UNIVERSITY OF CINCINNATI

June 4, 2003

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hereby submit this as part of the requirements for the degree of:

MASTER OF COMMUNITY PLANNING

in ENVIRONMENTAL PLANNING

It is entitled INTEGRATING GIS AND HYDROLOGIC MODELING IN WATERSHED PLANNING: A CASE STUDY IN WEST MILLCREEK BASIN, HAMILTON COUNTY, OHIO

Approved by:

INTEGRATING GIS AND HYDROLOGIC MODELING IN WATERSHED PLANNING: A CASE STUDY IN WEST MILL CREEK BASIN, HAMILTON COUNTY, OHIO

A graduate thesis submitted to the

Division of Research and Advanced Studies
of the University of Cincinnati

in partial fulfillment of the requirements of the degree of

MASTER OF COMMUNITY PLANNING

in the School of Planning
of the College of Design, Architecture, Art and Planning

2003

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ABSTRACT

Hydrologic response indicates the health and function of a watershed, and it can be significantly impacted by the changes in land use. In an urban watershed, storm water runoff and stream flow are two important issues reflecting the hydrologic health of the watershed. Urban planners, who are important players involved in the land development, are required to be more knowledgeable of the natural system of the watersheds and take more responsibility to protect the natural resources while they are making land development plans.

This study explores the potential of integrating Geographic Information Systems (GIS) and computerized hydrologic modeling in storm water runoff and stream flow simulation in watershed planning as a decision-supporting tool. Two hydrologic modeling software, including HEC-HMS (Hydrologic Modeling System developed by Hydrologic Engineering Center), HEC-GeoHMS (The Geospatial Hydrologic Modeling Extension for ArcView, also developed by Hydrologic Engineering Center) are applied in an urban watershed- the West Mill Creek basin, Hamilton County, Ohio, to estimate the current condition of storm water runoff and stream flow of the area. Then, the study investigates the impact of urbanization on the hydrologic health and function of the watershed by running the hydrologic models based on different land use scenarios. Finally, the study derives lessons and recommendations to better utilize the tool of hydrologic modeling in the watershed planning practice.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Dr. Xinhao Wang for his continuous guidance, support and valuable suggestion throughout this study. I would also like to express my sincere appreciation to Prof. Steve. G. Buchberger for leading me into the amazing world of hydrology and providing me with enlightening advice for my study. I would also like to extend my gratitude to Mr. Andy Swift for his insightful comments and unwavering support for the study.

I would also like to thank Cincinnati Area Geographic Information Systems (CAGIS), Metropolitan Sewer District of Greater Cincinnati Area (MSD), and U.S. Army Corps for providing valuable data and kind assistance to the study.

My deep sense of gratitude and love goes to my husband Zhigang, whose love is the reason that I could survive and the delight of my life. My deepest appreciation goes to my family for the love and support of all my way here and ahead.

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1. INTRODUCTION

Ever since the wake of environmental protection movement in the 'silent spring' (Carson, 1962) in the 1960s in the United States., people have been more awared that the natural environmental system plays a significant role in the development process of mankind. In a watershed, storm water runoff and stream flow are both issues reflecting the natural hydrologic health of watersheds and behaves as indicators of the functions watersheds. These two issues have been attracting growing concerns. Planners, who are important players in the land development process, are required to take the responsibility of protecting the natural resources while making land development plans. It is critical for planners to be more knowledgeable of the natural system of the watersheds, and take these environmental issues into planning consideration and integrate them into decision-making process.

According to U.S. Environmental Protection Agency (U.S. EPA), a watershed is the geographic area where all water running off the land drains to a given stream, river, lake, wetland or coastal water (U.S. EPA, 2003). Watershed planning and management comprise an approach to protecting water quality and quantity that focuses on a whole watershed. Like local planning processes which generally address problems or may seek to protect or improve quality of life, watershed planning has the same purpose. Watershed planning is different from the traditional approach, which manages individual water resources separately, in the way that it manages the water resources of the whole watershed. Watershed planning is necessary due to the nature of polluted runoff, which in most watersheds is the biggest contributor to water pollution. Polluted runoff is caused by a variety of land use activities, including land development, transportation, agriculture and forestry, and may originate anywhere in the watershed.

In most watersheds, flooding, upland soil and stream bank erosion, sedimentation, and contamination of drinking water from agricultural chemicals (nutrients and pesticides/herbicides) are the most serious environmental problems. Upland soil erosion causes loss of fertile soil, stream bank erosion results in the loss of valuable riparian lands, and both contribute large quantities of sediment (soil and rock particles) to the water flowing through streams and rivers. This ends in causing turbidity in sensitive biological resource areas and fills water supply and recreational lakes and reservoirs. Most of these physical damages occur during severe storm and flood events. Eroded soil and sediment also carry chemicals that pollute water bodies and stream/reservoir beds. (Borah and Bera, 2000, p. 40))

Scientists and engineers have been trying to understand the complex watershed processes of hydrology, soil erosion, transport of sediment and contaminants, and associated problems for a century (Borah and Bera, 2000, p. 40). There has been great progress in generating mathematical computer models to simulate these processes. Computerized hydrologic modeling emerged in 1960s with the development of modern computer. It has become a tool to "analyze these complex processes, understand the problems, and find solutions through land-use changes and best management practices (BMPs)" (Borah and Bera, 2000, p. 39). Effects of land-use changes and BMPs can be analyzed by incorporating these issues into the model inputs. Hydrologic models can help greatly in the watershed planning in evaluating and selecting alternative land-use and BMP scenarios that may help reduce damaging effects of flooding, soil and stream bank erosion, sedimentation (sediment deposition), and contamination to the drinking water supplies and other valuable water resources (Borah and Bera, 2000, p. 40).

Traditionally, when planners work with watershed development, they would consider the impact of the new development on the watershed, but mostly qualitatively, not in a quantified method. With the presence of computerized hydrologic modeling, planners can quantify the impact of the proposed land use change on watersheds with quantified data of their proposed development, like the change in the volume of storm water runoff and the stream flow. This study explores the potential of utilizing GIS and computerized hydrologic modeling in storm water runoff and stream flow simulation as a decision-assistant tool for watersheds planning. A set of computerized hydrologic modeling systems: HEC-HMS and HEC-GeoHMS (an extension of ArcView) are used in the West Mill Creek basin, which is located in Hamilton County, Ohio, to set up hydrologic models of the study area to assess the current situation of storm water runoff and stream flow. Then, the study investigates the effect of urbanization on the hydrologic health and function of a watershed by comparing different land use scenarios. Finally, the study derives conclusions and recommendations to use the tool of hydrologic modeling to improve planning practice in watersheds.

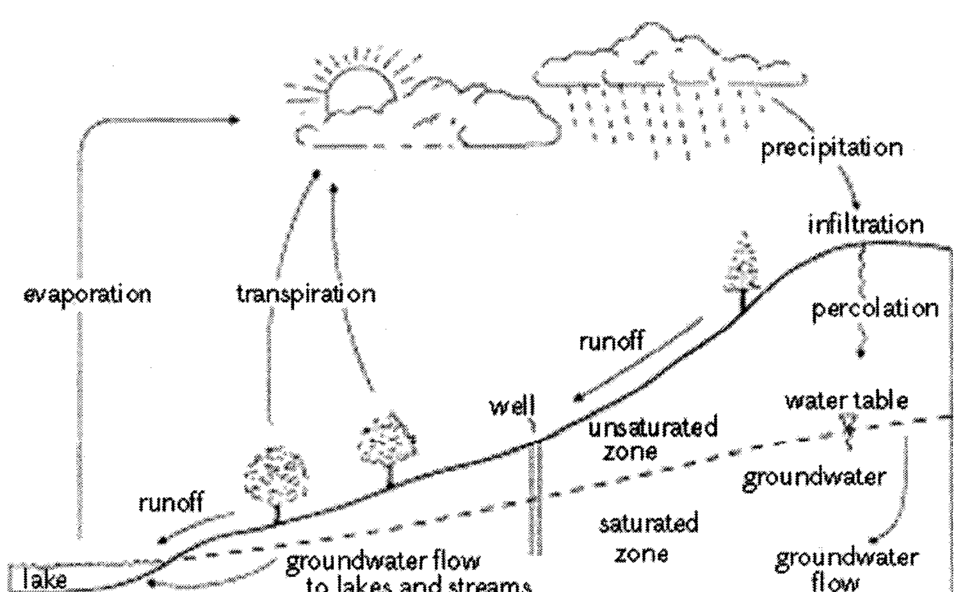
By combining GIS and computerized hydrologic modeling together, they have the potential to be very valuable tools in the watershed planning process, As the model capabilities are improved, more data are collected, and feedback from the landowner and local planning committees are received and incorporated, the results will be improved and become more reliable, and they will contribute more in watershed planning.

2 REVIEW OF THE LITERATURE

2.1 IMPACTS OF URBANIZATION ON THE HYDROLOGIC CYCLE

A hydrologic cycle is the flow of water from precipitation to surface water and back into the atmosphere. Evaporation of water occurs from oceans and land surfaces and this water is carried over the earth in atmospheric circulation in the form of water vapor. This water precipitates and reaches the earth again in the form of rain and snow. This water can either flow as runoff on the land surface or infiltrate into soils and recharge groundwater or be discharged into streams or be intercepted by trees and vegetation. It will ultimately flow into the oceans from which it will eventually evaporate once again. Water cycle is fueled by solar energy, driven by gravity and proceeds endlessly in the presence or absence of human activity (Maidment, 1993).

Figure 2.1 Hydrologic Cycle



Source: Water Resources Management Practicum, 2000

An urban watershed is a region in which considerable area is covered by impervious surfaces, which include roads, sidewalks, parking lots, and buildings. The natural flow paths in these watersheds may either be replaced or supplemented by paved gutters, storm sewers, or other elements of artificial drainage. This kind of traditional conception of urban storm drainage, which is planned to collect storm water runoff 'to the last drop' and to discharge it through piped sewer systems, has been recognized to show great disadvantages, such as:

- Prevention of groundwater recharge due to sealed surfaces causing depletion of ground water resources
- Accelerated drainage of paved, sewered catchment areas
- Increasing flood peaks in downstream natural water course
- Deterioration of water courses flow during dry weather periods (Corbett, 1997).

The world water balance is disturbed due to the change in land use patterns from green lands to paved areas. The amount of infiltration in vegetative cover is much more than in paved surfaces whereas runoff is more in paved surfaces as compared to the vegetative area. Water accumulation on the surface occurs when the rate of rainfall or snowmelt exceeds the interception requirements and the rate of infiltration. Water collects into the small depressions and holes at the ground level until the surface detention requirements are satisfied. Surface tension and friction forces lead to overland flow and water begins to travel down the slope. Continuous rainfall increases the depth of surface detention and the rate of overland flow and this water ultimately culminates in the river (Raudkivi, 1979).

Serious Issue of Storm Water Runoff in Urban Watersheds

In a place where humans have not changed land formations or land covers, storm water runoff is an integral part of the natural water cycle process. However, runoff patterns change immensely when vegetative cover is replaced by concrete or other impervious surfaces, and the bulldozing of land formations destroys natural drainage patterns.

Typically, urbanized watersheds have impervious surface areas and drainage systems designed for efficient removal of surface water. These alterations to the land surface results in increased runoff volumes, higher peak flow rates and reduce rainwater infiltration and pollutant filtering by subsurface flow. Surface runoff carries dissolved, suspended, and sediment absorbed materials into receiving water bodies. Studies have detected inorganic pesticide residues and heavy metals, fecal coliform bacteria and concentrations of nitrogen and phosphorus compounds and polycyclic aromatic hydrocarbons (PAH) that are substantially higher than concentrations observed in more pristine areas (Corbett, 1997).

Urbanization and Stream Flow

The quantity of water carried by a stream is termed discharge. Discharge is derived from four sources: channel precipitation, overland flow, interflow, and groundwater. In dry regions, cultivated lands, and urbanized areas, overland flow is usually a major source of stream flow, particularly in small streams. Overland flow is runoff generated directly from rainfall (or snowmelt) that begins as a thin layer of water that moves very slowly (typically less than 0.25 ft/sec.) over the ground. Under intensive rainfall in the absence of barriers such as rough ground, vegetation, and absorbing soil, however, it can mount up rapidly reaching stream channels in minutes and causing sudden rises in discharge. The quickest response times between rainfall and stream flow occur in urbanized areas where yard drains, street gutters, and stormsewers collect overland flow and route it to streams straightaway. (Marsh, 1998)

In an urbanized area, with the construction of roads, utilities, buildings, and parking areas, the basin would change to a 'dry' detention basin. The resultant increase in storm flow peak is severe. The larger and faster flows not only lead to the danger of flood, but also seriously eroded stream channels: banks sloughed in, bed materials shifted, and the streams generated huge sediment loads as the adjusted to their new flow regime driven by storm water. (Marsh, 1998)

The effects of urbanization on stream flow have been much more thoroughly analyzed than seasonal watershed responses such as the rate of change in base flow, which in a watershed is ultimately controlled by groundwater storage. Deforestation and the paving of groundwater recharge areas, both inevitable results of urbanization, increase imperviousness and thereby affect groundwater recharge and storage and the rates of groundwater discharge to streams. Five major effects of urbanization have been identified: (1) a higher proportion of precipitation appears as surface runoff; (2) the catchment response to precipitation is accelerated and the lag time between precipitation and runoff is decreased; (3) peak flow magnitudes are increased for all but the largest storm events: (4) low flow is decreased due to reduced contributions from groundwater storage; and (5) water quality is degraded by effluent discharges (Corbett, 1997).

2.2 Hydrologic Modeling

Modeling is being used by scientists in a variety of fields like hydrology, ecology, economics, and transportation. Maidment defines hydrologic modeling as "a mathematical representation of the flow of water and its components on some part of the land surface or subsurface environment" (Maidment, 1993). The hydrologic model, which is often referred to as the hydrological system, was defined by Dooge in 1968 and modified by Clarke in 1973 as "a set of physical, chemical and / or biological processes acting upon a set of input parameters to convert into a set of output parameters (Raudkivi, 1979).

Keeping track of records over an adequate length of time especially during extreme events is a difficult task because it is not economically feasible to collect data on every catchment in the world. Due to anthropogenic changes, the hydrological environment is being continuously altered and this results in heterogeneity in the data that is collected. It is very difficult to interpret the non-homogeneous and time-dependent data and this limits its usefulness for prediction of future behavior. For these reasons scientists have turned to modeling of the various hydrological processes and also computer simulation of catchment behavior. (Dixit, 2002)

Hydrologic modeling has the potential to analyze the current scenarios and needs for water utilization, pollution control and mitigation and flood control and mitigation. No matter what the required end result is, the use of hydrologic models involves several basic steps (Raudkivi, 1979):

- Definition of the problem,
- Choice of the class of the hydrologic model,
- Choice of the type of model in the chosen class,
- Calibration of the model or optimization of parameters,
- Evaluation of model performance, and
- Use of the model.

There are a large amount of hydrologic models used in the field. Some hydrologic models focus on short-term storm events of specific recurrence intervals. These help in estimating flood intensities by calculating peak discharge rates and hydrographs. There are some other models that concentrate on the long-term cumulative hydrologic impacts of land use change. These models might help in determining the effects on water quality by pollutants that are washed off from different land uses. (Dixit, 2002)

Technical Release–55 (TR-55) Model

Technical Release-55 (TR-55) is a hydrologic model to calculate storm water runoff depth and volume, peak discharge rate and hydrographs. This guideline gives special emphasis to small urban and urbanizing watershed in the United States.

Considering the complexity of storm water runoff problems in urbanizing areas, scope of this research, availability of data and the acceptable level of error, TR-55 was used to carry out this research. The Soil Conservation Service (SCS) initiated this model in January 1975 under the name of TR-20. This was later modified into TR-55 in 1986, which incorporates current SCS procedures (USDA, 1986) and was primarily designed as a set of manual worksheets because computer usage was not widespread during the innovation of this technique.

- Computation of Runoff Depth and Runoff Volume

Using a runoff curve number (CN), mass rainfall is converted to mass runoff. CN depends upon the type of urban development and is based on hydrologic soil groups (HSG), plant cover type, and amount of impervious areas, interception, and surface storage. Soils are classified into 4 HSG's (A, B, C, D) based upon their minimum infiltration rate, which is obtained for bare soil after prolonged wetting. Any change in the soil profile will significantly change the infiltration characteristics (USDA, 1986).

The two important parameters to be considered for calculating runoff depth and volume are soil type and plant cover type:

- **Soil Type:** Most urban areas are seldom covered completely by impervious structures. Soil properties play an important role in estimating the total direct runoff volume. Infiltration rates for soil indicate their ability to absorb rainfall and hence reduce the amount of direct runoff. Urbanization has a greater impact on runoff in watersheds with soil having a high infiltration rate such as sand, gravels, and so on, than on soil with a low infiltration rate such as silts and clays (USDA, 1975).
- **Plant Cover Type:** Plant cover type and its hydrologic condition affect runoff volume through its influence on the infiltration rate of the soil. For the same soil type, runoff from fallow land is more when compared to forested areas (USDA, 1975).

Based upon Hydrologic Soil Groups and canopy coverage for different land uses, Curve Numbers (CNs) are chosen. These standard values are defined by SCS and are listed in Appendix C of this report. CN can be within a range of 0 to 100.

