipitation time series, the GageInterp program from USACE was used. Eight rain gage stations surrounding the study watershed were compiled to create a precipitation time series. The inverse distance squared method was applied for the interpolation. Figure 2 shows a snapshot of a 3-D precipitation map of the Big Darby Creek Watershed using the precipitation record collected on April 23, 2005 at 11PM to 12AM. The eight blue dots represent precipitation gages used for the interpolation. For streamflow data, three gages inside the Big Darby Creek Watershed were used as assessment points: Hellbranch Run, Darbyville, and Little Darby (Figure 1). Hourly streamflow discharge data collected at the Darbyville station (April 15, 2005 to May 15, 2005 records) were used to calibrate and analyze the modeled hydrographs. A 30-m DEM was created from USGS DLG (Digital Line Graph) that was used to delineate subwatershed boundaries. A LULC data set developed by Ahn (2007) was used. 2005 Landsat TM imagery was used to develop the LULC map (30 m resolution), which had an overall accuracy of 89%. The total impervious area is estimated to be 18 square miles, which is about 3% of the watershed. Impervious area in the Hellbranch Run, the most urbanized subbasin in the Big Darby Creek Watershed, is estimated to be 9 square miles, which is 25% of the subwatershed. Table 1 shows the error matrix of the LULC data. For soils data, the NRCS STATSGO (Natural Resources Conservation Service State Soil Geographic) data base was used. Channel cross-section data for the Big Darby Creek Watershed have been collected by various sources and the Ohio Department of Natural Resources has compiled the data for river analysis (D. Mecklenburg, personal communication 2007).

3.2 THE BASIS FOR THE MODEL

Change in imperviousness is a characteristic of urban development. Urbanization affects hydrologic processes in the infiltration mechanism, by reducing the amount of soil infiltration as there are increasing proportions of hard surfaces. Urbanizing watersheds have a heterogeneous land use mix. Modeling such areas requires the application of spatially distributed parameters for land cover, imperviousness, and soils to best reflect the hydrologic conditions. As a result, distributed parameters can better define hydrologic processes in urbanizing watersheds (Yeo et al. 2007). The Soil Conservation Services (SCS) Curve Number (CN) method was used for the rainfall-runoff model (infiltration loss model). The CN method estimates the amount of runoff for various land use conditions and soil types using an empirical relation between runoff and infiltration (Rallison and Miller 1982). CN ranges from 100 (for water bodies) to approximately 30 for permeable soils with high infiltration rates (USACE 2000). CN was calculated cell by cell using the 2005 LULC data and soils data in 30 m resolution, followed by calculating the average surface imperviousness, average CN, and the initial abstraction for each subbasin. For the direct runoff model (overland routing), the ModClark method, which is a distributed parameter model at a 500 m resolution, was adopted. The 500-m grid spacing was chosen because it was the smallest possible grid spacing in HEC-GeoHMS processing for the Big Darby Creek Watershed. The model input format to run the direct runoff simulation is called the MOD file, which is an ASCII file that contains CN values for each grid, as well as the x-, y- coordinate, contributing area, and time of concentration within a subbasin.

For channel routing, the Muskingum-Cunge Routing method was used, which is a physics-based approach that requires parameters, such as channel area, slope, sediment diameter, Manning's *n*, and overbank *n* for each subbasin. A detailed description about these parameter calculations is described in Ahn (2007).

Table 1. Error matrix of the 2005 LULC data (unit in number of random samples).

