A hydrologic study of the Bear Creek watershed using GIS and the HEC-Hydrologic modeling system

by

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ABSTRACT

Floods are an increasingly significant hazard in the United States because of the major changes to the hydrology of the landscape. Floods cause financially greater loss and more loss of life per year than any other natural hazard. In order to best assess floods and their effects on landscape most effectively, hydrologic modeling was conducted on the Bear Creek watershed in central Iowa, which extends over portions of three counties, Hamilton, Hardin and Story. Geographic Information System (GIS) was used to obtain the necessary data for completion of this project. A Digital Elevation Model (DEM) was the primary data set used for the hydrologic modeling. The DEM was used to model hydrologic processes due to the changes in elevation. A triangulated irregular network (TIN) was created from the DEM to see these changes in another dimension. The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) was used to assess the landscape characteristics of the Bear Creek watershed. HEC-HMS is a modeling system designed to simulate the precipitation-runoff in watersheds. HEC-GeoHMS was used as a precursor for preprocessing data before input into HEC-HMS. A GIS soil's layer containing Iowa Soil Properties and Interpretations Database (ISPAID) was analyzed for this project. The analysis included a query within GIS of the flood frequency code to identify soil polygons that were labeled PONDED. These soil polygons were then displayed as an image within the boundaries of the Bear Creek watershed. GIS was used to calculate the amount of water (volume) that each of these soil polygons can hold. Changes in discharge under different storm events

were calculated and displayed based on discharges from HEC-Hydrologic Modeling System. This research provides information for landowners about flooding and its potential damaging impacts on the landscape. Using this hydrologic assessment, alternative strategies can be developed to minimize the impacts of flooding within the Bear Creek watershed. Those strategies include taking some areas out of production in order to construct wetlands. The wetlands will serve as a sink to hold the water, hopefully minimizing the impacts of floodwater.

CHAPTER 1. INTRODUCTION

Literature Review

Iowa has an interesting and diverse geological past that shaped its landscape into what it is today (Prior 1991). Iowa contains about 14,500,820 hectares of land. The Bear Creek watershed in central Iowa is a small drainage basin covering about 6,940 hectares. The watershed is located within the Des Moines Lobe subregion of the Western Corn Belt Plains ecoregion. This area is one of the youngest and flattest ecological subregion in Iowa (Griffith et al. 1994). About 10,500 to 30,000 years ago, the Des Moines Lobe was formed due to the continental glacier advancement through Iowa known as the Wisconsinan Glaciation. This landform region is marked by bands of small ridges, on a generally flat landscape, created by the stagnation of the retreating glacier. The glacier moved through Iowa's landscape carrying frozen soil and rocks collected from the northern landscape. In the present interglacial environment, Iowa's landscape and landforms are the result of quaternary processes operating at different times and intensities over different parts of the state.

The physical landscape has been influenced by rapid economic and social change within the last 150 years in particular since the 1930's. As populations continue to increase, the competition and conflict of the uses of rivers and steams also continues to increase. According to Rosgen, "Rivers and streams have been a major component of development over time, and as such, an understanding of the natural stability of rivers and streams is necessary if maintenance of their functions and health are to be secured" (Rosgen 1994).

Naturally flowing water also played a major role in shaping the landscape. Due to the changes in the environment such as channelization, scouring and downcutting of banks, forest and prairie land converted to agricultural fields leading to increased erosion, uplands were lowered in elevations, slopes were less steep due to erosion in some places and deposition in others, and lowlands were accumulations of sediment brought by surface runoff and stream flow (Prior 1991).

The Western Corn Belt Plains ecoregion, which covers most of Iowa, can be characterized as extensive cropland located on moderately level to slightly rolling dissected glacial till plains and morainal hills with broad smooth ridge tops (Griffith et al. 1994). The rolling, predominately agricultural landscape is generally characterized by low relief, fertile soils, and a poorly developed stream network.

This region in Iowa was once a tallgrass prairie ecosystem, with scattered wet prairie marshes in topographic lows and gallery forests along streams and rivers. Gallery forests are narrow tracts of woodland along the banks of a watercourse flowing through open country (Isenhart et al. 1997). Much of the landscape has been converted to agricultural uses. Most of the region is used for growing corn, soybeans and forage for livestock (Burkhart et al. 1994). Two-thirds of the native hardwood forests and about 99% of prairie have been converted to agricultural fields or pastures. Continuous cultivation of the land has led to reductions in soil quality and infiltration rates and an increase in surface runoff.