The value of S, which is the potential maximum retention after runoff begins, is related to the soil and cover conditions of the watershed. Hence, it is based on CN and calculated as:

$$S = (1000 / CN) - 10$$

Initial abstraction (I_a) is the water that is lost before runoff is initiated. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Though it is highly variable, it is correlated with soil and plant cover parameters. The level of I_a is less on concrete pavement than on pastures. Through many research studies conducted on small agricultural watersheds by SCS, I_a is based upon the empirical values as:

$$I_a = 0.2S$$

Once CN, S and I_a are determined, the SCS runoff curve number equation can be applied to calculate the runoff depth and volume, which is given by the formula (USDA, 1986):

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

where,

Q = runoff depth (in)

P = rainfall (in)

S = potential maximum retention after runoff begins (in) and

I_a = initial abstraction (in)

- Computation of Time of Concentration and Travel Time

Once the runoff is calculated the next step is the creation of unit hydrographs. Two major parameters, namely time of concentration (T_c) and travel time of flow through segments (T_t), are required to distribute the runoff into a hydrograph. The time taken for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed is T_c (USDA, 1986).

These depend on the surface runoff, flow length through segments of the watershed, and slope of the channel or pipe:

- **Surface Roughness:** A significant increase in the flow velocity can be observed when the flow path is changed from flow over rough surfaces of grassland, woodland, or natural channels to flow over smooth surfaces of storm sewers, parking lots, and gutters (USDA, 1975).
- **Flow Length:** Urbanization leads to reduction in overland flow length by conveying storm water runoff into the nearest channel through diversion dikes, storm sewers, or street gutters to larger collection systems (USDA, 1975).
- **Slope:** When overland flow occurs directly through storm sewers, gutters, diversion dikes, slope decreases, whereas when channels are straightened, slope tends to increase (USDA, 1975).

While computing travel time, the most prominent flow patterns are overland flow, storm sewer or road gutter flow and channel flow.

$$T_c = T_{t1} + T_{t2} + \ldots\ldots\ldots T_{tm}$$

where,

T_c = time of concentration (hr)

m = number of flow segments

$$T_t = L / 3600V$$

where,

T_t = travel time (hr)

L = flow length (ft)

V = average velocity (ft / sec)

3600 = conversion factor from seconds to hours

T_c influences shape and peak of the unit hydrograph. Urbanization is inversely related to T_c and directly to the peak discharge. Using the unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed, runoff is transformed into a hydrograph (USDA, 1986).

- Computation of Tabular Hydrograph

The assumption while applying this method is that all discharges to a stream reach the flow at the same velocity. Computation of hydrographs is done after T_c and T_t have been calculated for sub-areas in the watershed having relatively homogeneous and convenient routing reaches. The drainage area of each sub-area has to be computed, which will lead to the production of the final output, which is the ratio of (I_a / P). I_a is calculated on the basis of weighted CN and total runoff computed from CN and rainfall.

2.3 GIS as a Tool for Hydrologic Modeling and Computerized Hydrologic Modeling

Modeling can serve as an invaluable watershed management tool when combined with Geographic Information System (GIS). GIS not only helps in capturing watershed system state and dynamics, but also makes the simulation process more accessible

US Geological Survey defines Geographic Information Systems (GIS) as a general-purpose computer-based technology system capable of assembling, storing, manipulating, and displaying geographically referenced information that is data identified according to their locations. GIS is not just a computer system for producing maps, but GIS technology can be used for scientific investigations, resource management, and development planning (USGS, 2001). GIS contains both geometric data, that is coordinates and topological information, and attribute data that is information describing the properties of geometrical objects such as points, lines, or polygons (Singh et al, 1996).

An object-oriented data model is a useful intermediate step between spatial-relational model inherent in GIS and data structures of the hydrologic models, and this can only be achieved by linking GIS with hydrologic modeling. Hydrologic phenomena are driven by rainfall, which makes them time dependent. GIS data structures, which are time independent, can be linked to hydrologic models to have a spatial distribution of hydrologic phenomena (Maidment, 1993).

HEC

HEC is the abbreviation of The Hydrologic Engineering Center. It is an office of the US Army Corps of Engineers established to support the nation in its water resources management responsibilities by increasing the Corps technical capability in hydrologic engineering and water resources planning and management. By means of programs in research, training, planning analysis, and technical assistance, HEC incorporates hydrologic modeling procedures and techniques into manuals and comprehensive computer programs, which are available to the public (http://www.hec.usace.army.mil/).

- HEC-HMS

HEC-HMS (Hydrologic Modeling System, Version 2.2.1) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It provides a variety of options and represents a significant advancement in terms of both computer science and hydrologic engineering. In addition to unit hydrograph and hydrologic routing options, capabilities include a linear quasi-distributed runoff transform (ModClark) for use with gridded precipitation, continuous simulation with either a one-layer or more complex five-layer soil moisture method, and a versatile parameter estimation option (http://www.hec.usace.army.mil/software/software_distrib/hec-hms/hechmsprogram.html).

- HEC-GeoHMS, Version 1.0 for ArcView

The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) is a software package for use with the ArcView Geographic Information System. GeoHMS uses ArcView and Spatial Analyst to develop a number of hydrologic modeilng inputs. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. In addition to the hydrologic data structure, capabilities include the development of: grid-based data for linear quasi-distributed runoff transformation (ModClark), the HEC-HMS basin model, physical watershed and stream characteristics, and background map file.

HEC-GeoHMS provides an integrated work environment with data management and customized toolkit capabilities, which includes a graphical user interface with menus, tools, and buttons. The program features terrain-preprocessing capabilities in both interactive and batch modes. Additional interactive capabilities allow users to construct a hydrologic schematic of the watershed at stream gages, hydraulic structures, and other control points. The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS, where simulation is performed. HEC-GeoHMS is operational on Windows 95/98/NT/2000 operating systems (http://www.hec.usace.army.mil/software/software_distrib/geo-hms4arcview/geohmsprogram.html).

2.4 Land-Use Suitability Analysis

Land-use suitability analysis is a tool used to identify the most suitable places for locating future land uses. With the help of suitability analysis, land use planners and environmental managers are able to analyze the interactions among three types of factors: location, development actions, and environmental elements. The analysis results might be able to show: which land uses will have the least adverse impact on environmental processes, qualitative predictions of environmental impacts of proposed developments, and the most and least propitious locations for specific development proposals (Collins et al. 2001).

Suitability analysis is widely used in the development of land-use plans, environmental impact reviews, and site selection studies for many different land uses. The suitability factors included are determined by the available data and can include a broad range of natural features, e.g., slopes, soils, stream buffers, flood plains, wetland, hazardous areas, etc. or each land use considered in the study. Different factors should be considered for different land uses; for instance, soils may be assumed to be important for locating retail and office establishments but not important for locating single family developments.

3 METHODOLOGY

3.1 RESEARCH QUESTION

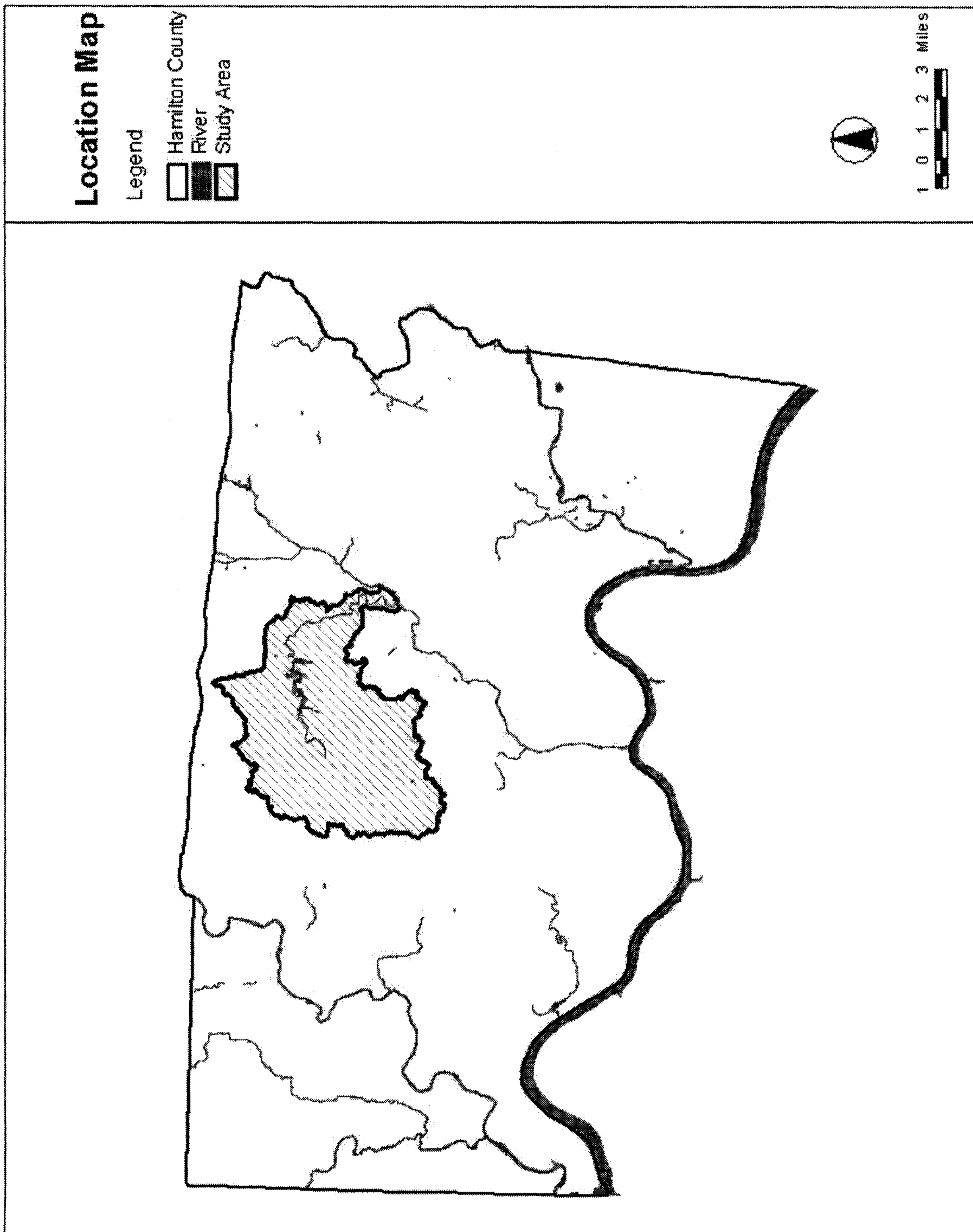
The main concerns of the study are explained in chapter 1. Specifically, the study strives to answer the following questions: Can hydrologic modeling be used as a tool to identify the impact of land development on watersheds, and therefore to improve traditional planning process?

The objectives of the study include:

- Set up hydrologic models for the study area
- Compare the model results with different land use scenarios
- Analyze how the change of land use can affect the hydrologic response of the watershed
- Give answers to the research question

3.2 STUDY AREA

The case study site is west Mill Creek basin, which is located in Hamilton County, Ohio (Map 3.1). Several factors have been considered for the site selection, including manageable size of the watershed, availability of data, and variability of land coverage types. The area of west Mill Creek basin is 36.33 sq.miles. Mid-density residential use is the dominating land use type. A large area of open land with tree coverage is preserved for the usage of public recreation and public service. There are several USGS stream flow gages and MSD rain gages located in the study area, which can provide useful data for the study.



Map 3. Location map of West Mill Creek basin.

3.3 Data Collection

3.3.1 Date required by HEC-GeoHMS

Digital Elevation Model (DEM): 30-by-30-meter DEM is recommended by HEC, mainly because of its availability and fair accuracy. Since more accurate data: 4-by-4-meter DEM is available from Cincinnati Area Geographic Information Systems (CAGIS), it is used for modeling the terrain.

Land Use: Year 1994. Source: CAGIS (Maps 3.2).

Hydrologic Soil Groups: Source: CAGIS (Map 3.3).

Land Cover: Year 2001. Source: CAGIS (Map 3.4).

3.3.2. Parameters required by HEC-HMS

Subbasin Modeling

Loss Rate Method: SCS curve number method is used for the study. Required parameters are the initial loss, curve number, and percentage of impervious surface. Source: TR55.

Transform Method: SCS Unit Hydrograph is used. Required parameter is the SCS lag in minutes or hours, which is computed as follows:

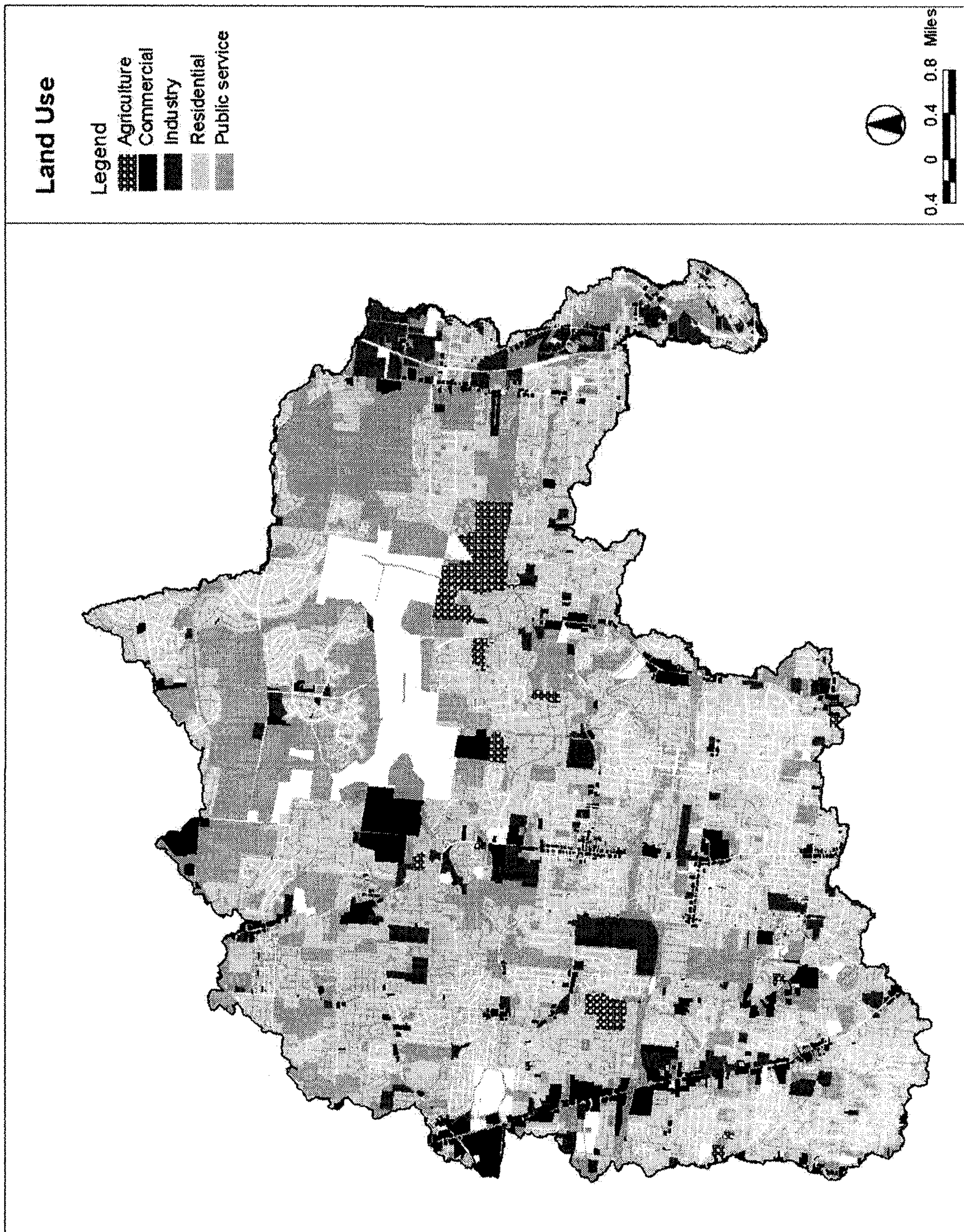
t_p = basin lag time estimated as (0.60) T_c