Class Name	W	R	Pa	F	RR	SH	LR	MD	HD	T	Row Total
Water	22	1	3	1	0	1	0	0	0	0	28
Rowcrop	0	133	1	3	1	0	0	0	0	0	138
Pasture	0	0	16	5	0	0	0	0	0	0	21
Forest	0	2	0	27	0	0	0	0	0	0	29
Rural Residential	0	1	2	0	19	0	0	0	0	4	27
Suburban High Density	0	0	1	1	0	18	0	0	0	0	19
Low Density Urban	0	0	0	0	0	0	20	0	0	0	20
Medium Density Urban	0	0	1	0	0	0	0	19	0	0	20
High Density Urban	0	0	0	1	0	0	0	0	21	0	22
Transportation	0	1	2	0	2	1	1	1	0	20	30
Column Totals	22	138	26	38	22	20	21	20	21	24	400

Producer's Accuracy	**User's Accuracy**
Water = 100.00%	Water = 78.57%
Row crop = 96.38%	Row crop = 96.38%
Pasture = 61.54%	Pasture = 76.19%
Forest = 71.05%	Forest = 93.10%
Rural Residential = 86.36%	Rural Residential = 70.37%
Suburban High Density = 90.00%	Suburban High Density = 94.74%
Residential Low Density = 95.24%	Residential Low Density = 100.00%
Residential Medium Density = 95.00%	Residential Medium Density = 95.00%
Residential High Density = 100.00%	Residential High Density = 94.45%
Transportation = 83.33%	Transportation = 66.67%
Overall Accuracy	89.5%
Overall Kappa Statistic	0.88

3.3 CALIBRATING THE BASIC MODEL

The HEC-HMS model works with the following steps: (1) Excess rainfall is calculated using the SCS CN method for each subbasin. (2) Once the soil is saturated, the remaining water will flow through the surface, where the ModClark algorithm takes that flow into account. The ModClark model translates excess runoff in a grid-based travel time model. (3) Finally, when water reaches an open channel, the Muskingum-Cunge routing method carries water downstream through the open channel.

The 2005 LULC was selected as a baseline land surface condition. We first developed the MOD file for the baseline hydrologic condition using HEC-HMS. Figure 3 (a) shows the precipitation at the Columbus Airport station and three streamflow gage stations at Darbyville, Little Darby, and Hellbranch Run used for calibrating the HEC-HMS model. The selected precipitation event is modest in terms of precipitation volume. It was expected that this storm event would represent the overall hydrologic characteristics due to the urban development of the Big Darby Creek Watershed. Figure 3 (b) shows the calibration results. Baseflow was removed using the straight line method before the calibration. The dotted curve represents the observed hydrograph and the solid line depicts the simulated hydrograph at the Darbyville station. The two dashed lines are simulated hydrographs at the upstream end of the Darbyville station and at the small catchment that includes the Darbyville station. Adding these two hydrographs equals the simulated hydrograph (solid line). The peakflow is well matched to within 3%. The calibration results at the Hellbranch Run and Little Darby Creek were not as well matched, mainly because of the lack of precipitation volume.

3.4 TESTING THE SENSITIVITY TO POSSIBLE ERRORS IN LULC CLASSIFICATION

Testing the impact of LULC error was possible by updating the CN values in the model to reflect possible systematic errors in classification. CN is determined based on the land use and soil hydrologic group of a particular location (in this case our 30 m cells) as shown in Table 2. Soils are classified by the Natural Resource Conservation Service (NRCS) into four Hydrologic Soil Groups (HSG) based on the soil's runoff potential: A, B, C, and D. In general, the HSG-'A' group (sand, loamy sand or sandy loam types of soils) has the smallest runoff potential, while the HSG-'D' group (clay loam, silty clay loam, sandy clay, silty clay or clay) has the highest runoff potential. To facilitate easy estimation of CN values, we developed a linear regression of CN values in the watershed as a function of imperviousness for each of the three hydrologic soil groups found in the watershed. The CN table values for LULC vs. soil type vs. imperviousness were used (USDA 1986 and EDAW 2006). A linear relationship between percent imperviousness and CN for different soil types was established as below:

$$Y = aX + b \tag{1}$$

where Y represents CN and X represents surface imperviousness, and a and b are regression coefficients.

The Big Darby Creek watershed consists of soil types B, C, and D. Table 3 shows the results of the linear regression to build a model of CN as a function of imperviousness. The linear regression model made it possible to more easily estimate the sensitivity of the HEC-HMS hydrologic model to imperviousness.