From a geological perspective, floods are a natural consequence of stream flow in a continually changing environment. Floods are dangerous, life threatening and destructive and have been occurring throughout history (Nelson 2000). Floods are caused by weather occurrences that deliver more water to a drainage basin than can be readily absorbed or stored within the basin. A number of factors can contribute to flooding such as heavy, intense rainfall, runoff from deep snow cover, over-saturated soil, frozen soil, ice jams, changes in agricultural practices, changes in infiltration rates and urbanization (Hirschboeck 1991).

Throughout history, humans have developed civilizations along rivers and streams. Streams are sources for water for human consumption, industry and agriculture. Streams provide transportation corridors, energy and a way to dispose of waste (Nelson 2000). Where a floodplain exists, flow that cannot be contained spreads onto the adjacent floodplain. Because humans usually construct civilizations and grow crops along floodplains, techniques to reduce the impact of floods or overflow are necessary (Leopold 1994).

Efforts are increasing to protect streams and their natural environments. For example, riparian vegetation is an important resource that should protect streams in a way that the vegetation will serve as a sink for sediments, nutrients, and pesticides. It also will protect the streambank from erosion and reduces surface runoff (National Research Council 1993). Most of the evidence about the uses and benefits of riparian zones and the role they play as sinks for pollutants comes from existing vegetated riparian zone research (Lowrance 1984, Isenhart et al. 1997).

Content of the Problem

Bear Creek flows into the Skunk River, and its upper region was originally characterized as low, wet prairie with connections to defined marshes with very good soil. Changes in the upper watershed from a low, wet prairie with a meandering stream and slow moving water to one with a well-defined stream and increased velocities of water are the results of altered watershed hydrology (Isenhart et al. 1997). Whether or not the Bear Creek watershed is classified as stable or unstable depends on the specific reach of the stream observed. In the northern section of the stream, according to the Channel Evolution Model (Leopold 1998), the stream is classified as unstable due to the disequilibria of the landscape because of the most recent channelization efforts. In the southern section of the stream, a stable classification is observed because of the restabilization of the landscape.

With the arrival of European settlers and the moldboard plow, the Iowa landscape was converted from prairie to agricultural land in a relatively short period of time. Along with tillage came drainage and channelization that has caused a loss of about 45% of Iowa's original stream resource (Bulkley 1975). With the introduction of extensive subsurface tile drains, excavation of surface drainage ditches or dredging and stream channelization, the land conversion from native vegetation to agricultural uses has contributed to problems of water flow and water quality and also has resulted in stream channel incision and widening. Records indicate that artificial drainage of the marshes and wet prairie in the upper region was completed by 1902 (Isenhart et al. 1997). Artificial drainage in the rest of the Bear Creek watershed continued after 1902. These early drainages have increasingly transformed the surface and subsurface hydrology of the landscape. Results show that nearly all naturally occurring wetlands have been replaced by streams that are a result of artificial tile drainage and other hydrologic changes (Anderson et al. 2000). Stream channelization on Bear Creek continued into the 1970's and still affects the nature of the stream today. Typical modifications during channelization include the removal of any obstructions, whether natural or artificial, that inhibit the stream's water flow and widening and deepening of a new or previously straightened channel to maximize conveyance of water (Simpson et al. 1982, Keller 1996). These modifications affect one or more of the dependent hydraulic variables of slope, depth, width, and roughness of the channel, thus disturbing the dynamic equilibrium of the stream. This may lead to instability of the channelized section of the stream (Brookes 1988).

Vegetation influences the channel width, depth and slope (Zimmerman et al. 1967). Removal of debris and bankside vegetation increases the hydraulic efficiency, increases current velocity adjacent to the bank, and reduces the resistance to erosion (Shields and Nunnally 1984). Through altering one or more of the interdependent hydraulic variables, the existing equilibrium is disrupted, and, to compensate for this, there are natural changes in the remaining hydraulic variables in an attempt to attain a new equilibrium. For example, a straightened stream may immediately react to the increased slope by increasing the sediment discharge through bank erosion resulting from incision and increase slope. Eventually, the channel may widen through erosion, with a corresponding reduction of velocity, and the adjusted cross-section will be more efficient in dissipating the energy (Jansen et al. 1979).

Table 1.1 illustrates some of the detrimental impacts that human-caused developments have on natural floodplains (Water Resources Council 1976). These

Table 1.1. Human-caused impacts on floodplains

Changes in Hydrology	**Changes in Geomorphology**
Increased in magnitude and frequency of severe floods	Stream channel widening and downcutting
Increased frequency of erosive bankfull floods	Increased streambank erosion
Increased in annual volume of surface runoff	Stream relocation/enclosure or channelization
Increased stream velocity	Shifting bars of course-grained sediments
Decrease in dry weather baseflow	Imbedding of stream sediments

impacts are based on a comparison of the changes in hydrology and geomorphology.