$T_c = 0.0078\, L^{0.77}\, S^{-0.385}$

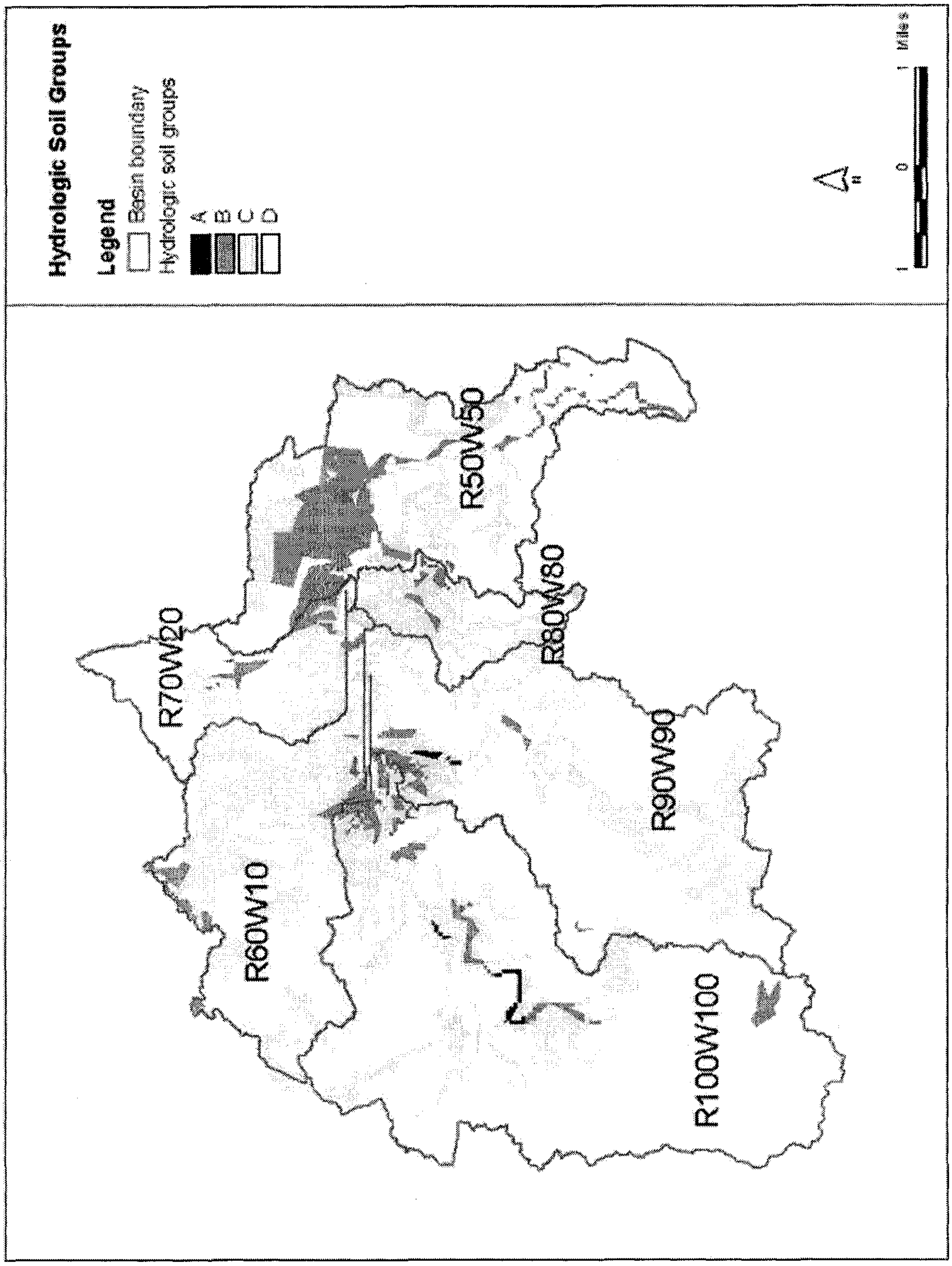
T_c = time of concentration

L = length of channel / ditch from headwater to outlet, ft

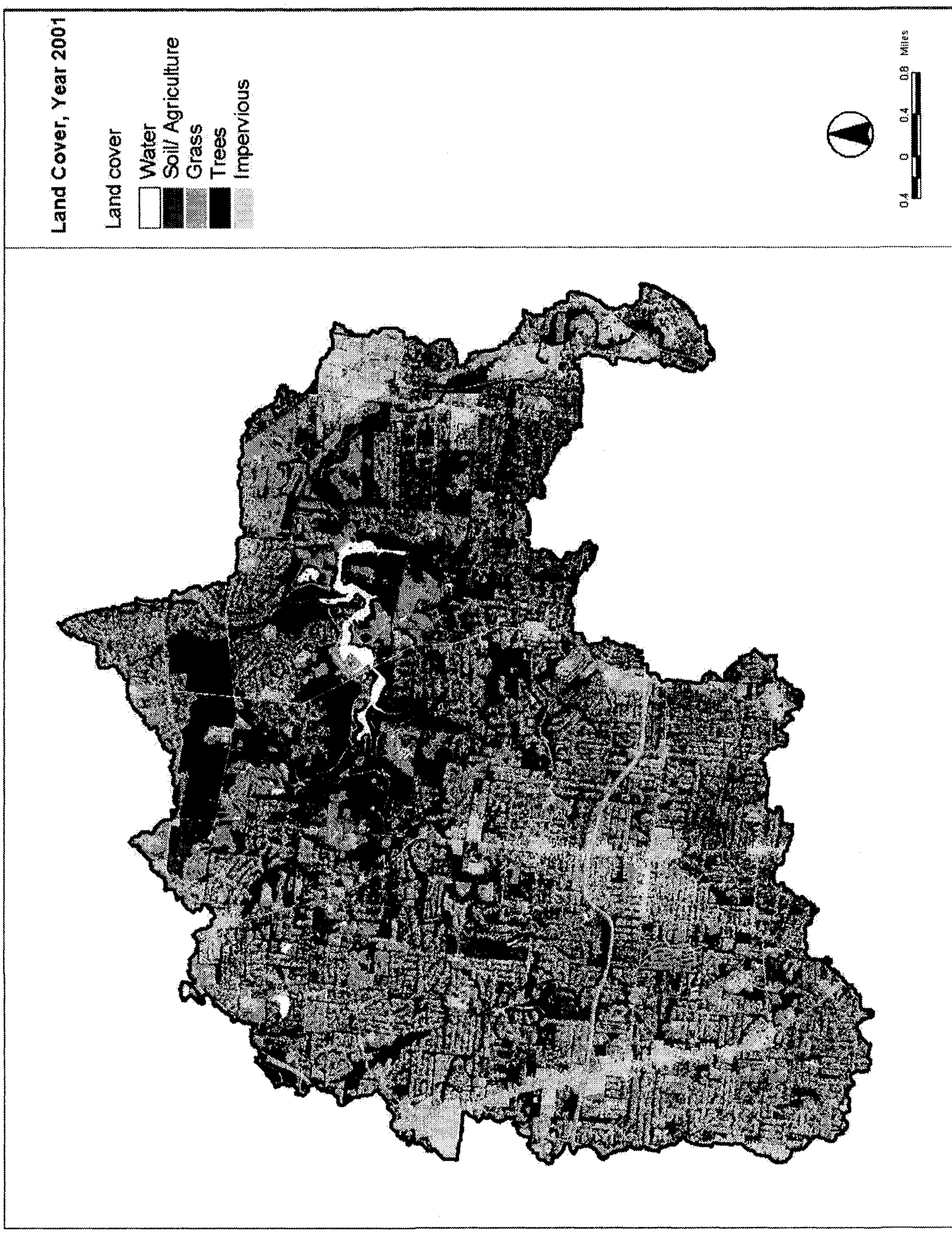
S = average watershed slope, ft/ft



Map 3.2 Land Use of West Mill Creek basin



Map 3.3 Hydrologic Soil Groups of West Mill Creek basin



Map 3.4 Land cover of West Mill Creek basin

Baseflow Methods: Constant monthly baseflow method is used. Data is interpolated using linear regression method based on several stream flow gages located in or near the study area, listed in *Low-Flow Characteristics of Streams in Ohio through Water Year 1997* (U.S. Department of the Interior & U.S. Geological Survey, 1997).

Reach: As the reaches in the study area are short, which range from 744.1ft to 35622.4 ft (the value is generated by HEC-GeoHMS), so according to expert opinions, no reach routing method is used (Buchberger, 2003).

Reservoir: The storage-outflow relationship of the reservoir can be specified from three available methods: Storage-outflow, Elevation-storage-outflow, and Elevation-area-outflow. Required parameters: storage method, initial condition, and storage-outflow curve. (The initial condition, depending on storage method, can be inflow equals outflow or a reservoir storage, outflow, or elevation value. The storage-outflow input data must span the range of possible values. No extrapolation is used beyond the input data. Outflow cannot be computed when storage falls below the first value in the table or exceeds the last value.) The data is required from US Army Corps of Engineers, and there is further discussion about reservoir modeling in the following section.

Meteorologic Models

Precipitation Methods: The methods available include User hyetograph, User gage weighting, Inverse-distance gage weighting, Gridded precipitation, Frequency storm, SCS hypothetical storm, Standard project storm. User hyetograph is the method applied in the study. Source: Metropolitan Sewer District of Greater Cincinnati (MSD).

3.3.3 Defining Three Land Use Scenarios

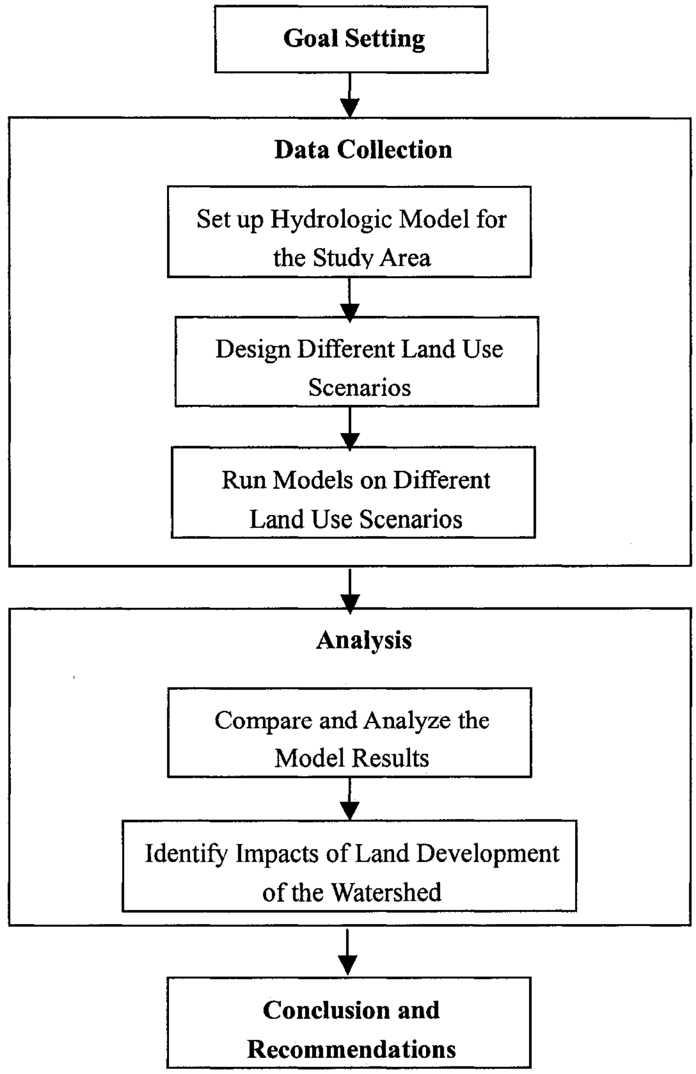
Three different land use scenarios are proposed, and the hydrologic models are created based on these scenarios. In order to investigate the relationship between land development and hydrologic response of the watershed, two additional land use scenarios are designed in addition to the current land use. Scenario two is a conservative land development plan incorporating the concept of suitability analysis, while scenario three is a built out plan.

3.4 PROJECT DESIGN

This study is carried out in four major phases as indicated below:

1 Goal Setting
2 Data Collection
3 Analysis
4 Conclusion and Recommendations

The flow chart illustrates detailed procedure of the study.


Goal Setting
Data Collection
Set up Hydrologic Model for the Study Area
Design Different Land Use Scenarios
Run Models on Different Land Use Scenarios
Analysis
Compare and Analyze the Model Results
Identify Impacts of Land Development of the Watershed
Conclusion and Recommendations

4. HYDROLOGIC MODELING

4.1 BASIN MODELING IN HEC-GEOHMS

HEC-GeoHMS is a set of ArcView scripts developed using the Avenue programming language and Spatial Analyst. It includes integrated data management and a graphical user interface (GUI). Through the GUI, which consists of menus, tools, and buttons, the user can analyze the terrain information, delineate subbasins and streams, and prepare hydrologic inputs.

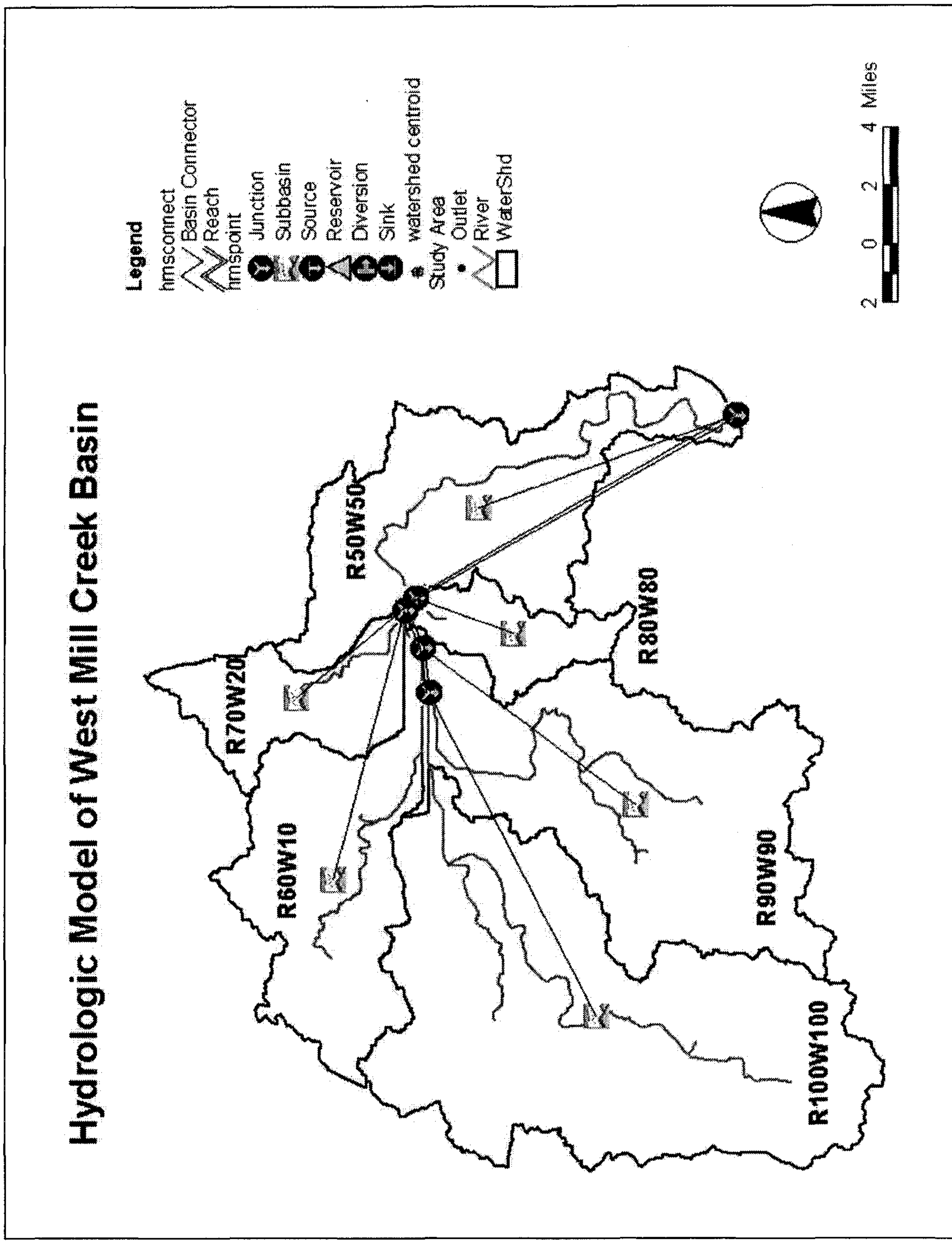
The following is the major steps in the process:

- Data Processing
    - Data Collection
    - Data Assembly
- Terrain Preprocessing
- Hydrologic Processing
    - Basin Processing
    - Stream and Watershed Characteristics
    - HMS Model Files Creation

In this study, the 4-meter DEM file is used to generate the drainage network of West Mill Creek Basin. Using the functions of HEC-GeoHMS combined with the best judgment of the author, a set of drainage network is derived and serves as the basin model in HEC-HMS modeling. The network is made up of six subbasins with attributes computed by HEC-GeoHMS automatically list in Table 4.1. The problem of this process is that HEC-GeoHMS can not model the West Fork Lake located within the study area, which makes it a significant limitation of the study. The dam can not be modeled because of its unsteady nature. The hydrologic model set up in this study can be considered as a drainage network without dam regulation. It is recommended that further study tackle this problem and set up hydrologic models better reflect the reality of the watershed. This issue will be discussed further in the section later.

Table 4.1. Major attributes of subbasins

Basin Name	**Area** (sq.mile)	**Slope**	**Longest Flow Length** (ft)
R50W50	6.229	0.006	46710.029
R60W10	5.044	0.006	35042.951
R70W20	2.444	0.010	20719.520
R80W80	1.441	0.011	15326.560
R90W90	8.388	0.005	42742.807
R100W100	12.320	0.004	48031.006



Map 4.1 Hydrologic model of the study area created in HEC-GeoHMS

4.2 Hydrologic Modeling in HEC-HMS

The modeling in HEC-HMS is first operated based on current condition, 2001 data.

4.2.1 Create a Basin Model

The basin model is imported from the model already created in HEC-GeoHMS. But still there are many parameters left to be calculated, which are list in Table 4.1. The following discusses in detail how these parameters are calculated and achieved.

Loss Rate

- SCS Curve Number (CN)

The process of calculating the CN value is:

- Overlay the layer of soil hydrologic groups and the layer of current land cover using Intersect function in Geoprocessing Wizard, ArcView. The resulted polygon has both information of soil hydrologic groups and land cover;
- Assign the appropriate CN value to each of the overlaid polygons according to *Urban Hydrology for Small Watersheds, TR55, Table 2-2a and Table 2-2c.* A shapefile with CN value distribution of the study area is created: CN2000.
- Calculate the weighted CN value for each subbasin.

$$\text{CN (weighted)} = \frac{\text{Sum (CN * Area)}}{\text{Sum (Area)}}$$

- Initial Loss

Based on CN value, the value of initial loss is checked up in *Table 4-1, Urban Hydrology for Small Watersheds, TR55.*

- Percentage of Impervious Surfaces

Percentage of Impervious Surfaces is calculated using the land cover layer. Land cover is classified into five groups: water, grass, trees, soils/agriculture, and impervious surface.

Table 4.2. Parameters of Loss Rate

Basin Name	Weighted CN	Percent of Impervious	Initial Loss
R90W90	81	28.60	0.469
R80W80	74	12.23	0.703
R50W50	79	28.90	0.532
R70W20	76	21.05	0.632
R100W100	82	30.19	0.439
R60W10	76	18.04	0.632

Transform

- SCS Lag Time

The SCS lag time for each basin (Table 4.4) is calculated using the formula list in Section 3.3.2.