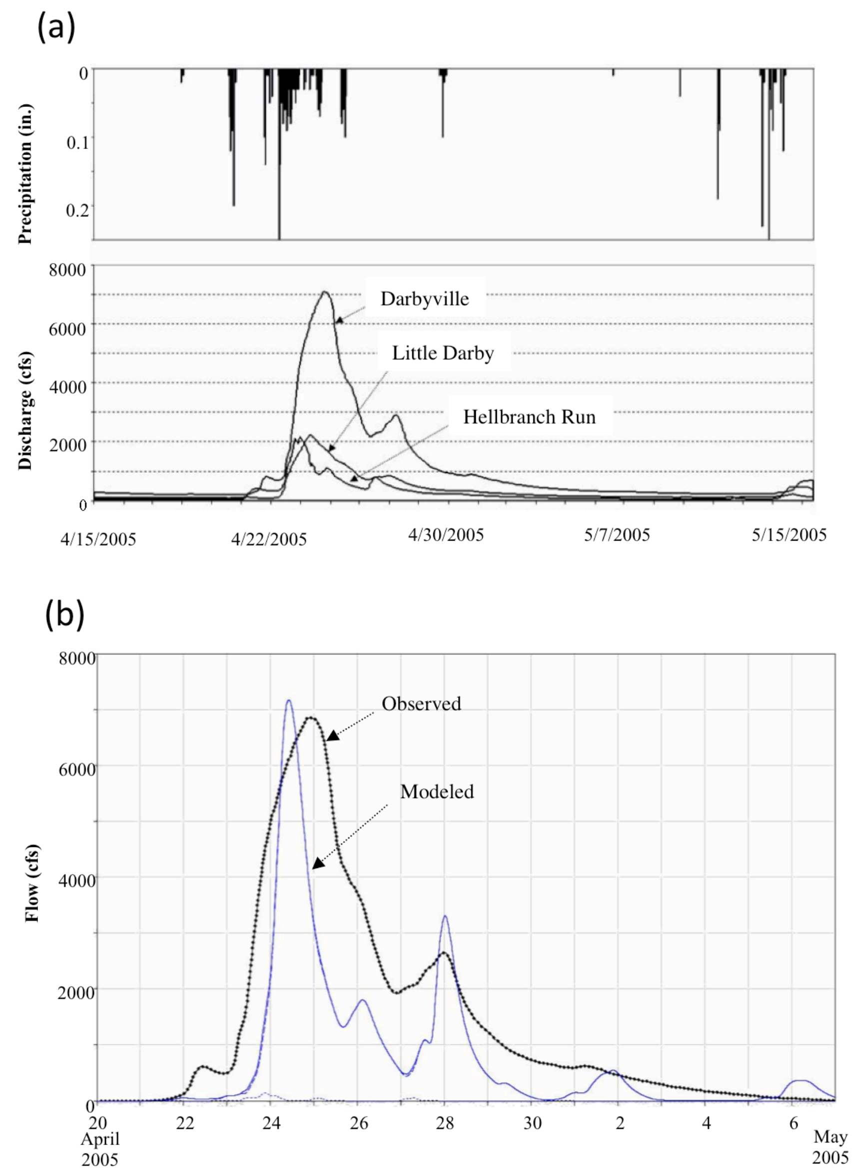


Figure 3. Hydrologic inputs and calibration results. (a) Precipitation and streamflow data (b) calibration results.

For each of the scenarios described below, we applied systematic changes in imperviousness, used the regression model to alter the CN appropriately, updated the data inputs for the hydrologic model, and projected changes in the storm hydrograph. The scenarios we used are described next.

Table 2. CN for various soil types with the associated percent imperviousness.

LULC	Soil Type			Imperviousness (%)
	B	C	D	
Rural Residential	66	77	81	12
Residential Low Density	71	80	85	27.5
Residential Medium Density	75	83	87	38
Suburban High Density	80	87	90	52
Residential High Density	85	90	92	65
Transportation	98	98	98	98

Table 3. Statistics of regression coefficients (*a* and *b*) predicting CN as a function of imperviousness for the different soil types in the Big Darby Creek Watershed.