A variety of agricultural management practices have contributed to altered flow regimes and to the detriment of the stream's integrity. Many factors are disruptive to the natural environment such as deforestation and drainage activities in combination with cropping and grazing practices (Trautman 1939). Drainage practices have had, among other environmental impacts, serious disruptive effects on the flow regime of regional streams by substantially increasing discharge peaks and stream erosive power. Conditions of channel morphology disequilibria have been created in many drainage systems. The impact of changes to the stream environment is to reduce average water depth, eliminate most forms of bank cover and broadly expose the water surface (Brookes 1988).

The morphology of a stream is important if stream stabilization is to occur. The physical appearance and functional status of a stream is the result of the adjustment of stream boundaries to the magnitude and intensity of streamflow and erosional debris produced in a watershed. Under normal conditions, water flows within the channel and is called channelized flow. The volume of flow when the channel is filled to its maximum determines much of the channel's geometry (i.e., channel width and depth, meander amplitude and wavelength, channel sinuosity and slope). When the volume of water in a channel is above its maximum-holding potential, flooding occurs (Rosgen 1996).

Stream channel morphology is often described in terms of a width/depth ratio related to the bankfull stage cross-section. The width/depth ratio varies primarily with: 1) the dimension of the channel cross-section for a given slope, 2) the boundary roughness as a function of streamflow and sediment regime and bank erodibility factors including the nature of streambank materials, and 3) the distribution of energy (boundary stress) in the stream channel (Rosgen 1985).

Stream width is a function of streamflow occurrence and magnitude, size and type of transported sediment and the bed and bank materials of the channel. Channel width generally increases downstream as the square root of discharge increases (Leopold et al. 1964). The bankfull cross-sectional area of a stream is correlated with streamflow and drainage area as it relates to channel size (Rosgen 1994). The word "bankfull" in its original context was used to describe the elevation on the bank where flooding began, and this usually applies to streams with an observed floodplain. Bankfull has a great influence on stream morphology and flooding potential (Rosgen 1996).

In unstable streams, bankfull indicators are difficult to determine (Wharton 1995). Bankfull indicators are usually based on a minimum width/depth ratio (Wolman 1955) when associated with changes in natural environment such as change in vegetation or sediment. Bankfull can be measured based on the sediment size, location, level and type of vegetation and the width/depth ratio (Williams 1978). According to Rosgen, the usage of the indicators must correspond with four basic principles:

(1) Indicators must be in designated areas for specific stream types

(2) Know recent history of droughts and floods in the area to avoid misleading indicators

(3) Use multiple-indicators for assurance of a common stage or elevation

(4) Calibrate field determined bankfull stage to verify the difference between the floodplain and the terrace (Rosgen 1996).

In Figure 1.1, the discharge above the elevation of the bankfull stage is the bankfull discharge based on the Manning equation. Manning's equation is noted below:

$$V = 1.49/n * (R^{2/3}) (S^{1/2})$$

After a bankfull elevation has been established, a stage vs. discharge curve can be calculated to aid in determining the magnitude of the discharge relative to the elevation. The bankfull curve was developed for a hypothetical stream by computing discharge for different elevations. When discharge is greater than bankfull, water spreads onto the floodplain thus causing the bankfull stage to increase.