Table 4.3 SCS lag time of each subbasin

BASIN NAME	Slope	Length (ft)	L0.77	S-0.385	Tc (sec)	Lag Time = 0.6*Tc (sec)	Lag Time (min)
R50W50	0.006	46710.029	3939.543	7.168	220	132	2.20
R60W10	0.006	35042.951	3157.494	7.168	177	106	1.77
R70W20	0.010	20719.520	2106.747	5.888	97	58	0.97
R80W80	0.011	15326.560	1670.292	5.676	74	44	0.74
R90W90	0.005	42742.807	3679.294	7.689	221	132	2.21
R100W100	0.004	48031.006	4025.054	8.379	263	158	2.63

Base Flow

The method of constant monthly base flow is applied. The values are interpolated based on the results of the statistical analysis listed in *Low-Flow Characteristics of Streams in Ohio through Water Year 1997* (U.S. Department of the Interior & U.S. Geological Survey, 1997). According to expert opinion (Buchberger, 2003) The 90-day flows with a 2-year recurrence interval (90Q2) of five gages in the tri-state area are used to interpolate the base flow values of the subbasins of the study area using least squared method (linear trend). The contributing basin areas of the gages range from 32 sq.miles to 476 sq.miles. Considering the areas of the subbasins are all smaller than the available data, another interpolation only using the three gages with smallest contributing area is conducted. Because many of the projected value from 5 gages drop below zero, which can not be realistic , the second approach appears more reasonable, which comes out with much less negative results (Figure 4.1). Second approach still comes out with several negative values. For those negative values, zero is assigned to replace the negative ones. The projected outcome is list in Table 4.5. The detailed calculation and results are in Appendix.

Table 4.4. Base flow of each subbasin

	Base Flow (cfs)			
Basin Name	**Mar. - Apr.**	**May.-Aug.**	**Sep.-Nov.**	**Dec.-Feb.**
R50W50	1.7	0	1.5	15.4
R60W10	1.4	0	1	14.1
R70W20	0.8	0	0	11.1
R80W80	0.6	0	0	10
R90W90	2.2	0	2.4	17.9
R100W100	3.1	0.5	4.1	22.3

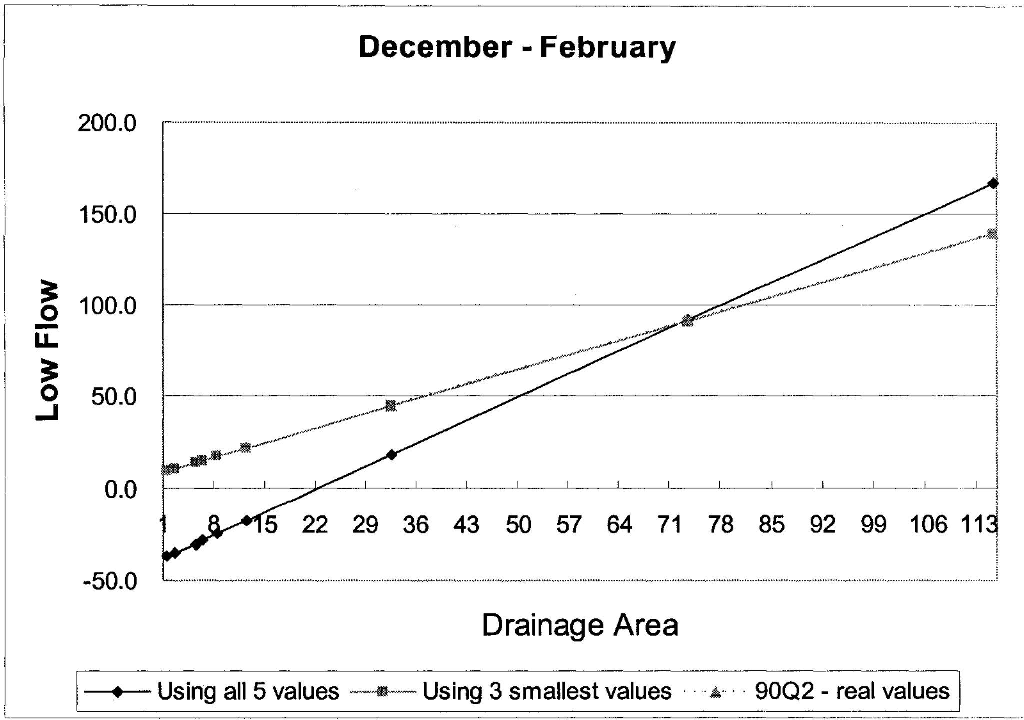


Figure 4.1 Two sets of interpolation results of base flow, December to February

Discussion of West Fork Lake (Dam)

West Fork Lake is a problem in the modeling process. It turned out that the HEC-GeoHMS can not model a dam in its operation. It can only be modeled later in HEC-HMS, by adding a dam component manually. But still, based on the current understanding and the data provided by U.S. Army Corps, the dam can not be modeled in HEC-HMS. The reason is that West Fork Lake is a manually controlled lake and the outflow is based on the gate settings. So there is no Discharge Coefficient of the outlet can be entered in order to complete the model. The detailed data of the dam is provided in the Appendix 5.

4.2.2 Create a Meteorologic Model

The rain event used to create the meteorologic model is the June 13, 2000 storm provided by Metropolitan Sewer District (MSD) (Figure 4.1). The reason of picking this storm because it is one of the largest storm event in year 2001, which could cause significant hydrologic response of the watershed. The time interval is 10 minutes and the total rainfall is 1.92in. The detailed data is in Appendix 6.

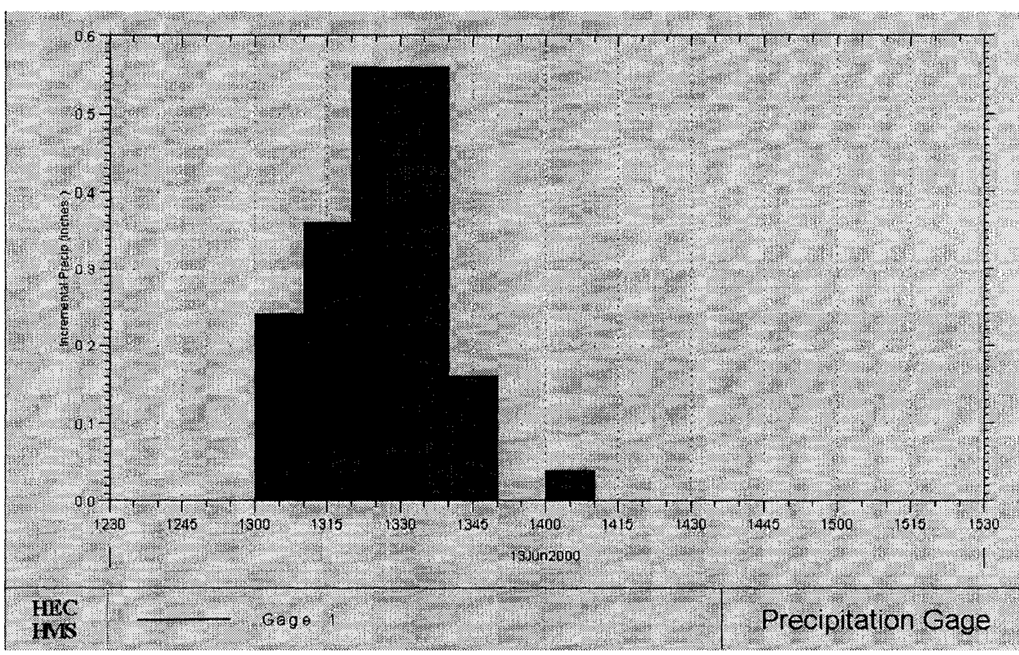


Figure 4.2. Incremental precipitation of the June 13, 2000 storm

4.2.3 Simulation and Results

The condition of current land use is simulated for the storm event of June 13, 2000. The peak discharge formed at 13:40, with the value of 47,495 cfs at the outlet of the study area. Total volume of storm water runoff of the entire study area is 1,680 ac ft. In the next chapter, two more land use scenarios are modeled and further analysis based on all three land use scenarios is conducted.

Table 4.5. Summary of simulation results for the current land use

Hydrologic Element	Discharge Peak (cfs)	Total Volume (ac ft)	Drainage Area (sq mi)
R100W100	18045.0	654.740	12.32
R90W90	11828.0	422.780	8.388
R60W10	5361.4	175.450	5.044
R70W20	2697.0	91.080	2.444
R80W80	1285.0	39.166	1.441
R50W50	8278.2	296.800	6.229
Outlet_study1	47495.0	1680.000	35.866

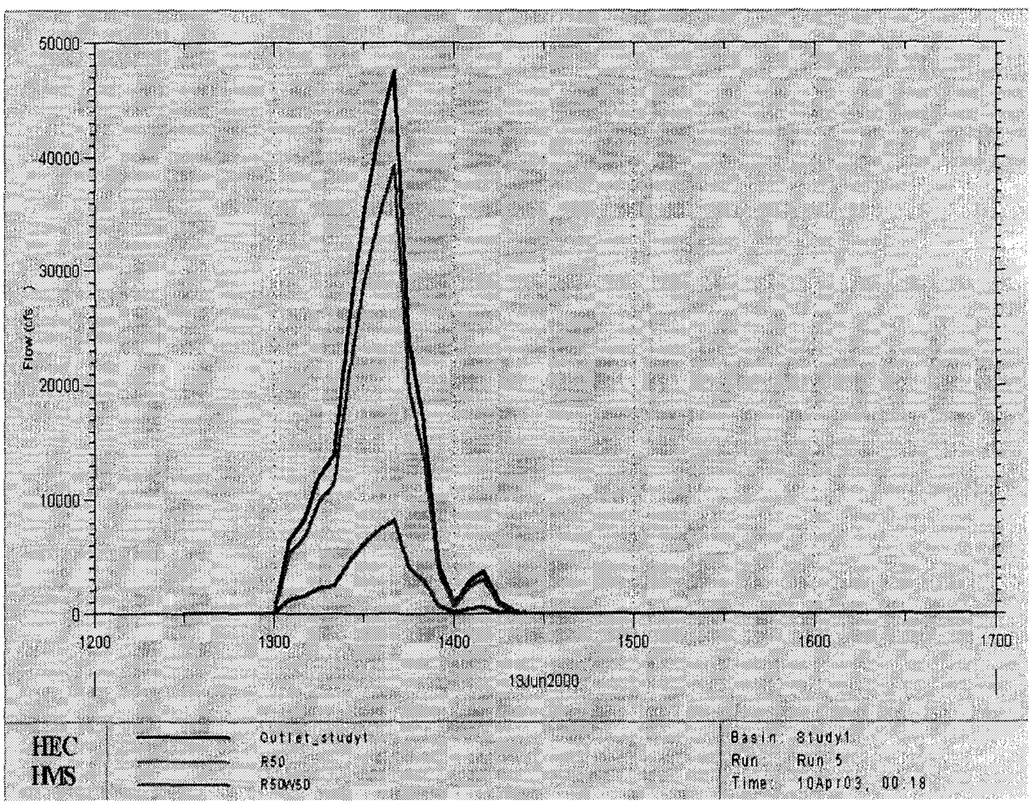


Figure 4.3. Stream Flow of the outlet of the study area

4.3. SIMULATION OF DIFFERENT LAND USE SCENARIOS

In order to investigate the change in hydrologic response due to urbanization, hydrologic modeling was carried out based on three land use scenarios. Scenario one consists of current land use. Another two land use scenarios are based on the assumption that there will be moderate density residential development in the study area, with a lot size of 1/4 acre, impervious percentage of 38% (Appendix 1) Upon examining the current land use of the study area, it turns out that subbasins R90W90 and R100W100 are both already heavy developed. Therefore, the allocation of the assumed residential development will be focused within the boundary of the other four subbasins (subbasin R50W50, R60W10, R70W20, R80W80). In scenario two, the rationale to define the location of the new development is incorporating the concept and method of suitability analysis to convert those suitable lands of existing land use of vacant land and agriculture to mid-density residential use. The detailed procedure is described below. The third scenario is a built out plan, which converts all the land parcels of vacant, agriculture, public recreation, and public service into mid-density residential use.

4.3.1 Allocation of Assumed Development and Calculation of the New CN

Procedure of Scenario Two

1) Suitability analysis of the study area

The suitability factors taken into consideration are:

- Slope: 0~10 is considered suitable
- Stream buffer: It is a buffer zone with width of 100ft along the stream. The area out of the buffer zone is considered suitable
- 100-year flood plain: all the area is out of the 100-year flood plain.

By using the intersect function of the Geoprocessing Wizard in ArcView, the area meets all the above requirements is delineated as the suitableland shapefile.

2) Delineate suitable and convertible land

The land of existing land use of vacant land and agriculture within the boundaries of subbasin is considered convertible to the residential use. Those lands are selected and become convertible land shapefile. By intersecting the suitable land shapefile and convertible land shapefile, the area for the assumed development is delineated as land4develop shapefile, and is assigned the land use of moderate density residential use.

3) Calculation of new CN of the four subbasins

Following the same procedure to calculate CN in section 4.2.2, new CN is caculated and a shapefile with new CN value is created: CN_scenario2.

Procedure of Scenario Three

The procedure of scenario three is simpler than scenario two:

1) Convert CN2000 shapefile to a new shapefile called CN_scenario3. Select land parcels of vacant, agriculture, public recreation, and public service, and change the land use to moderate density residential.
2) Assign CN value to these newly changed parcel according to TR 55. A shapefile

of CN value of the four subbasins is created.

4.3.2 Hydrologic modeling and stream flow simulation in HEC-HMS

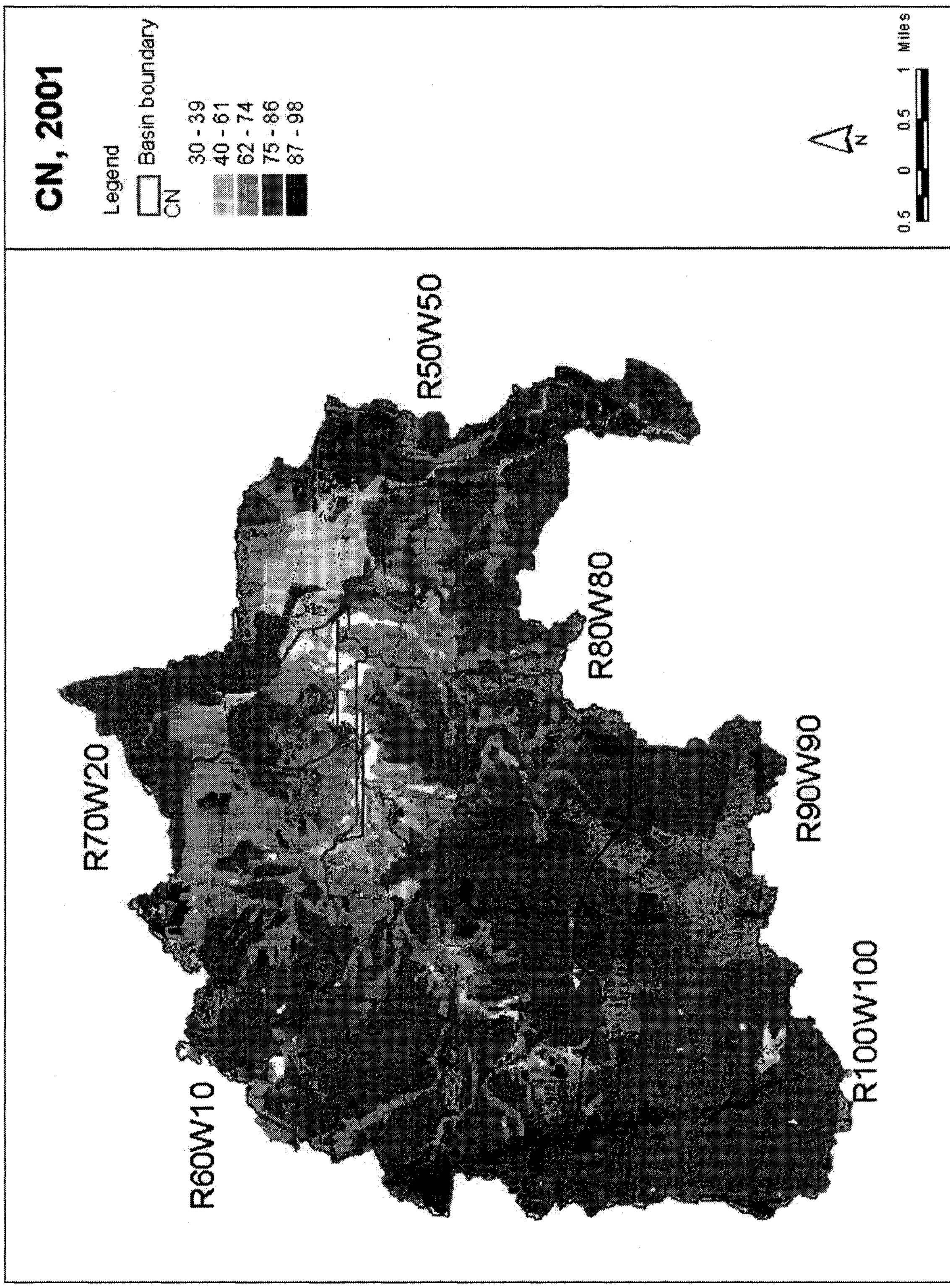
New hydrologic models of the study area for land use scenarios two and three are set up after changing several parameters. All the changes happen in basin model, and the parameters changed are CN, percentage of impervious surface, and initial loss. Subbasin R90W90 and R100W100 remain the same. Storm event is still the 1.92in event in June 13, 2001 and control specifics remain the same.

5. Discussion of Simulation Results

Land development replaces pervious surface with impervious surface. Paving of watersheds and the related development of artificial channels or drains increases the direct input of precipitation into stream channels (Rose and Peters, 2001, P. 1446). Forest removal in urban watersheds increases the percentage of precipitation that results in runoff by decreasing evapotranspiration (ET) losses. To evaluate changes in runoff associated with urbanization, the storm water runoff volumes of the six subbasins with current land use, and four subbasins with assumed and built out land use were compared.