Parameter Est. / Soil Group	*a*	*b*	Statistics		
			rmse	R^2	*p*-value
B	0.37	61.06	0.43	0.78	0.5×10^{-7}
C	0.25	73.83	0.43	0.78	0.4×10^{-6}
D	0.19	79.59	0.51	0.78	0.3×10^{-5}

3.5 SCENARIOS

For the LULC sensitivity analyses, two scenarios were considered. The first scenario distributed the errors to impervious surfaces throughout the watershed, simulating errors that applied regardless of spatial location. For scenario-1, imperviousness errors of ± 1%, ± 3%, ± 5%, ± 10%, and ± 30% were propagated into each impervious pixel. The average surface imperviousness for each MOD grid was used to recalculate the average CN value using the linear regression model reassigning the values based on the soils characteristics in each cell. Also, each subbasin's SCS CN parameters (the average surface imperviousness, the average CN, and the initial abstraction) were updated. The hydrograph produced from HEC-HMS was calculated using the updated data file to analyze the sensitivity in the hydrograph to the changes.

For scenario 2, the relatively high impervious areas were identified as areas with a denser urban signature that are prone to much higher variability and thus errors in land use classification (Xian and Crane, 2005). Subbasins with an average imperviousness of 3.5% or greater were identified as the target areas for changes. Of the 119 subbasins in the watershed, 25 were found that had more than 3.5% impervious surface. The average imperviousness was changed by 1%, 3%, 5%, and 10% for those selected subbasins. The surface imperviousness map for each subbasin was updated, followed by updating the model input data files. Then, the average surface imperviousness for each grid cell was calculated for each soil type. Finally, each subbasin's SCS CN parameters (the average surface imperviousness, the average CN, and the initial abstraction) were updated and the model run for each case.

3.6 MODEL OUTPUTS

The simulation results are shown in Figure 4. Three locations were selected as assessment points (red dots in Figure 1) to compare the differences in peakflow due to LULC errors: Hellbranch Run, Little Darby, and Darbyville, downstream of the Big Darby Creek Watershed. The top row plots show the simulated hydrographs at the Darbyville station. The middle row plots show the simulated hydrographs at the Little Darby station. The bottom row plots show the simulated hydrographs at the Hellbranch Run station. Tables 4 and 5 summarize the simulated hydrographs' peakflow and percent change in peakflow with respect to the LULC error levels. Figure 5 summarizes the impervious % error vs. its impact of hydrologic response in terms of RMSE.