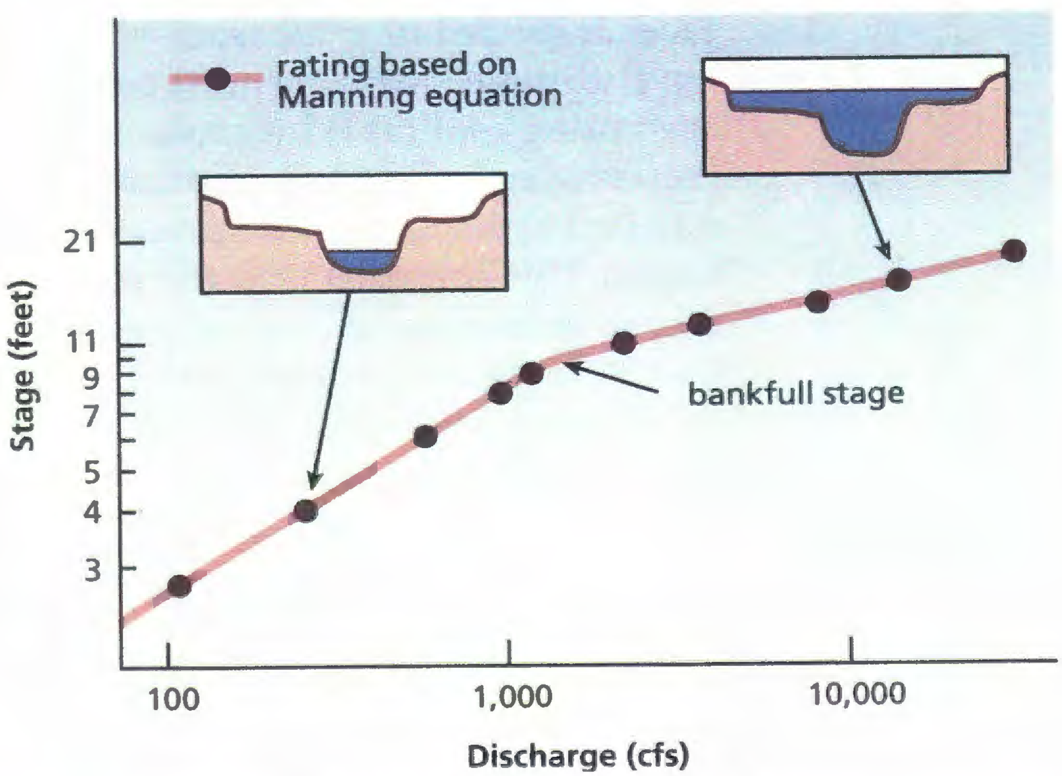

Figure 1.1. Determination of bankfull stage from a rating curve (Leopold 1998).

An accurate definition of “bankfull” is important because it helps determine how stream width, cross-sectional area and average channel depth are measured (Rosgen 1994). Bankfull discharge is associated with maximum flow and has a frequent recurrence interval, which, in a “natural” stream, generally occurs every 1.5 to 2 years as determined by using a flood frequency analysis (Dunne and Leopold 1978).

The most widely accepted definition of bankfull stage is defined by Dunne and Leopold (page 156):

> Bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders and generally doing work that results in the average morphologic characteristics of channels.

A stream flowing at bankfull, whether stable or unstable, will not be at the overflow level everywhere along the channel because there are differences in height of bank and depth of channel (Leopold 1997). The determination of the frequency of floods is a very important aspect of flood modeling. A common problem in hydrology is the flood frequency analysis, the determination of flood flows at different recurrence intervals. Continuous hydrologic simulation is a valuable tool to determine flood frequencies in watersheds (Water Resource Council 1976). Due to channelization and other variables, such as bankfull and increased velocity, being altered, flooding of streams and rivers has become a major problem in Iowa.

Watershed Hydrologic Modeling

Spatially distributed precipitation-runoff models are useful for assessment of the hydrologic effects of land surface change (Storck et al. 1998). Hydrologic modeling as defined by David Maidment (page 1) is “a mathematical representation of the flow of water and its components on some part of the land surface or the subsurface environment.” (Frey 2001). Hydrologic simulation (also called precipitation-runoff) modeling began in the 1950’s and 1960’s. The purpose is to predict streamflow, given an observed precipitation, with certain time intervals (Storck et al 1998). Hydrologic modeling is also used to translate precipitation into water depths, water flow and volumes of water in storage (Maidment 1993). A diagram comparing a natural and designed stream is shown in Figure 1.2. In the designed channel, the bankfull volume compared to the natural channel is twice as large, the floodplain has been reduced to approximately half the size and the baseflow within the designed channel has more than tripled.

Thesis Organization

This thesis includes the candidate’s original work on a hydrologic study of the Bear Creek watershed using GIS and HEC-HMS technologies. This thesis contains one manuscript written by the author in a format suitable for publication. The manuscript entitled “Using GIS and HEC-HMS to assess the hydrologic conditions of the Bear Creek watershed” was written for submission to the Journal of the American Water Resources Association.

The manuscript contains an abstract, introduction, methodology, results, conclusion and references. The manuscript is preceded by an abstract, introduction that includes the literature review, content of the problem, watershed hydrologic modeling, objectives, importance of the study and references. The manuscript is followed by a general conclusion and perspective section.