5.1 Comparison of Six Subbasins with Current Land Use

Results of simulation of six subbasins with current land use indicate that urbanization is a significant factor controlling the storm water runoff in the study area. Simulation results illustrate that in general, the trends are: increasing the impervious surface and decreasing the vegetation cover resulted in increased runoff. The mechanisms responsible for this inverse relationship are the land cover, which affect interception depth and infiltration and roughness, changed from vegetation to impervious, allows more overland flow and decreases infiltration and storage.



Map 5.1 CN, current land use (Year 2001)

Another interesting observation on the relationship of CN and percentage of impervious surface is that a higher percent of impervious surface does not necessarily leads to a higher CN. Subbasin R60W10 has a higher percentage of impervious surface (18.04%) than R80W80 (12.23%), but R60W10 has a lower CN (74) than R80W80 (76). The reason can be contributed to that in subbasin R60W10, most of the pervious surface is covered with trees, while in R80W80, a significant percentage of pervious surface is covered with grass. As tree coverage is assigned a considerately lower CN than grass coverage, which demonstrates tree coverage has better rainfall retaining capacity, the CN of the whole subbasin is lowered significantly. It is a meaningful reminder for site planning. If it is desirable to minimize the impact of development on watersheds, like to reduce after development storm water runoff and stream flow rate, it is a smart idea to plant more trees wherever possible in stead of planting grass.

Table 5.1. Comparison of six subbasins with current land use

Subbasin	CN	Percent of Impervious	Peak Discharge (cfs)	Storm Water Runoff (in)	Area (sq.mile)	Slope
R50W50	81	28.90	8278.2	0.89	6.229	0.006
R60W10	74	18.04	5361.4	0.65	5.044	0.006
R70W20	79	21.05	2697.0	0.70	2.444	0.010
R80W80	76	12.23	1285.0	0.51	1.441	0.011
R90W90	81	28.60	11828.0	0.95	8.388	0.005
R100W100	82	30.19	18405.0	1.00	12.32	0.004

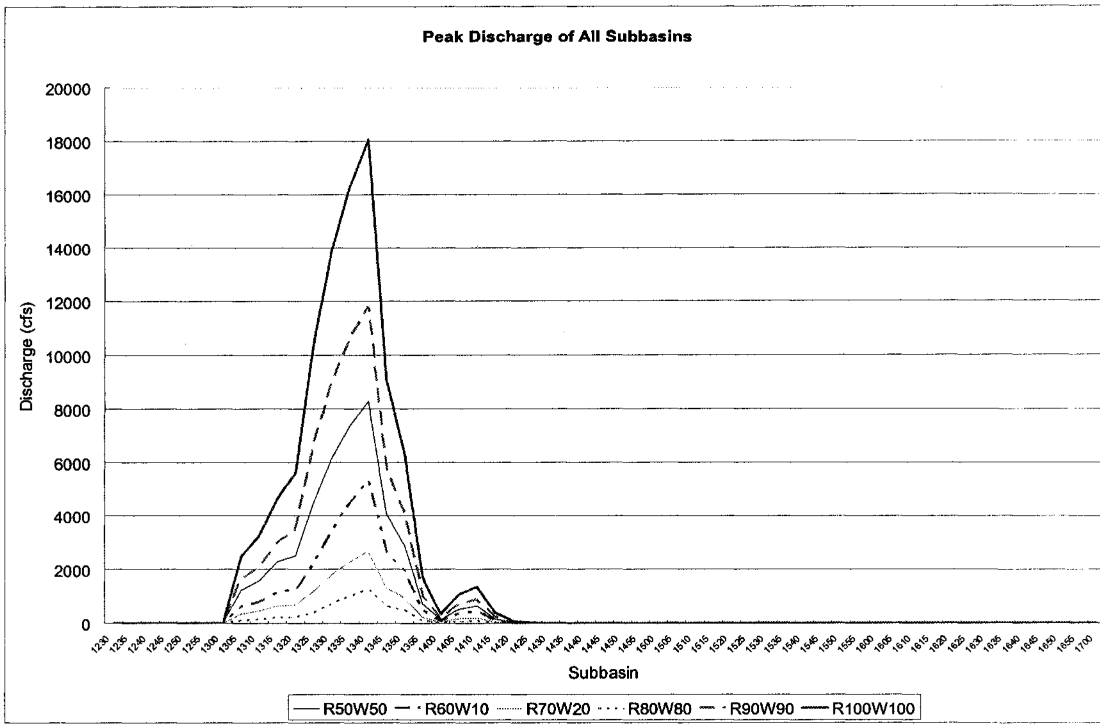
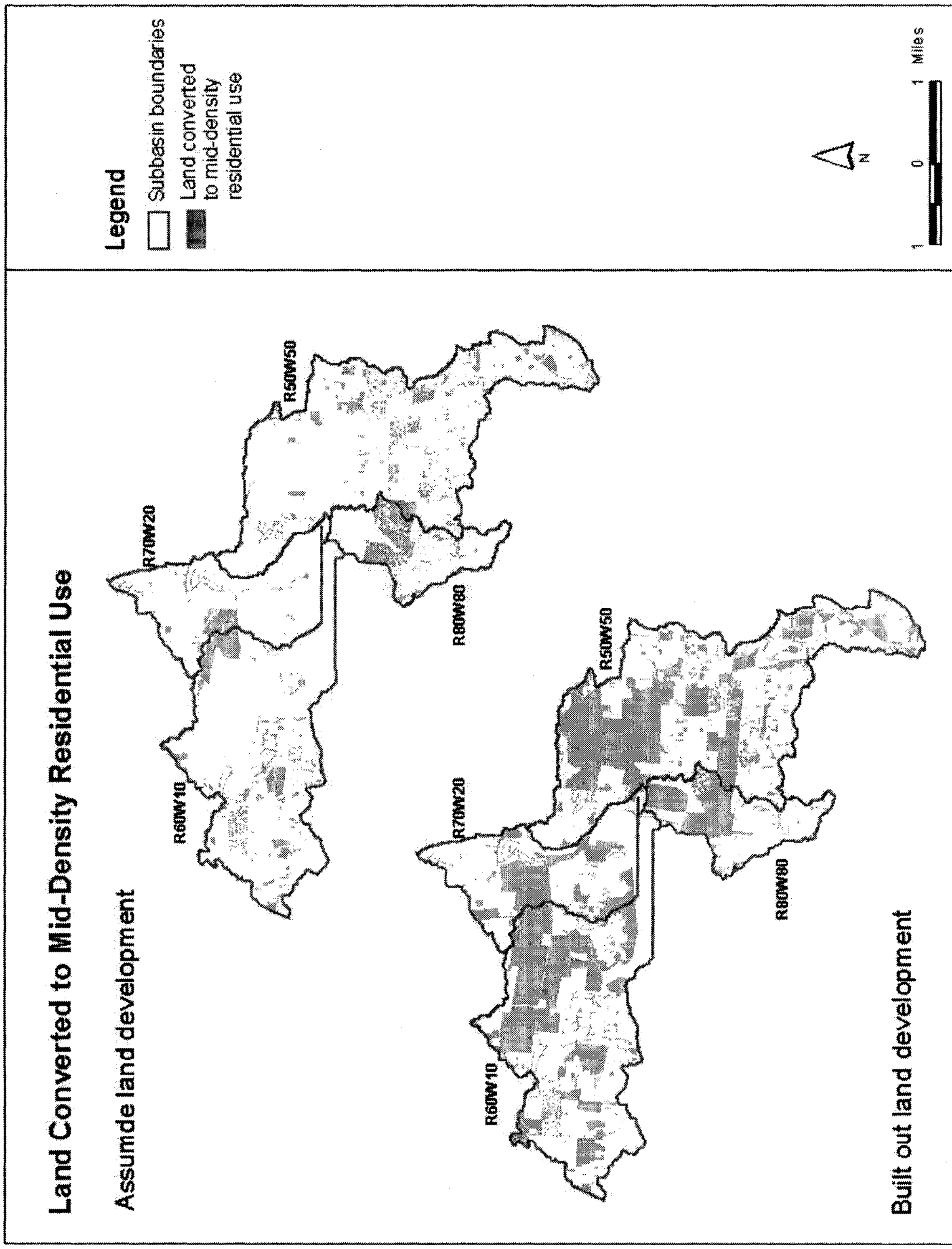


Figure 5.1. Stream flow of six subbasins with current land use

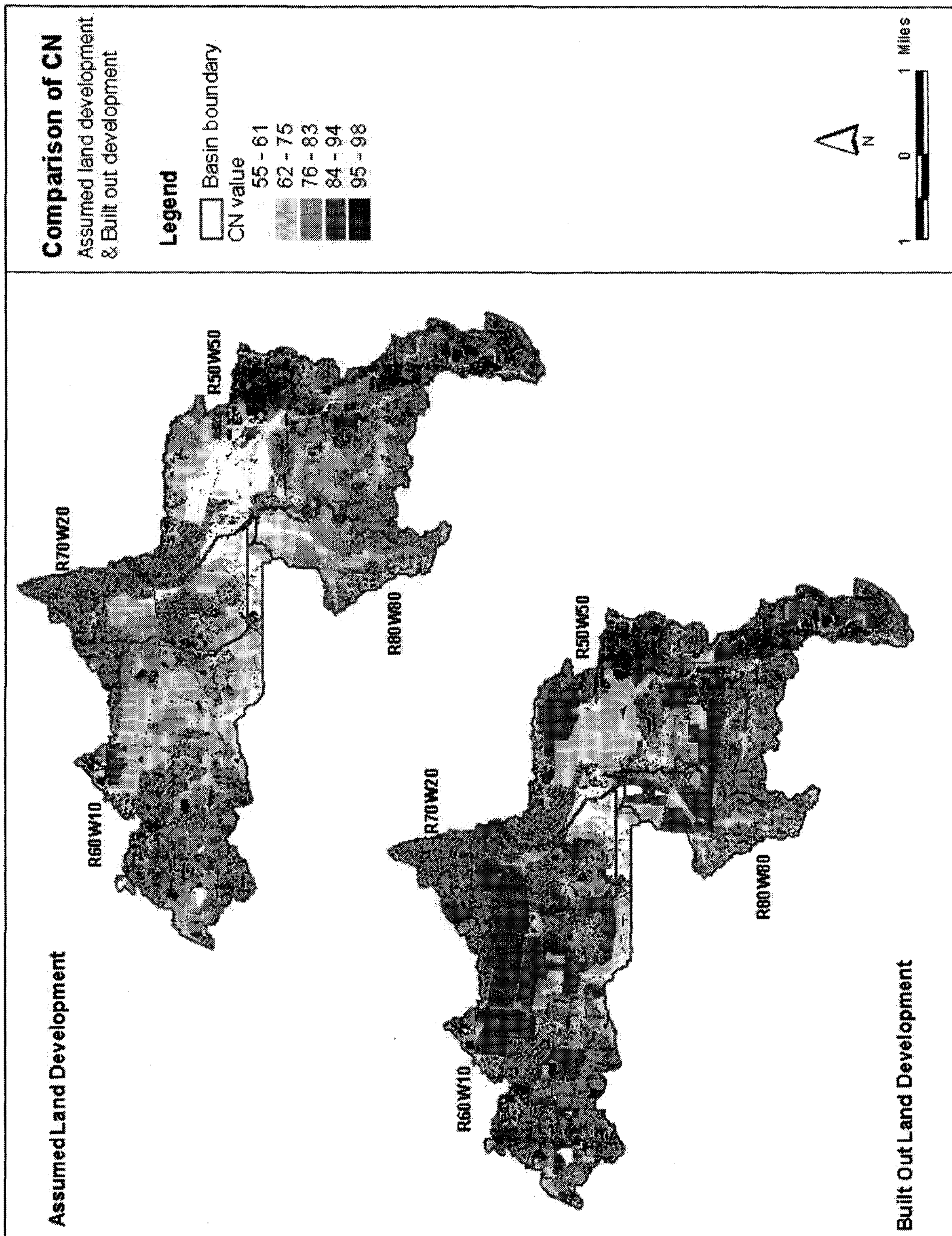
5.2 COMPARISON OF CURRENT LAND USE, CONSERVATIVE DEVELOPMENT, AND BUILT OUT DEVELOPMENT

In order to further understand the impact of land development on the hydrologic response of watersheds, another two land use scenarios were designed and hydrologic response were simulated based on each land use scenarios in HEC-HMS.

Note that the land use change affects three parameters in HEC-HMS: CN, percentage of impervious surface, and initial abstraction. The simulation results reveal a similar trend as the one shown in the comparison of six subbasins with the same land use: when pervious surface are replaced by impervious surface and vegetation coverage is razed, stream flow rates and storm water runoff volume are increased.



Map 5.2 Converted land of land use scenarios two and three



Map 5.3 CN of land use scenario two and three

Scenario 2, the conservative development, does not result in a significant change in the watersheds response. The development is very conservative and avoids transforming the land with tree coverage to residential use as much as possible, so most of the land with best rainfall retaining capacity is protected. Most land converted is currently covered with agriculture or grass. The increase of impervious surface is no more than 10% for each subbasin except subbasin R80W80, and the increase in CN is only by 1 point for each subbasin including subbasin R80W80. It is still interesting to see in subbasin R80W80 that a significant increase in percentage of impervious surface (34.83%) only results in a slight increase in CN value (from 74 to 75). The reason might still be that more than half of the lands converted are originally covered by grass, so the change in CN is not as much as converting lands with tree coverage.

The third land use scenario, the built out development, leads to a significant change in the hydrologic response of all four subbasins. In this scenario, all the land of vacant, agriculture, public recreation and public service are converted to mid-density residential use. By doing so, nearly all the land of tree coverage is replaced with urban development, which greatly affects the stream flow and storm water runoff of the watersheds, as the rainfall retaining capacity of the land changes significantly from trees to mid-density residential use. Such changes are reflected in the increase of CN value and percentage of impervious surface when parameterizing the hydrologic model in HEC-HMS. Below are the summary of such changes and corresponding simulation results.

Table 5.2. Comparison of four subbasins with different land use scenarios

Subbasin	CN			Percent of Impervious		
	Current	Assumed	Built out	Current	Assumed	Built out
R50W50	79	80	83	28.90	29.60	37.95
R60W10	76	77	80	18.04	19.77	29.56
R70W20	76	77	79	21.05	22.05	29.34
R80W80	74	75	78	12.23	16.49	24.47

Table 5.3. Change in percentage of impervious surface of three land use scenarios

Sub-basin	Percent of Impervious Surface				
	Current	Assumed	Increase%	Built out	Increase%
R50W50	28.90	29.60	2.42	37.95	31.31
R60W10	18.04	19.77	9.59	29.56	63.86
R70W20	21.05	22.05	4.75	29.34	39.38
R80W80	12.23	16.49	34.83	24.47	100.08

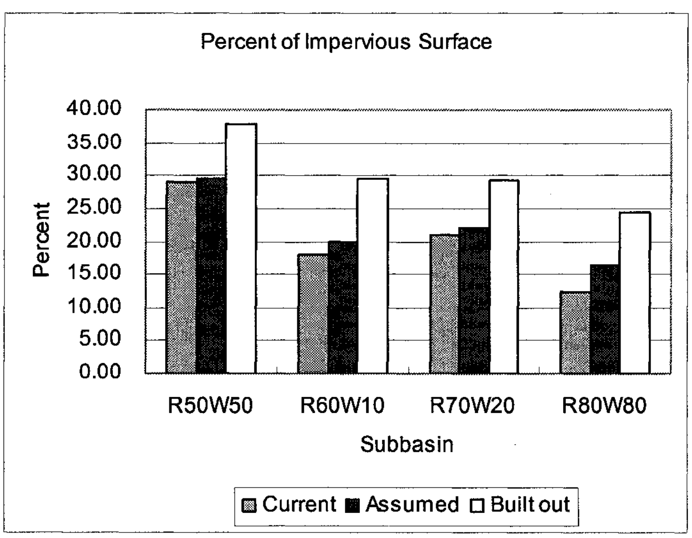


Figure 5.2. Change in percentage of impervious surface of three land use scenarios

Table 5.4. Change in CN value of three land use scenarios

Sub-basin	CN		
	Current	Assumed	Built out
R50W50	79	80	83
R60W10	76	77	80
R70W20	76	77	79
R80W80	74	75	78

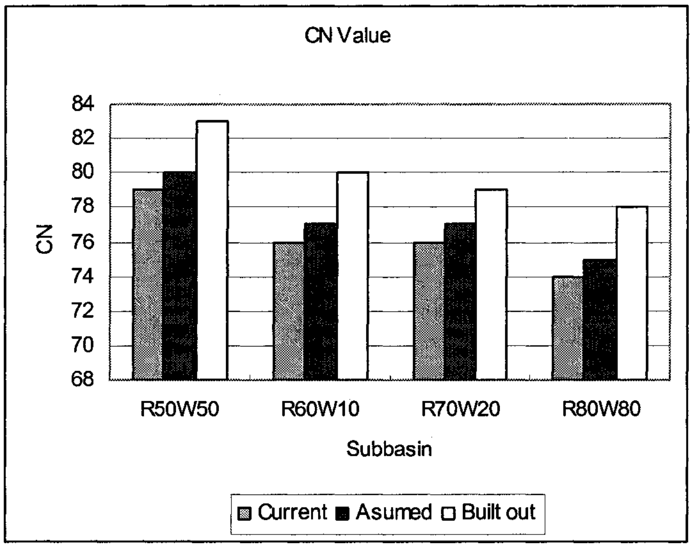


Figure 5.3. CN value of three land use scenarios

Table 5.5. Change in storm water runoff of three land use scenarios

Sub-basin	**Storm Water Runoff (in)**				
	Current	Assumed	Increase%	Built out	Increase%
R50W50	0.89	0.93	4.49	1.03	15.73
R60W10	0.65	0.71	9.23	0.93	43.08
R70W20	0.70	0.74	5.71	0.90	28.57
R80W80	0.51	0.60	17.65	0.80	56.86