3.7 RESULTS FOR SELECTED AREAS

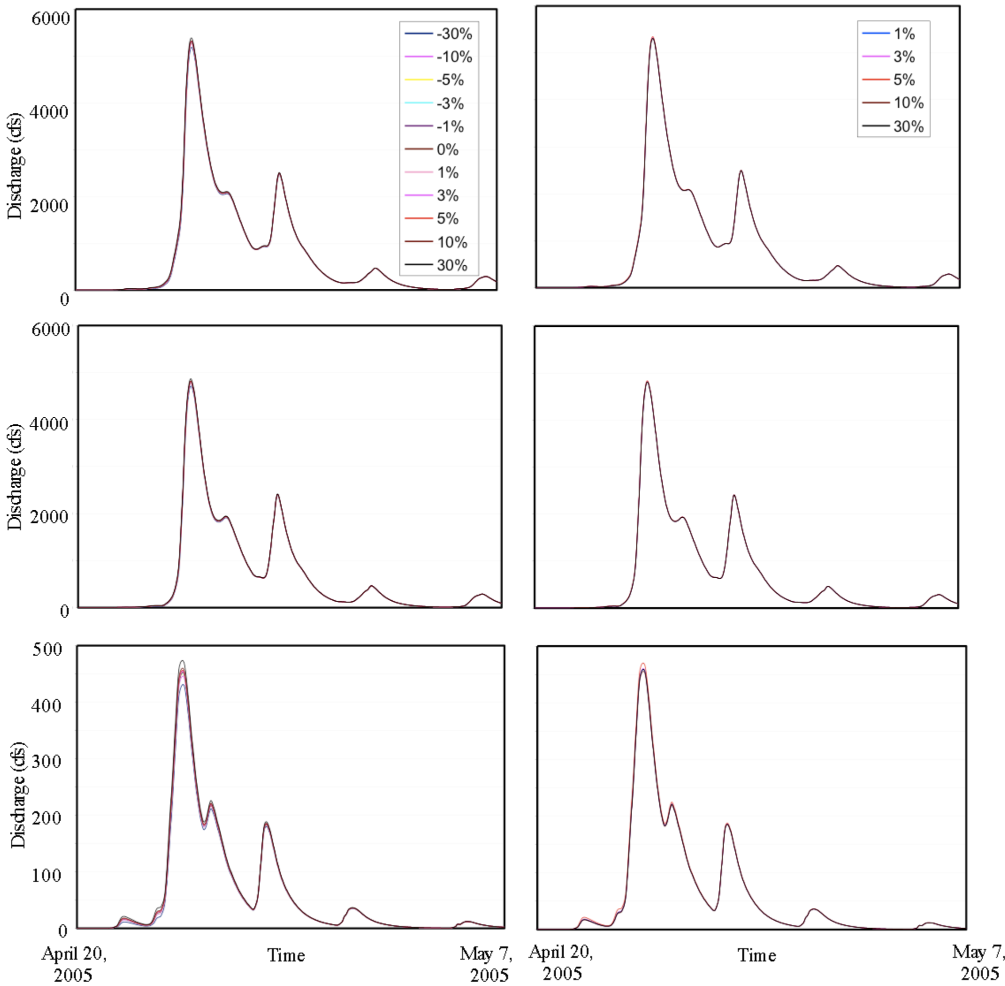
The simulation for scenario 1 examines the effect of connected impervious area, while scenario 2 investigates the hydrologic response of the effect of the aggregated impervious error within a subbasin. With a highly accurate (over 85%) LULC map, the change in hydrologic runoff is minor for both scenarios as shown in Figure 4, and Tables 4 and 5.

However, for a highly urbanized subbasin, such as the Hellbranch Run, the hydrograph starts to show a noticeable change in peak flow (about 5%). This demonstrates that unless there is a significant error in mapping urban land use, the LULC map and impervious data with a 10% classification error do not cause a significant change in the hydrologic modeling runoff.

Even though the impervious mapping error is minor, the simulation results show that hydrologic modeling error is higher when impervious area is under-estimated than over-estimated for both scenarios. Also, the hydrologic impact due to impervious mapping error is higher in the downstream junction point than upstream. In addition, the hydrologic modeling error for scenario 1 is higher than for scenario 2. This means that the hydrologic impact due to the connected impervious surfaces is higher than the hydrologic impact from scattered impervious surfaces when both cases have the same amount of impervious errors.

4. CONCLUSIONS

In this study, we quantitatively assessed the peak hydrograph response according to the accuracy of remote sensing-based LULC data by developing a regression model that estimates hydrologic modeling parameters from the LULC. Two scenarios were developed to understand the hydrologic sensitivity analysis based on the accuracy of the imperviousness data. Simulation results for both scenarios showed that the hydrograph from the simulated LULC error was minor for small urbanizing areas. However, for both scenarios, the Hellbranch Run subwatershed produced noticeable changes in peakflow (5% for scenario 1 and 3.5% for scenario 2). Error analysis on the two scenarios suggests that accurate impervious mapping in a subbasin with connected impervious surfaces will improve the hydrologic modeling accuracy in urbanizing watersheds.



(a) Scenario 1 (b) Scenario 2

Figure 4. Simulation results for the two scenarios. Hydrographs from top to bottom are Darbyville, Little Darby, and Hellbranch Run.