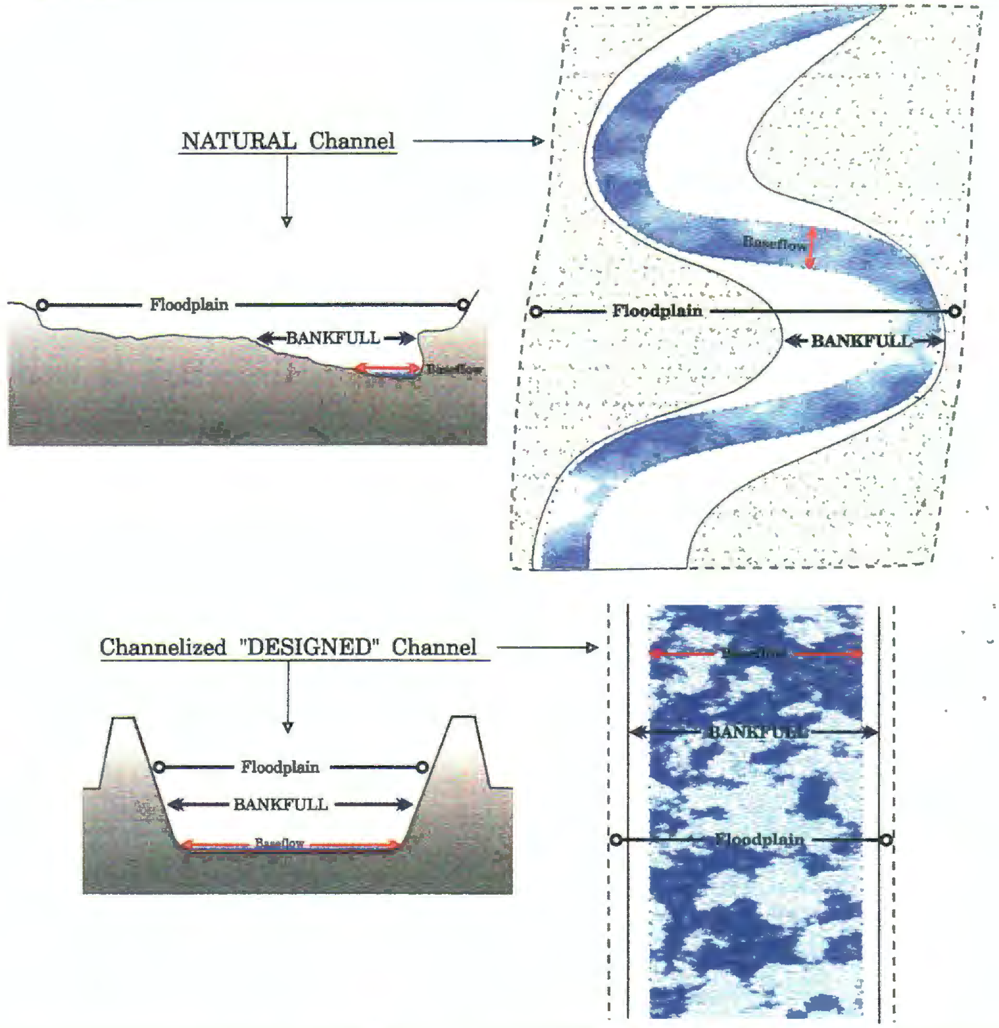

Figure 1.2. A comparison diagram between a "designed" and channelized stream (Rosgen 1993).

Objectives

The objectives of this study are to:

(1). Model the hydrologic processes of the Bear Creek watershed.

(2). Calculate and display the changes in discharge of the stream under different storm conditions.

(3). Delineate areas of the watershed that are prone to ponding.

Importance of Study

This study is valuable for the assessment of the conditions of the Bear Creek watershed after storm events. Certain areas are more prone to flooding and ponding than others. The results from this study will show the areas that are prone to ponding and assess changes in stream channel discharge as a result of a series of simulated rainfall events. This information will be important in assessing the impacts of storm events on a particular area. This information will also be a useful aid in selecting potential sites for constructed wetlands.

Wetlands are areas of soil that are covered by water. This water remains at or near the soil surface all year or for extended periods of time during the year. Water saturation is an important determinant in how the soil develops and the type of plant and animal communities that exist within and on the soil. There are many different types of wetlands. Ponded areas can be classified as a type of wetland because of the saturation of the soil after storm events. The time that the water remains in these ponded areas present the difficulty in classifying ponded areas as wetlands. If flooding occurs on a continuous basis and the ponded areas are always saturated, this area can potentially be classified as a wetland (Environmental Protection Agency 2001).

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CHAPTER 2. USING GIS AND HEC-HMS TO ASSESS THE HYDROLOGIC CONDITIONS OF THE BEAR CREEK WATERSHED

A paper to be submitted to the Journal of the American Water Resources Association

Rodney K Jones and Steven E Jungst

Abstract

Floods are an increasingly significant hazard in the United States because of major changes to the hydrology of the landscape. Floods cause financially greater loss and major loss of life per year than any other natural hazard. There have been several significant floods within the past ten years that have had a tremendous impact on the landscape of Iowa. Geographic Information System (GIS) and Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) technologies were used to develop flood simulations to assess the conditions of the Bear Creek watershed in central Iowa. HEC-HMS is a modeling system designed to simulate the precipitation-runoff in watersheds. The model provides information about stream discharge rates that can then be used to determine potential flood distribution on the landscape. Information from this study can be used as input to evaluate the extent of flooding for a given storm event and to evaluate alternative strategies to minimize the impacts of flooding.