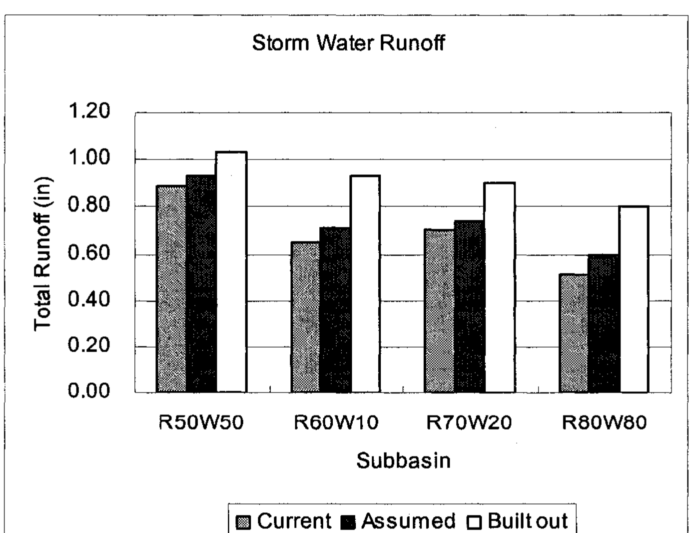


Figure 5.4. Change in storm water runoff of three land use scenarios

Table 5.6. Change in peak discharge of three land use scenarios

Sub-basin	**Peak Discharge (cfs)**				
	Current	Assumed	Increase%	Built out	Increase%
R50W50	8278.2	8587.3	3.73	9875.6	19.30
R60W10	5361.4	5703.1	6.37	6951.4	29.66
R70W20	2697.0	2835.4	5.13	3260.7	20.90
R80W80	1285.0	1437.2	11.84	1777.7	38.34

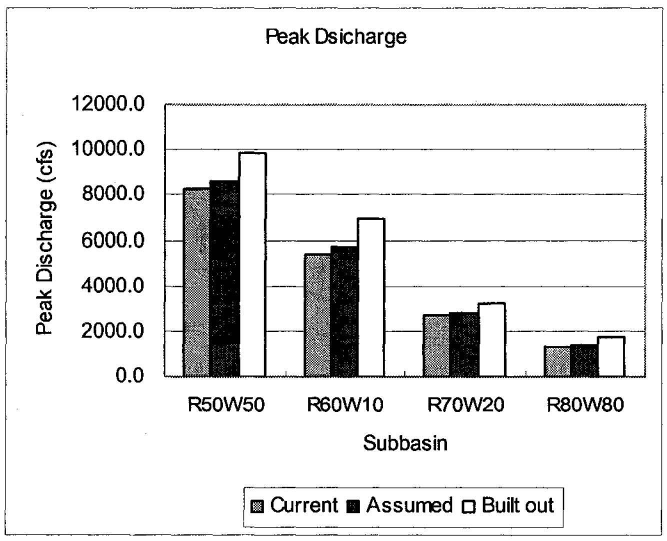


Figure5.5. Change in peak discharge of three land use scenarios

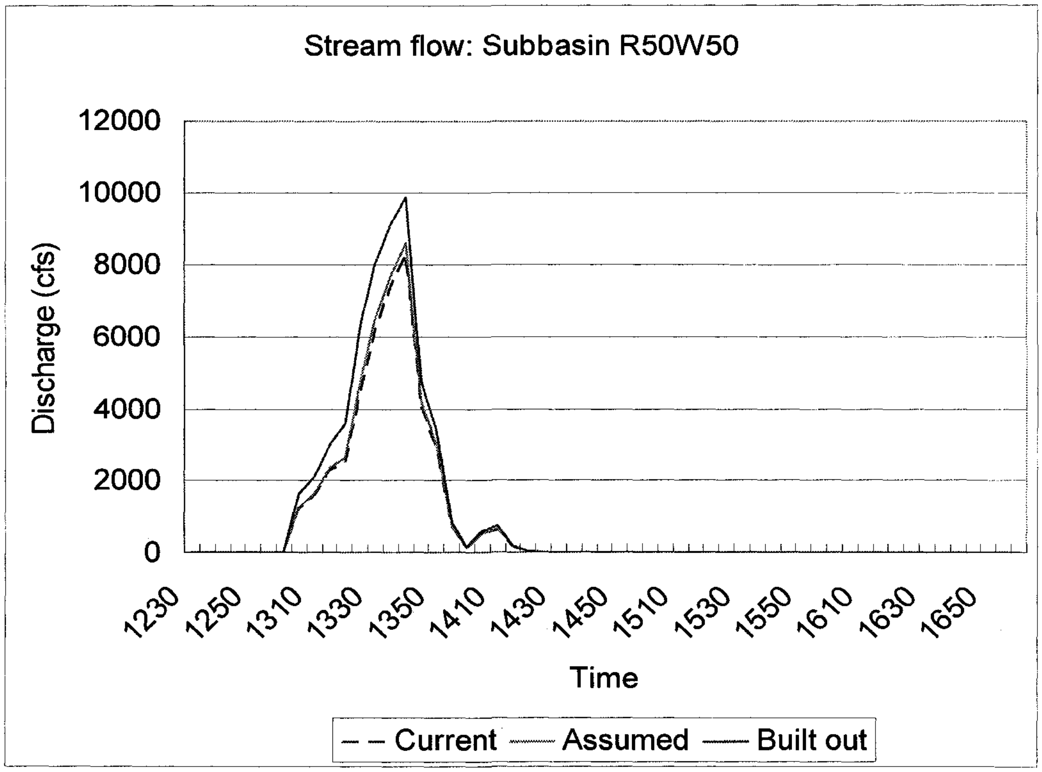


Figure 5.6. Stream flow of subbasin R50W50, three land use scenarios

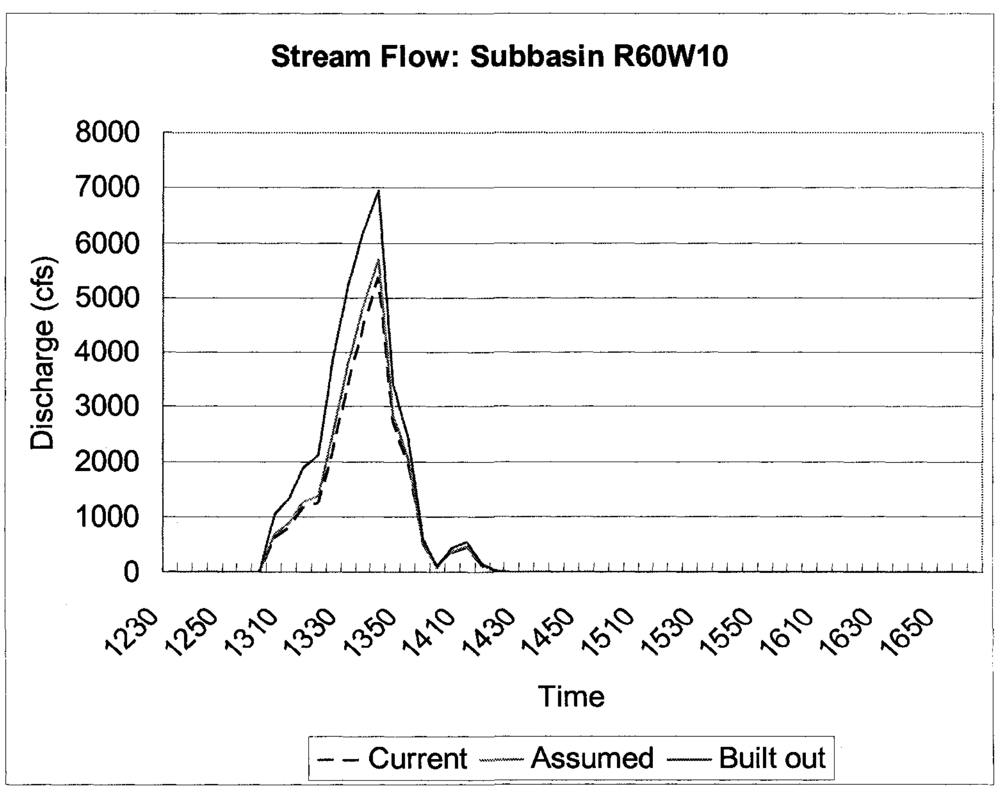


Figure 5.7. Stream flow of subbasin R60W10, three land use scenarios

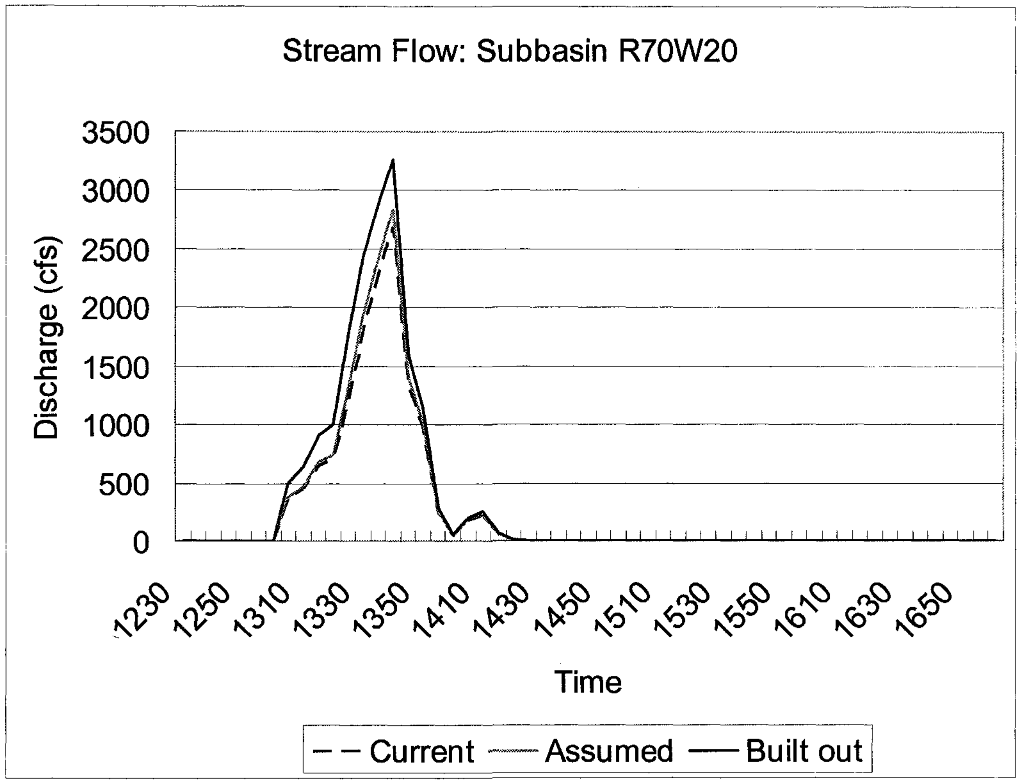


Figure 5.8. Stream flow of subbasin R70W20, three land use scenarios

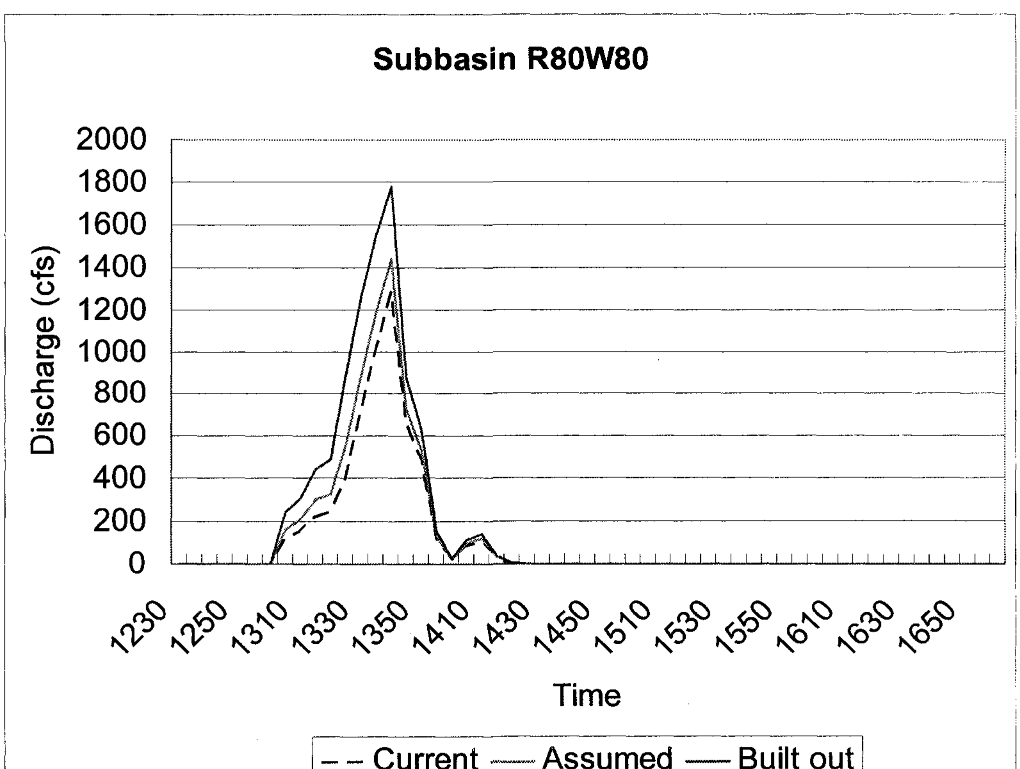


Figure 5.9. Stream flow of subbasin R80W80, three land use scenarios

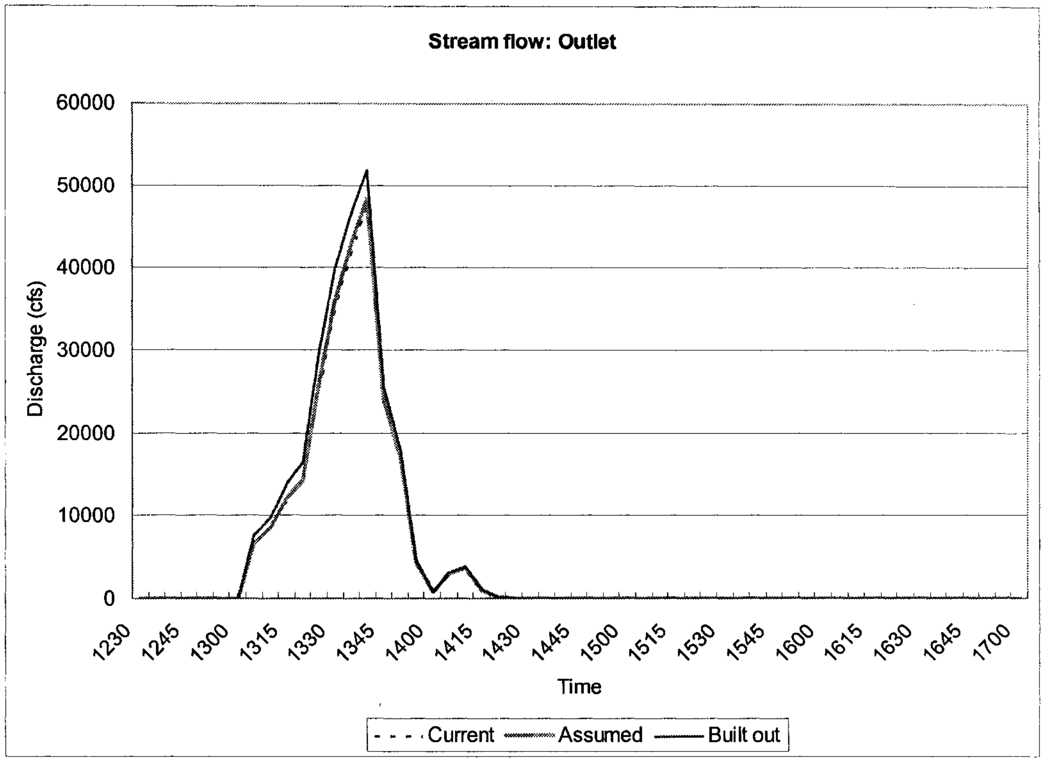


Figure 5.10. Stream flow of outlet of the study area, three land use scenarios

As observed from the simulation results, with increase of the degree of urbanization, more pervious lands with good rainfall retaining capacity are converted to impervious lands with poor rainfall retaining capacity, and the stream flow rate and storm water runoff depth increase correspondingly. Increased runoff volumes could increase nonpoint source pollution loads; increased flow rates may be beneficial for scouring land surfaces and flushing pollutants from a terrestrial system, but may have a detrimental effect downstream by transporting pollutants rapidly into receiving waters. Rapid transport reduces time for pollutant decomposition, infiltration and natural processing en route to receiving estuarine waters (Corbett et al., 1997, P. 141). Meanwhile, the bank erosion and soil sediment are also worsened with higher flow rates, and downstream area is faced with increasing danger of flooding, especially flash flood.

Results from HEC-HMS simulations show that the model can characterize the relative effects of different land cover conditions. However, if the HEC-HMS model is to be used for quantitatively evaluating the effects of land cover change on watershed response, it is necessary to adjust the CN parameter to improve model efficiency. Also, runoff volume was independent of the spatial distribution of impervious surface area, however, flow rates changed depending on the distribution and location of impervious cells. In the second land use scenario, the suitability analysis protects stream buffer, which should have made a difference in stream flow. However the models set up in this study were unable to reveal the relationship between flow rates and the distribution and location of impervious surface since a lumped basin modeling method is used. Further study is recommended to investigate such relationship, and it will be more beneficial for land planners to plan ahead to avoid heavy development happening in the hydrologic sensitive area to minimize the impact of land development on watersheds.