We limited the MOD grid size to 500 m. In future efforts, evaluating the sensitivity of the LULC at the pixel-level is desirable in a fully distributed model setting to better understand the behavior of the distributed hydrologic model. To do that, an experiment is required to be developed in a smaller, highly urbanized area. The method developed in this study can be expanded to other LULC types, which will allow us to better understand the impact of hydrologic response due to LULC errors. A framework developed in this study can be used to study urbanizing watersheds for developing future modeling efforts to understand the hydrological impact of LULC change in a watershed on a larger scale.

Table 4. Simulation results for scenario 1

Station	Imp % Error	Time to Peak (24-Apr-05)	Peakflow (cfs)	Change in Peak Flow (%)	Statistics (cfs)				
					Min	Max	Std	MAE	RMSE
Darby Creek	-30	16:30	5184.4	-2.2	-0.1	248.7	34.8	15.1	37.9
	-10	16:20	5259.9	-0.7	-0.5	92.4	12.6	5.1	13.6
	-5	16:20	5278.8	-0.4	-0.9	54.7	7.2	2.7	7.6
	-3	16:20	5287.1	-0.2	-1.3	37.2	4.8	1.7	5
	-1	16:20	5294.3	-0.1	-2	24	3	1.2	3
	1	16:20	5302.6	0.1	-6	9.3	1.7	1	1.8
	3	16:20	5307.9	0.2	-9.5	4.2	2.1	1.5	2.5
	5	16:20	5313.8	0.3	-16.8	3.3	3.4	2.2	4
	10	16:20	5327.6	0.5	-41.7	0.6	7.1	4	8.1
	30	16:10	5383.8	1.6	-147.1	0	23	11.4	25.6
Little Darby	-30	12:40	4712.8	-1.9	-0.3	179	25.4	10.6	27.5
	-10	12:40	4772.2	-0.6	-1.1	67.3	9.4	3.6	10.1
	-5	12:40	4786.6	-0.3	-1.9	41	5.7	2.1	6
	-3	12:30	4793.2	-0.2	-2.2	28.3	4	1.5	4.1
	-1	12:30	4798.9	-0.1	-3.1	19.2	2.8	1.2	2.8
	1	12:30	4805.6	0.1	-6.1	10.8	1.9	1.1	2
	3	12:30	4809.7	0.2	-8.7	5	1.9	1.3	2.2
	5	12:30	4814.1	0.3	-11.6	4.4	2.6	1.6	2.9
	10	12:30	4824.6	0.5	-26.4	3.2	4.8	2.8	5.5
	30	12:30	4867.1	1.3	-97.8	0.1	15.5	7.6	17.3
Hellbranch Run	-30	5:10	431.3	-4.9	-0.1	26.0	5.3	2.8	6.0
	-10	4:50	446.0	-1.5	-0.6	8.9	1.7	1.0	2.0
	-5	5:00	450.1	-0.6	-1.4	4.4	0.8	0.5	0.9
	-3	4:50	451.3	-0.3	-1.7	3.3	0.6	0.3	0.6
	-1	4:50	452.7	-0.2	-1.9	2.6	0.4	0.2	0.4
	1	4:50	454.2	0.4	-2.7	2.0	0.4	0.2	0.5
	3	4:50	455.4	0.6	-4.0	1.9	0.7	0.3	0.7
	5	4:40	456.7	0.9	-5.6	1.8	1.0	0.5	1.1
	10	4:50	460.2	1.7	-9.4	1.5	1.8	0.9	2.0
	30	4:30	473.6	4.4	-24.4	0.5	4.9	2.6	5.6