Introduction

The physical landscape has been influenced by gradual economic and social change within the last 150 years, in particular since the 1930's. Human impact on streams and stream channels has been widespread throughout the period of habitation of the planet (Cole 1976). As populations continue to increase, the competition and conflict for uses of steams also continues to increase. Rivers and streams have been a major component of development over time, and as such, an understanding of the natural stability of rivers and streams is necessary if maintenance of their functions and health are to be secured (Rosgen 1994).

A flood is the occurrence of a flow that overtops the streambanks. Hydrologic research concludes that floods occur when parts of a drainage basin is saturated and unable to absorb additional water, so the water runs onto and across the surface as overland flow (Leopold 1994). Bankfull stage-discharge has a great influence on stream morphology and flooding potential (Rosgen 1996). An accurate definition of “bankfull” is important because it helps determine how stream width, cross-sectional area and average channel depth are measured (Rosgen 1994). In a “natural” stream, flooding generally occur every 1.5-2 years as determined using a flood frequency analysis (Dunne and Leopold 1978).

The purpose of this research is to develop a technique for modeling stream discharge rates in the Bear Creek watershed by using Geographic Information System (GIS) and Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS). HEC-HMS, a hydrologic modeling system, is used to predict stream discharge in the simulation of an actual flood situation. The study specifically uses a GIS digital elevation model and Geo HEC-HMS software (Environmental Systems Research Institute 2000) for the initial analysis of the HEC-HMS model. From this research, the areas within the Bear Creek watershed that are prone to ponding and the changes in discharge of the stream under different storm conditions have been determined.

Hydrologic modeling is important because it provides an assessment of the Bear Creek watershed by modeling hydrologic processes. Hydrologic modeling can provide landowners with important information about the benefits of taking ponded areas out of agricultural production and possibly constructing wetlands in order to minimize the impacts of flooding.

Description of Study Area

Iowa has an interesting and diverse geological past, which shaped its landscape into what it is today (Prior 1991). Iowa contains about 14,500,820 hectares of land. The Bear Creek watershed in central Iowa is a small drainage basin covering about 6,940 hectares. The watershed is located within the Des Moines Lobe sub-region of the Western Corn Belt Plains eco-region. This area is one of the youngest and flattest ecological sub regions in Iowa (Griffith et al. 1994). Land use in the watershed is primarily row cropping, which is typical of the Corn Belt (Mohanty et al. 1994). Figure 2.1 shows the land cover of the Bear Creek watershed. Corn and soybeans make up about 85% of the land cover within the Bear Creek watershed.

Flowing water has contributed to the formation of Iowa's valleys. In these valleys, flooding has been a major concern over the years because of the altered conditions of the streams and the landscape (Prior 1991). The condition of the soils in the watershed has been affected greatly by the changes in the landscape.

Many of the soils in north central Iowa are naturally poorly drained or somewhat poorly drained and contain excess water which could interrupt farm operations or ruin crops. Therefore, tile drainage systems are used to regulate the water level in the soils (Seigley 1999).