6. Conclusions and Recommendations

6.1 Conclusions

The growing concern in the environmental impact of land development has motivated more research to integrate environmental assessment tools into planning process. In this study, it is demonstrated that, the change of land use on the stream flow and storm water runoff can be reflected clearly using the hydrologic model set up by HEC-GeoHMS and HEC-HMS. Hydrologic modeling can serve as a powerful tool in the watershed planning process to analyze and predict the impacts of land use change on the hydrologic response of the watershed. When there is development proposed by planners or developers, by running the model based on the proposed land use scenario, the corresponding change in stream flow and storm water runoff can be revealed in a visualized, detailed, and quantified manner.

When Geographic Information Systems (GIS) and hydrologic modeling software, in this case the HEC-GeoHMS and HEC-HMS software, are combined together, they demonstrate powerful capacities of in data management, spatial analysis, hydrologic analysis, and visualization of inputs/outputs. These capacities are particularly beneficial for planners when dealing with watersheds.

Urbanization does have a direct impact on stream flow and storm water runoff. Basically, when the pervious surface, like the area covered by grass and trees, is replaced by impervious surface, there will be increase in the volume of storm water runoff and peak discharge rate of the stream flow. Suitability analysis can help to locate the development in a way that the adverse impact to the natural system could be minimized.

6.2 Recommendations

Recommendations come out of this research include the following:

- For the hydrologic modeling programs
- For planners to better use GIS and the hydrologic modeling tools
- For the further study based on this research

For the hydrologic modeling programs

HEC-GeoHMS is a very easy and convenient to use program. Its performance is very satisfying during this research. However, HEC-HMS is a little bit difficult to use. Especially for the outputs of simulation results, the user can not export the tabular data and graphs generated by the program directly. So the recommendation here for the programmer of HEC-HMS is to make the software more user friendly, and to make it easy for the user to save the results in spread sheet format for further analysis.

Also, HEC-HMS can not model the artificial drainage network (the storm sewer), which makes the modeling less reliable for the area with large storm sewer network. So it is recommended the software integrate the artificial drainage system into the modeling.

For planners to better use GIS and the hydrologic modeling tools

In order to carry out the hydrologic modeling and watershed analysis, planners, especially land use planners and environmental planners should be knowledgeable of the operation of GIS, and have fundamental understanding of hydrologic concepts. It is recommended planning students take more courses in GIS, hydrology, and other environmental related issues when they prepare themselves to become a planning profession.

In order to enhance the efficiency of the modeling process, it is highly recommended that a hydrologic database is created for major watersheds of local area. In this research project, without such a database, a large amount of time and effort were spent in collecting, compiling, and organizing the needed data for HEC-HMS, from various sources, such as different websites, local agencies, previous research, and U.S. Army Corps. If a hydrologic database is available, the efficiency of modeling will be greatly improved. Potential data to be included in the database can be: land use, land cover, stream network, watershed boundary, hydrologic soil group, percentage of impervious surface of the watershed, base flow, rainfall, and so forth. There is a need to construct more efficient cooperation and data sharing access among different institutions and organizations.

For further study based on this research

A recommendation for future study is to consider a compared study using lower resolution data. In this study the source data used is high resolution, such as DEM is 4 meter, and the resolution of land cover data is 2 feet. The advantage of using high resolution data is a good accuracy. However it also has several drawbacks, like both of the data is not available to the public, and the computer processing time is very long. So a compared study using the data available to public of lower resolution can help to identify if such data can also provide satisfying results, in a much less cost and time.

Another limitation of the research is that the West Fork Lake (dam) was not included into the model because it is an unsteady manually controlled dam which can not be modeled by HEC-HMS. So the recommendation for further study is to identify a way to model this dam and set up a more realistic hydrologic model for the study area.

Planning is a complex process. For a single development project, there are various interested parties involved: developers, local government, planners, and environmental engineers. Different parties care different issues: profits, tax base, a healthy developed community, and environmental protection. In the reality, it is hard that every party could finally reach its own goals. There is always conflict going on and comprise is being made. Watershed planning is a more advanced approach than traditional planning in the way that it takes into consideration of the impact of the development in the scale of the whole watershed, not individual land parcels or jurisdiction boundaries. It is the direction where the planning effort should be oriented. However people should still be aware that given the current economic and political environment, there is still many difficulties for watershed planning to be effective, especially the conflict of political boundaries versus environmental boundaries. Hydrologic modeling is the tool to achieve planning goals. And powerful as it is, there are models like HEC-HMS that could deal with an entire watershed, and other models that work to fit in the restriction of reality, like the CAGIS TR55 Storm Water Runoff Calculator, which can calculate runoff volume generated by individual parcels. This study illustrates that hydrologic modeling can serve as a valuable tool in watershed planning effort, and with more development in the hydrologic modeling field, people should be confident that more advanced model would be created. And land development could achieve more balanced result in the three aspects of economy, politics, and environment.

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Appendix 1. Table of SCS Curve Number Values Used in the Study

Cover Description	Average Percent Impervious Surface	Curve numbers for Hydrologic soil group A	B	C	D
Impervious areas		98	98	98	98
Soil/Agricultural		77	86	91	94
Grass		39	61	74	80
Trees		30	55	70	77
Residential districts by average lot size:					
1/4 acre	38%	61	75	83	87

Source: Technical Release 55, Urban Hydrology for Small Watersheds. Table 2-2a, 2-2c

Appendix 2. Initial Abstraction (Ia) values for runoff curve numbers. Source: Technical Release 55, Urban Hydrology for Small Watersheds, Table 4-1

Curve number	I_a (in)	Curve number	I_a (in)
40	3.000	71	0.817
41	2.878	72	0.778
42	2.762	73	0.740
43	2.651	74	0.703
44	2.545	75	0.667
45	2.444	76	0.632
46	2.348	77	0.597
47	2.255	78	0.564
48	2.167	79	0.532
49	2.082	80	0.500
50	2.000	81	0.469
51	1.922	82	0.439
52	1.846	83	0.410
53	1.774	84	0.381
54	1.704	85	0.353
55	1.636	86	0.326
56	1.571	87	0.299
57	1.509	88	0.273
58	1.448	89	0.247
59	1.390	90	0.222
60	1.333	91	0.198
61	1.279	92	0.174
62	1.226	93	0.151
63	1.175	94	0.128
64	1.125	95	0.105
65	1.077	96	0.083
66	1.030	97	0.062
67	0.985	98	0.041
68	0.941		
69	0.899		
70	0.857		

Appendix 3. Table of Low Flow Data Used to Interpolate the Base Flow of the Subbasins

GageID	Basin	Tributary to	Location
3257500	Mill Creek	Mill Creek	Woodlawn, Ohio
3255500	Mill Creek	Mill Creek	Reading, Ohio
3259000	Mill Creek	Mill Creek	Carthage, Ohio
3247050	Little Miami	Little Miami River	Batavia, Ohio
3247500	Little Miami	Little Miami River	Clermont, Ohio

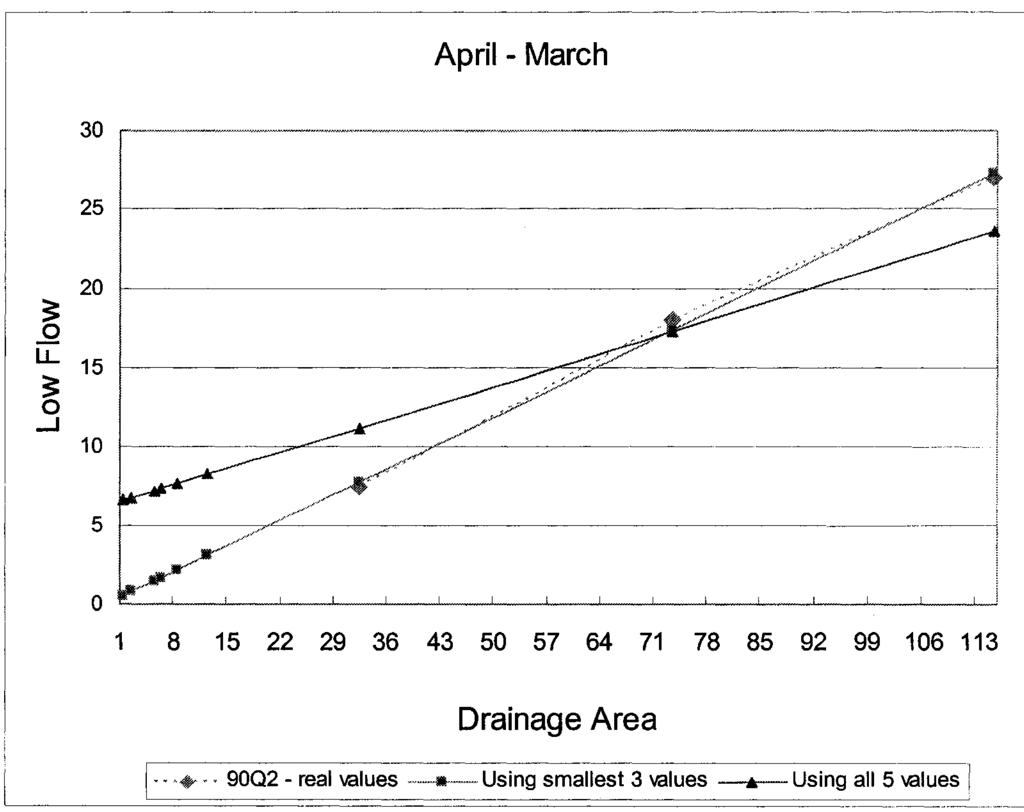
Period	GageID	Drainage Area	90Q2
	3257500	32	7.5
	3255500	73	18
	3259000	115	27
	3247050	352	60
Apr.-Mar.	3247500	476	76
	3257500	32	5.1
	3255500	73	19
	3259000	115	28
	3247050	352	60
May-Nov	3247500	476	76
	3257500	32	45
	3255500	73	91
	3259000	115	139
	3247050	352	580
Dec. Feb	3247500	476	829
	3257500	32	12
	3255500	73	32
	3259000	115	48
	3247050	352	175
Sep.-Nov.	3247500	476	218

Source: U.S. Department of the Interior & U.S. Geological Survey. Low-Flow Characteristics of Streams in Ohio through Water Year 1997. Water-Resources Investigations Report 01-4140

Appendix 4. Interpolation results based on low flow data

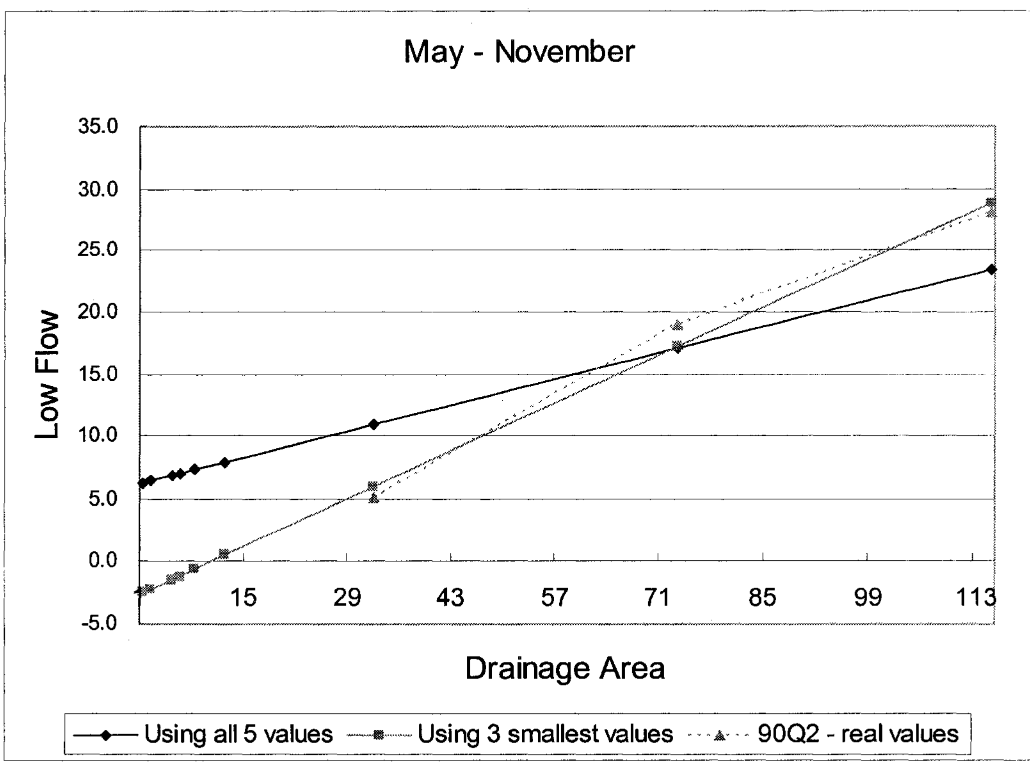
Apr.-Mar.

Subbasin/ GageID	Drainage Area	Using 5 values	Using 3 values	90Q2
R80W80	1.44	6.6	0.6	
R70W20	2.44	6.8	0.8	
R60W10	5.04	7.2	1.4	
R50W50	6.23	7.3	1.7	
R90W90	8.39	7.7	2.2	
R100W100	12.32	8.2	3.1	
3257500	32.20	11.2	7.8	7.5
3255500	73.00	17.3	17.4	18
3259000	115.00	23.6	27.3	27
3247050	352.00	59.0	83.1	60
3247500	476.00	77.5	112.3	76



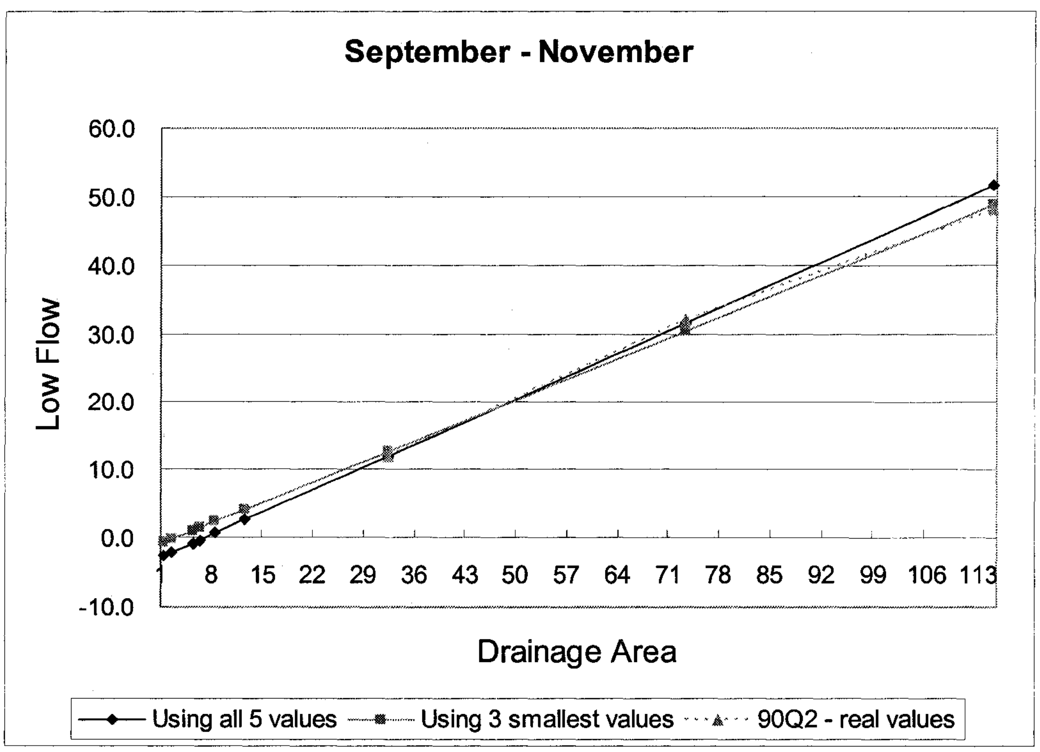
May-Nov

Subbasin/ GageID	Drainage Area	Using 5 values	Using 3 values	90Q2
R80W80	1.441	6.3	-2.5	
R70W20	2.444	6.4	-2.2	
R60W10	5.044	6.8	-1.5	
R50W50	6.229	7.0	-1.2	
R90W90	8.388	7.3	-0.6	
R100W100	12.320	7.9	0.5	
3257500	32	10.9	6.0	5.1
3255500	73	17.0	17.3	19
3259000	115	23.4	28.9	28
3247050	352	59.1	94.3	60
3247500	476	77.7	128.6	76

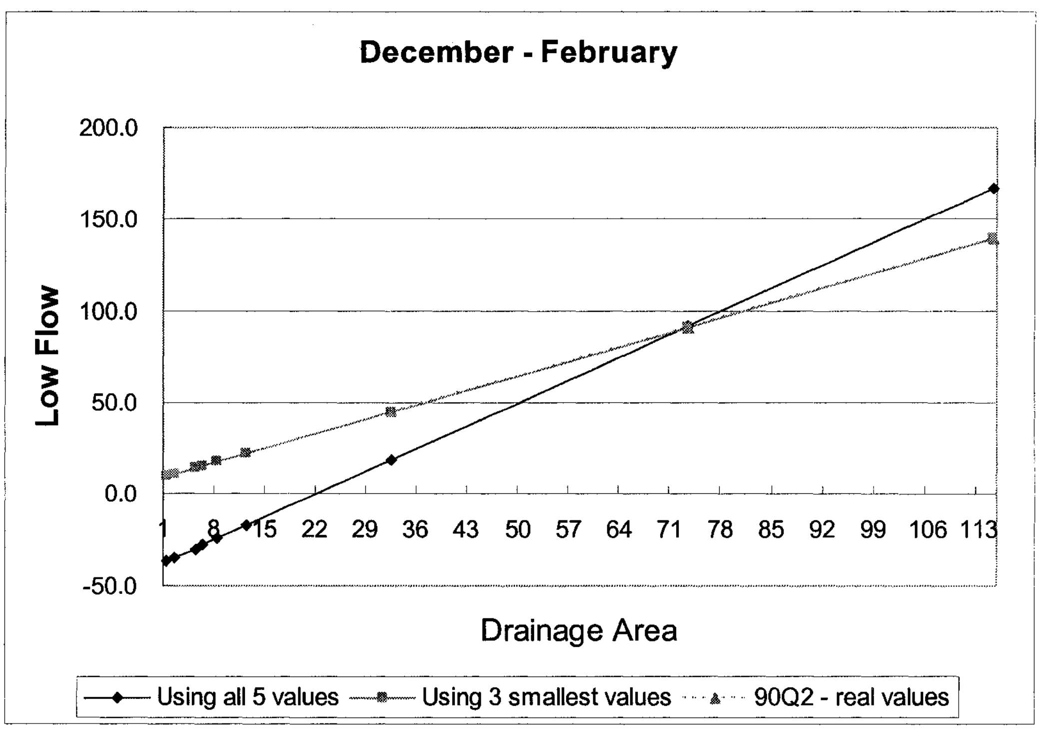


Sep.-Nov.