Table 5. Simulation results for scenario 2

Station	Imp % Error	Time to Peak (24-Apr-05)	Peakflow (cfs)	Change in Peak Flow (%)	Statistics (cfs)				
					Min	Max	Std	MAE	RMSE
Darby Creek	1	16:20	5306.6	0.1	-8.3	4.3	1.9	1.4	2.3
	3	16:20	5309.5	0.2	-11.1	3.6	2.6	1.8	3.1
	5	16:20	5310.5	0.2	-12.3	3.3	2.9	2	3.5
	10	16:20	5323.1	0.5	-34	1.5	6.3	3.7	7.3
	30	16:20	5346.0	0.9	-87.1	0.1	14.2	7.4	16
Little Darby	1	12:30	4808.4	0.1	-7.6	4.9	1.7	1.2	1.9
	3	12:30	4809.1	0.1	-8	4.9	1.8	1.2	2
	5	12:30	4809.8	0.1	-8.5	4.7	1.9	1.3	2.1
	10	12:30	4820.6	0.4	-19.2	3.5	4	2.5	4.6
	30	12:30	4835.4	0.7	-46.7	2.6	8.1	4.4	9.2
Hellbranch Run	1	4:40	455.6	0.4	-4.4	1.9	0.7	0.3	0.8
	3	4:40	458.8	1.1	-7.9	1.7	1.4	0.7	1.6
	5	4:50	459.2	1.2	-8.3	1.7	1.5	0.8	1.7
	10	4:40	460.5	1.5	-9.8	1.6	1.8	1	2.1
	30	4:30	470.2	3.5	-20.9	0.9	4.3	2.3	4.8

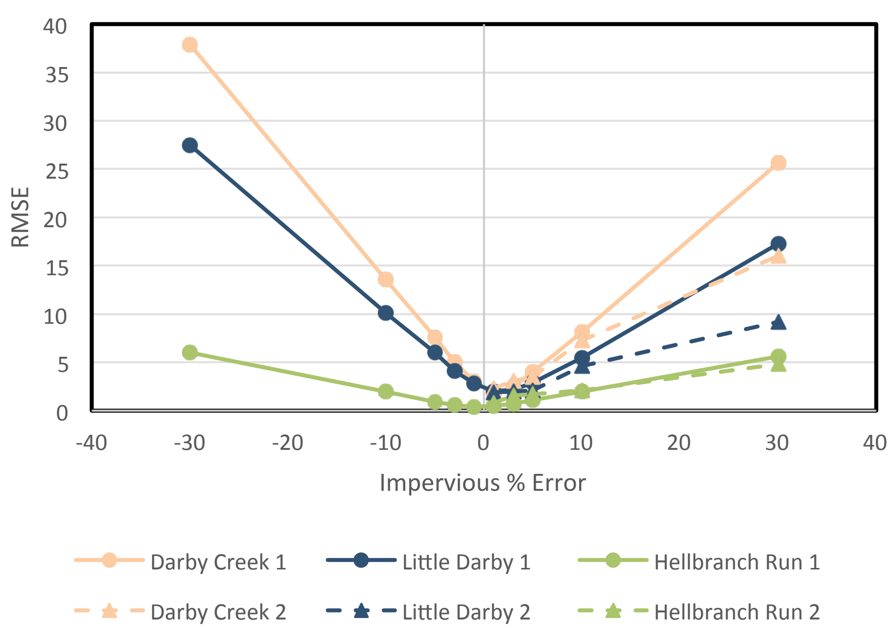


Figure 5. Impervious percent errors vs. RMSE errors of the simulated hydrograph with respect to the hydrograph of no impervious error for the scenario 1 and scenario 2.

RERERENCES

Ahn, G. C. (2007). *The Effect of Urbanization on the Hydrologic Regime of the Big Darby Creek Watershed, Ohio*. Ph.D. Dissertation, The Ohio State University, Columbus, Ohio.

Beighley, R.E., Melack, J.M. and Dunne, T. (2003). Impacts of California's climatic regimes and coastal land use change on streamflow characteristics. *Journal of the American Water Resources Association*, 39, 1419–1433.

Boggs, G.S., Evans, K.G., and Devonport, C.C. (2004). Rugged plateaus and extensive floodplains – modeling landform evolution in a Northern Australian Catchment, *Australian Geographical Studies*, 42 (2), 260-273.

Booth, D.B. and Jackson, C.R. (1997). Urbanization of aquatic systems - degradation thresholds, stormwater detention, and the limits of mitigation, *Water Resources Bulletin*, 33, 1077-1090.

Brabec, E., Schulte, S., and Richards, P. L. (2002). Impervious surfaces and water quality: A review of current literature and its implications for watershed planning, *Journal of Planning Literature*, 16 (4), 499-514.