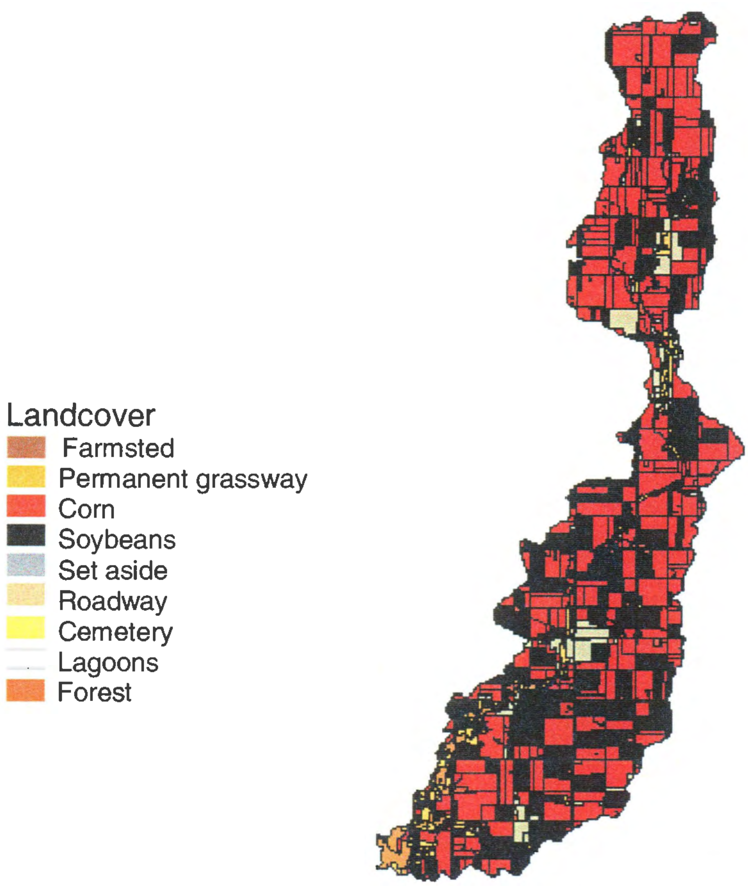

Figure 2.1 Land cover of the Bear Creek watershed.

Table 2.1 indicates characteristics of some of the soils in the Bear Creek watershed. These soils range from well to poorly drained. Approximately 55% of the soils within the Bear Creek watershed are poorly drained or somewhat poorly drained. The drainage class information was obtained from the Iowa Soil Properties and Interpretations Database (ISPAID).

Restoration research efforts began in the Bear Creek watershed in the early 1990's by the Agroecology Issue Team of the Leopold Center for Sustainable Agriculture. Within this project, a riparian management system was created along stretches of Bear Creek. A multispecies riparian buffer model was used that consists of a 33-foot-wide strip of four to five rows of trees, a 12-foot wide strip of one to two rows of shrubs and a 21-foot-wide strip of native, warm-season grasses (Isenhart et al 1997).

Table 2.1. Characteristics of some of the Bear Creek watershed soils (Note: mixed drainage class means soils can range from well to poorly drained).

Soil Name	Soil Map Symbol	Area (ha)	% of watershed	Drainage Class	Slope (%)
Harps-Okoboji	956	52	2.56	very poor	0-2
Canisteo	507	1259	9.27	poor	0-2
Coland	135	97	8.84	poor	0-2
Talcot 32-40	559	19	2.57	poor	0-2
Webster	107	859	2.22	poor	0-2
Clarion-Storden	638C2	79	3.08	mixed	5-9
Coland-Terril	201B	122	7.40	mixed	1-5
Hanlon-Spillville	1314	10	5.20	mixed	0-2
Spillville-Coland	1585	129	14.02	mixed	0-2
Spillville	485	42	4.56	moderate	0-2
Farrar	253B	186	2.47	well	2-5
Lester	236B	81	2.94	well	2-5

Along with the buffer, the Bear Creek watershed restoration project incorporates soil bioengineering and grade control technologies for streambank stabilization and constructed wetlands. The objectives of these components are to minimize soil erosion and intercept surface and subsurface agricultural chemicals from adjacent crop fields, slow floodwaters, improve wildlife habitat and provide alternative, marketable products (Environmental Protection Agency 1999).

The Bear Creek watershed empties into the Skunk River just north of Ames, Iowa. The Skunk River can produce major floods in Ames. Figure 2.2 is the location of the Bear Creek watershed located in portions of Hamilton, Hardin and Story counties.

Methodology

Figure 2.3 illustrates the relationship between GIS and HEC-HMS model and the steps used in this project. The first step of the process was the acquisition of the raw GIS data. A Digital Elevation Model (DEM) of the watershed area were processed and analyzed within GIS using a spatial hydrology database for the creation of the Triangulated Irregular Network (TIN) from the DEM. The data was then preprocessed using the HEC-GeoHMS. After the preprocessing, the hydrologic data, HMS Inputs and watershed characteristics were entered into HEC-HMS for the modeling processes. The results were viewed and displayed in HEC-HMS.