Subbasin/ GageID	Drainage Area	Using 5 values	Using 3 values	90Q2
R80W80	1.441	-2.6	-0.6	
R70W20	2.444	-2.1	-0.2	
R60W10	5.044	-0.9	1.0	
R50W50	6.229	-0.3	1.5	
R90W90	8.388	0.7	2.4	
R100W100	12.320	2.6	4.1	
3257500	32	12.1	12.8	12
3255500	73	31.6	30.5	32
3259000	115	51.7	48.7	48
3247050	352	165.1	151.7	175
3247500	476	224.5	205.6	218



Dec. Feb				
Subbasin/ GageID	**Drainage Area**	**Using 5 values**	**Using 3 values**	**90Q2**
R80W80	1.44	-36.9	10.0	
R70W20	2.44	-35.1	11.1	
R60W10	5.04	-30.4	14.1	
R50W50	6.23	-28.3	15.4	
R90W90	8.39	-24.4	17.9	
R100W100	12.32	-17.4	22.3	
3257500	32.20	18.3	44.9	45
3255500	73.00	91.6	91.2	91
3259000	115.00	166.9	138.9	139
3247050	352.00	592.3	408.0	580
3247500	476.00	814.9	548.7	829



Appendix 5. List of data required by HEC-HMS for dam modeling, Source: U.S. Army Corps

Outlet - Orifice Outlet
Center Elevation (ft): 662.19
Cross-Sectional Area (sq.ft):108.4
Discharge Coefficient: varies according to gate opening (this is a manually operated dam and is not full open at all times)

Spillway - Broadcrested Spillway
Crest Elevation (ft): 702.0
Crest Width (ft): 50.0
Discharge Coefficient: Approx. 2.8

Overflow - No Overflow

Dam Break - No Dam Break

Appendix 6. Table of June 13, 2000 Storm Event

Date	Time	Incremental Precipitation (in)
6/13/2000	12:30	0.00
6/13/2000	12:40	0.00
6/13/2000	12:50	0.00
6/13/2000	13:00	0.00
6/13/2000	13:10	0.24
6/13/2000	13:20	0.36
6/13/2000	13:30	0.56
6/13/2000	13:40	0.56
6/13/2000	13:50	0.16
6/13/2000	14:00	0.00
6/13/2000	14:10	0.04
6/13/2000	14:20	0.00
6/13/2000	14:30	0.00
6/13/2000	14:40	0.00
6/13/2000	14:50	0.00
6/13/2000	15:00	0.00
6/13/2000	15:10	0.00
6/13/2000	15:20	0.00
6/13/2000	15:30	0.00
Total		1.92

Source: Metropolitan Sewer District of Greater Cincinnati

Appendix 7. HEC-HMS simulation results, discharge of current land use

Time	r50w50 Total Q (cfs)	R60W10 Total Q (cfs)	r70w20 Total Q (cfs)	r80w80 Total Q (cfs)	r90w90 Total Q (cfs)	r100w100 Total Q (cfs)
1230	0	0	0	0	0	1
1235	0	0	0	0	0	1
1240	0	0	0	0	0	1
1245	0	0	0	0	0	1
1250	0	0	0	0	0	1
1255	0	0	0	0	0	1
1300	0	0	0	0	0	1
1305	1242.8	628.2	355.2	121.7	1656	2498
1310	1590.8	804.1	454.6	155.7	2120	3262
1315	2280.6	1152.8	651.8	223.3	3039	4670
1320	2511.5	1247.6	705.4	241.6	3528	5614
1325	4533.5	2217.9	1211.6	408.2	6655	10431
1330	6144.2	3428.2	1791.3	713.7	8955	13889
1335	7348.2	4490.8	2290.1	1021.4	10595	16282
1340	8278.2	5361.4	2697	1285	11828	18045
1345	4063.3	2687.5	1345.7	655.8	5783	9071
1350	2899.8	1956.2	975.5	485.3	4112	6339
1355	721.5	488.1	243.3	121.4	1022	1696
1400	128.4	87.1	43.4	21.7	182	329
1405	515	351.7	174.9	88.1	728	1089
1410	633.9	433.7	215.7	108.8	896	1355
1415	165.9	113.6	56.5	28.5	235	382
1420	32.7	22.4	11.1	5.6	46	80
1425	5.5	3.7	1.9	0.9	8	15
1430	0	0	0	0	0	2
1435	0	0	0	0	0	1
1440	0	0	0	0	0	1
1445	0	0	0	0	0	1
1450	0	0	0	0	0	1
1455	0	0	0	0	0	1
1500	0	0	0	0	0	1
1505	0	0	0	0	0	1
1510	0	0	0	0	0	1
1515	0	0	0	0	0	1
1520	0	0	0	0	0	1
1525	0	0	0	0	0	1
1530	0	0	0	0	0	1

Appendix 8-1. HEC-HMS simulation result, outflow of outlet of the study area, three land use scenarios.

Time	Outflow (cfs)		
	Current	Assumed	Builtout
1230	1	1	1
1235	1	1	1
1240	1	1	1
1245	1	1	1
1250	1	1	1
1255	1	1	1
1300	1	1	1
1305	6502	6652	7554
1310	8388	8579	9734
1315	12017	12292	13949
1320	13848	14199	16351
1325	25457	26318	30011
1330	34921	35925	39789
1335	42028	43020	46637
1340	47495	48436	51738
1345	23607	24035	25513
1350	16768	17049	18007
1355	4293	4362	4597
1400	792	804	845
1405	2947	2994	3153
1410	3643	3701	3895
1415	981	996	1047
1420	198	201	211
1425	35	35	37
1430	2	2	2
1435	1	1	1
1440	1	1	1
1445	1	1	1
1450	1	1	1
1455	1	1	1
1500	1	1	1
1505	1	1	1
1510	1	1	1
1515	1	1	1
1520	1	1	1
1525	1	1	1
1530	1	1	1

Appendix 8-2. HEC-HMS simulation result, discharge of subbasin R60W20, three land use scenarios.

Time	Total Q (cfs)		
	Current	Assumed	Built out
1230	0	0	0
1235	0	0	0
1240	0	0	0
1245	0	0	0
1250	0	0	0
1255	0	0	0
1300	0	0	0
1305	1242.8	1273	1632
1310	1590.8	1629.4	2089
1315	2280.6	2335.9	2995.9
1320	2511.5	2625.1	3599.1
1325	4533.5	4819	6338.4
1330	6144.2	6473.1	8020.9
1335	7348.2	7673.8	9101.6
1340	8278.2	8587.3	9875.6
1345	4063.3	4203.7	4777.5
1350	2899.8	2992.1	3361.8
1355	721.5	744.2	834.7
1400	128.4	132.3	148.2
1405	515	530.5	591.6
1410	633.9	652.8	727.3
1415	165.9	170.9	190.4
1420	32.7	33.7	37.5
1425	5.5	5.6	6.3
1430	0	0	0
1435	0	0	0
1440	0	0	0
1445	0	0	0
1450	0	0	0
1455	0	0	0
1500	0	0	0
1505	0	0	0
1510	0	0	0
1515	0	0	0
1520	0	0	0
1525	0	0	0
1530	0	0	0

Appendix 8-3. HEC-HMS simulation result, discharge of subbasin R60W10, three land use scenarios.

Time	Total Q (cfs)		
	Current	Assumed	Built out
1230	0	0	0
1235	0	0	0
1240	0	0	0
1245	0	0	0
1250	0	0	0
1255	0	0	0
1300	0	0	0
1305	628.2	688.5	1029.4
1310	804.1	881.2	1317.6
1315	1152.8	1263.3	1888.9
1320	1247.6	1367.4	2123
1325	2217.9	2530.1	3898.8
1330	3428.2	3792.6	5238.6
1335	4490.8	4850.9	6211.3
1340	5361.4	5703.1	6951.4
1345	2687.5	2843	3403
1350	1956.2	2058.6	2422.3
1355	488.1	513.3	602.5
1400	87.1	91.5	107.1
1405	351.7	368.9	429.4
1410	433.7	454.7	528.5
1415	113.6	119	138.3
1420	22.4	23.5	27.3
1425	3.7	3.9	4.5
1430	0	0	0
1435	0	0	0
1440	0	0	0
1445	0	0	0
1450	0	0	0
1455	0	0	0
1500	0	0	0
1505	0	0	0
1510	0	0	0
1515	0	0	0
1520	0	0	0
1525	0	0	0
1530	0	0	0

Appendix 8-4. HEC-HMS simulation result, discharge of subbasin R70W20, three land use scenarios.

Time	Total Q (cfs)		
	Current	Assumed	Built out
1230	0	0	0
1235	0	0	0
1240	0	0	0
1245	0	0	0
1250	0	0	0
1255	0	0	0
1300	0	0	0
1305	355.2	372.1	495.1
1310	454.6	476.2	633.7
1315	651.8	682.7	908.4
1320	705.4	738.9	1000.1
1325	1211.6	1327.6	1797.5
1330	1791.3	1933.4	2428
1335	2290.1	2433.8	2898
1340	2697	2835.4	3260.7
1345	1345.7	1409.1	1599.8
1350	975.5	1017.4	1141.2
1355	243.3	253.6	283.9
1400	43.4	45.2	50.5
1405	174.9	182	202.6
1410	215.7	224.3	249.4
1415	56.5	58.7	65.3
1420	11.1	11.6	12.9
1425	1.9	1.9	2.1
1430	0	0	0
1435	0	0	0
1440	0	0	0
1445	0	0	0
1450	0	0	0
1455	0	0	0
1500	0	0	0
1505	0	0	0
1510	0	0	0
1515	0	0	0
1520	0	0	0
1525	0	0	0
1530	0	0	0

Appendix 8-5. HEC-HMS simulation result, discharge of subbasin R80W80, three land use scenarios.

Time	Total Q (cfs)		
	Current	Assumed	Built out
1230	0	0	0
1235	0	0	0
1240	0	0	0
1245	0	0	0
1250	0	0	0
1255	0	0	0
1300	0	0	0
1305	121.7	164.1	243.4
1310	155.7	210	311.6
1315	223.3	301	446.7
1320	241.6	325.8	486.3
1325	408.2	555.6	890.4
1330	713.7	882.2	1258.1
1335	1021.4	1184.6	1548.5
1340	1285	1437.2	1777.7
1345	655.8	724.6	878.6
1350	485.3	530.3	631.2
1355	121.4	132.4	157.2
1400	21.7	23.6	28
1405	88.1	95.7	112.5
1410	108.8	118	138.6
1415	28.5	30.9	36.3
1420	5.6	6.1	7.1
1425	0.9	1	1.2
1430	0	0	0
1435	0	0	0
1440	0	0	0
1445	0	0	0
1450	0	0	0
1455	0	0	0
1500	0	0	0
1505	0	0	0
1510	0	0	0
1515	0	0	0
1520	0	0	0
1525	0	0	0
1530	0	0	0

Appendix 9. Description of the GIS data set

The projection of all the data layers is State Plane-1983.

No.	Data Layer	Feature	Format	Accuracy	Description	Source
1	Digital Elevation Model (DEM)	Grid	Grid	4 meter	Generated by CAGIS	CAGIS
2	Soil Hydrologic Groups	Grid/ Polygon	Grid/ Shapefile	2 feet	Generated by CAGIS	CAGIS
3	Land Cover	Grid/ Polygon	Grid/ Shapefile	2 feet	Classified satellite image generated by CAGIS	CAGIS
4	Suitableland	Polygon	Shapefile	2 feet	The land in subbasin R50W50, R60W10, R70W20,R80W80, which are suitable for the assumed development based on the suitability factors outlined in section 5.1.1	Author
5	Landfordevelop	Polygon	Shapefile	2 feet	Land to allocate assumed development, achieved based on the method outlined in section 5.1.1	Author
6	CN2000	Polygon	Shapefile	2 feet	CN value distribution of the study area	Author
7	CN_scenario2	Polygon	Shapefile	2 feet	CN value distribution of the four subbasins with land use scenario 2	Author
8	CN_scenario3	Polygon	Shapefile	2 feet	CN value distribution of the four subbasins with land use scenario 3	Author

Appendix 10 Procedure of Model Operation in HEC-GeoHMS and HEC-HMS
(Detailed manuals of the two programs can be downloaded from
http://www.hec.usace.army.mil/default.html)

I. Modeling Process in HEC-GeoHMS

Based on a digital terrain model, eight additional data sets are derived that collectively describe the drainage patterns of the watershed. The first five data sets in the grid representation are the flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation grids. The next two data sets are the vectorized representation of the watersheds and streams – watershed polygons and the stream segments. The last achieved data set is the aggregated watersheds, which is used primarily to improve the performance in watershed delineation.

In this study, the 4-meter DEM file is used to generate the drainage network of West Mill Creek Basin. Using the functions of HEC-GeoHMS combined with the best judgment of the author, a set of drainage network is derived and serves as the basin model in HEC-HMS modeling. The steps taken in HEC-GeoHMS process are described as below.

Task 1. Obtain DEM

Free DEM can be downloaded from http://data.geocomm.com/dem/demdownload.html, USGS, state natural resources department, or other resources. CAGIS has 4 meter DEM for the entire Hamilton County.

Task 2. Terrain Preprocessing, which determines:

- Flow direction
- Flow accumulation
- Stream definitions
- Stream segmentation
- Subbasin delineation

1. Open ArcView and load the extension of HEC-GeoHMS
2. Set up working directory with terrain data. Subsequent derived data sets will be stored in the directory.
3. Perform drainage analysis by running the command under Terrain Processing menu one by one: Fill Sinks – Flow Direction – Flow Accumulation – Stream Definition – Stream Segmentation – Watershed Delineation – Watershed Polygon Processing – Stream Segment Processing – Watershed Aggregation.

   Note that in Stream Definition, specify the map units as meters if working with USGS data, feet if working with CAGIS DEM. Specify the Distance Units as miles. Select the threshold type as "Area in Distance Units squared", and specify the threshold for stream initiation.

4. Extract pertinent spatial data and set up a hydrologic model. In this step, a watershed is defined by its outlet. Under HMS Project Setup menu, choose Start New Project, and use Specify Project

Point tool to locate the outlet of the watershed area of interest. Choose Generate Project to create the study area. Pertinent data sets are extracted from the specified outlet location. A ProjView is used for basin processing, basin characteristics, and HMS inputs.

Task 3 Basin Processing. After the terrain preprocessing the data is processed into HMS format.
1. Subbasin delineation can be revised by merging or subdividing basins.

2. Generating basin characteristic. In this step, several basin characteristics are computed and saved in the attribute tables of the watershed and river (stream) shapefiles, by running the command under Basin Characteristics menu. The characteristics including:

- River length
- River Slope
- Basin Centroid
- Length and location of longest flow path
- Length and location of centroidal flow path

3. Preparing HEC-HMS Input. In this step, the required files to be used in HEC-HMS are prepared, by running the commands under HMS menu, run the commands one by one. Outcomes include:

- Background map file
- Lumped basin schematic

Task 4. Hydrologic Modeling System. In this step, the basin system and background map file are imported into HMS. First copy the two files created in the last step into the right working directory. On the HMS*Project Definition window, under Component menu, select Basin Model then select Import. Select the file to be imported. Under File menu, select Basin Model Attributes, then browse to locate the right file to be used as Map File. The basin model and background map file are brought into HMS for further editing.

II. Modeling Process in HEC-HMS

Task 1. Edit the Basin Model

As the basin model is created by HEC-GeoHMS, the user can directly enter data using the editing window. The data required and computation methods involved are described in Chapter 4. Save the basin model after data input.

Task 2. Create a Meteorologic Model

Under Component menu, select Metoerologic Model then select new to create a new meteorologic model. Under Data menu, select Precipitation Gages, Select User Hyetograph as the precipitation method and manually enter data as a precipitation gage. In the Metoerologic Model window, assign the gage just created to each of the subbasin.

Task 3. Create Control Specifications

Under Component menu, select Control Specifications then select New to set up a new control. Here the user is asked to define the starting and ending time of the period of interest, as well as the time interval.

Task 4. Create and Compute a Run

In the basin model window, under Simulate menu, select Run configuration, then choose the basin model, meteorologic model, and control specifications of interest. When back in the Basin Model, under Simulate menu, choose Compute Run1 to compute the run. There will be errors, warnings, and notes reported to the user.

Task 5. View Results

In the Basin Model window, under View menu, select Global Summary Table to view the summary results of peak flow for all elements. For individual subbasin, reach, and outlet, click on the element and right click to select to view results.