Center for Watershed Protection (2003). *Impacts of Impervious Cover on Aquatic Ecosystems*. Watershed Protection Research Monograph No. 1. http://www.cwp.org/online-watershed-library/doc_download/595-impacts-of-impervious-cover-on-aquatic-systems-watershed-protection-research-monograph.

DeFries, R. and Eshleman, K. N. (2004). Land-use change and hydrologic processes: a major focus for the future, *Hydrological Processes*, 18, 2183-2186.

Du, J., Qian, L., Rui, H., Zuo, T., Zheng, D., Xu, Y., and Xu, C.-Y. (2012). Assessing the effects of urbavnization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China, *Journal of Hydrology*, 465, 127-139.

Eckhardt, K., Breuer, L., Hans-Georg, F. (2003). Parameter uncertainty and the significance of simulated land use change effects, *Journal of Hydrology*, 273, 164-176.

EDAW Inc. (2006). Big Darby Accord: Watershed Master Plan.

Fleming M.J. and Doan, J.H. (2010). *HEC-GeoHMS Geospatial Hydrologic Modeling Extension*, Version 5.0, US Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, Davis, CA.

Hu, H.H, Kreymborg, L.R., Doeing, B.J., Baron, K.S., and Jutila, S.A. (2006). Gridded snowmelt and rainfall-runoff CWMS hydrologic modeling of the Red River of the North Basin, *Journal of Hydrologic Engineering*, 11 (2), 91-100.

Hundecha, Y. and Bardossy, A. (2004). Modeling of the effect of land use changes on the runoff generation of a river basin through parameter regionalization of a watershed model, *Journal of Hydrology*, 292, 281-295.

Knebl, M. R., Yang, Z.-L., Hutchinson, K., and Maidment, D.R. (2005). Regional scale flood modeling using NEXRAD rainfall, GIS and HEC-HMS/RAS: a case study for the San Antonio River Basin summer 2002 storm event, *Journal of Environmental Management*, 75, 325-336.

McColl C. and Aggett, G. (2007). Land-use forecasting and hydrologic modeling integration for improved land-use decision support, *Journal of Environmental Management*, 84 (4), 494-512.

McLin, S.G., Springer, E.P., and Lane, L.J. (2001). Predicting floodplain boundary changes following the Cerro Grade wildfire, *Hydrological Processes*, 15 (15), 2967-2980.

Miller, S. N., Guertin, D. P., and Goodrich, D. C. (2007). Hydrologic modeling uncertainty resulting from land cover misclassification, *Journal of the American Water Resources Association*, 43 (4), 1065-1075.

Rallison, R.E. and Miller, N. (1982). Past, present, and future SCS runoff procedure, Proceedings of the International Symposium on Rainfall Runoff Modeling: Rainfall-Runoff Relationship, V.P. Singh (Ed.), May 18-21, 1981, Mississippi: Mississippi State University, 353-364.

U. S. Army Corps of Engineers (USACE) (2000). *Hydrologic Modeling System HEC-HMS–Technical Reference Manual*, U. S. Army Corps of Engineers, Hydrologic Engineering Center.

U. S. Department of Agriculture (USDA) (1986). *Urban Hydrology for Small Watersheds*. TR-55, Washington, D.C.

Viessman, W., Lewis, G.L., and Knapp, J.W. (1989). *Introduction to Hydrology*, Third Edition, Harper Collins, New York, NY, 243-246.

Weng, Q. (2001) Modeling urban growth effects on surface runoff with the integration of remote sensing and GIS, *Environmental Management*, 28 (6), 737-748.

Xian, G. and Crane, M. (2005) Assessments of urban growth in the Tampa Bay watershed using remote sensing data, *Remote Sensing of Environment*, 97, 203-215.

Yeo, I. Guldmann, J-M., and Gordon, S.I. (2007). A Hierarchical Optimization Approach to Watershed Land-Use Planning, *Water Resources Research*, 43, W11416, doi:10.1029/2006WR005315.