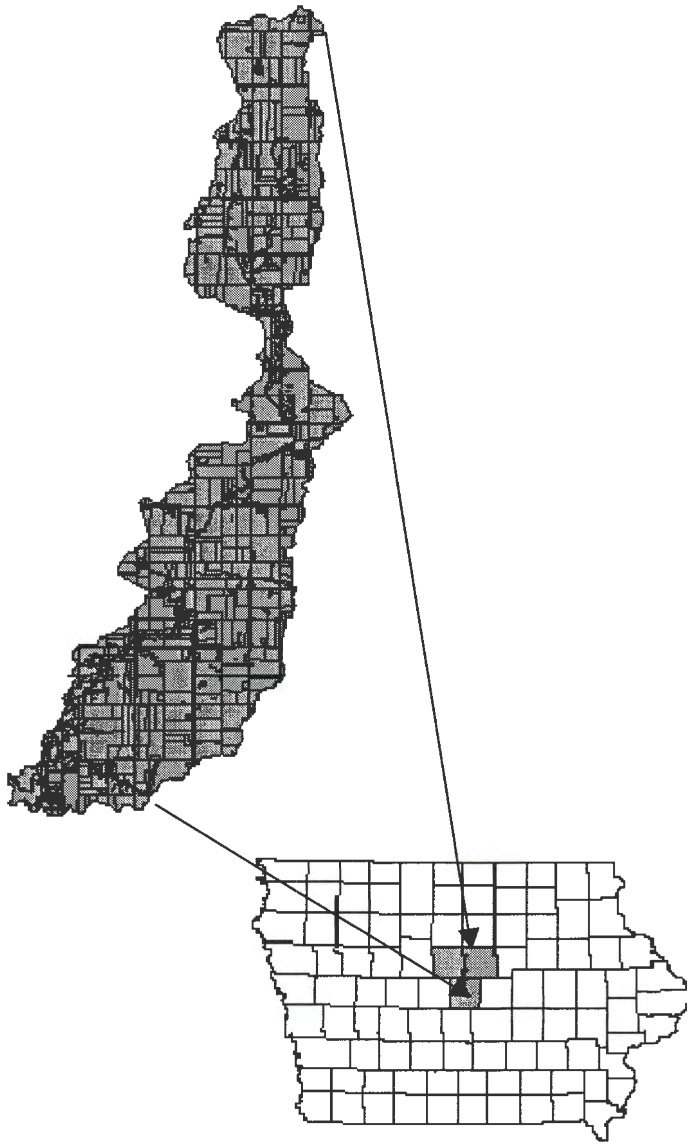

Figure 2.2 Location of the Bear Creek watershed.

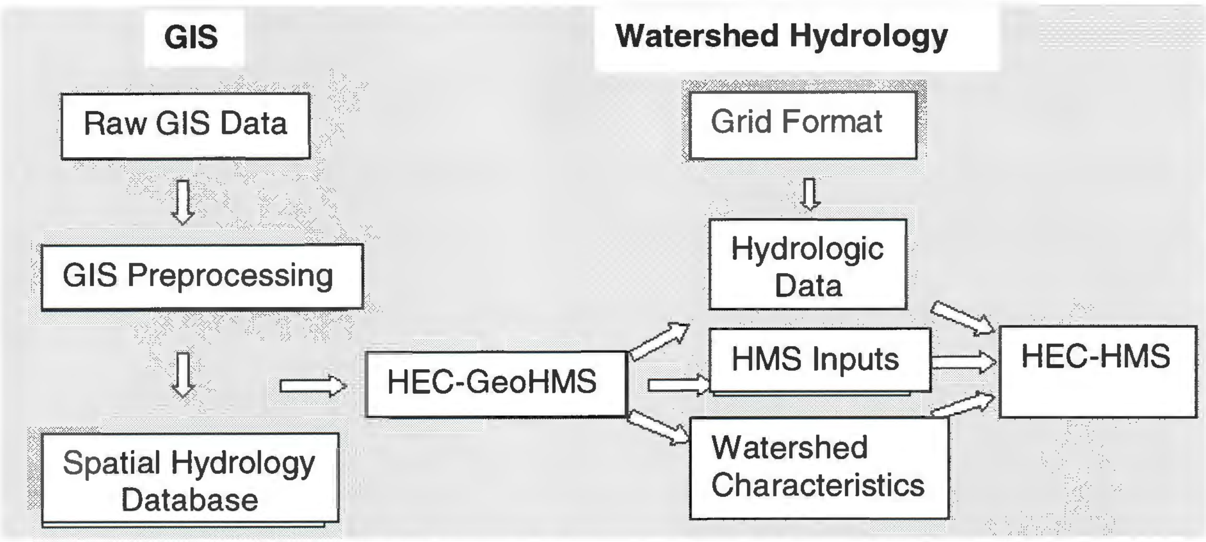

Figure 2.3 The relationship between GIS, HEC-GeoHMS and HEC-HMS (Hydrologic Engineering Center 2000).

Preparation of Digital Elevation Model (DEM)

A DEM is a digital representation of a continuous variable over a two-dimensional topographical surface by a regular array of z values referenced to a common datum (United States Geological Survey 1987). As a raster data set, the DEM contains elevation points of the earth's surface in a grid format spaced at 10-meter intervals. The data were obtained from USGS 7.5 minute quad maps with elevations measured in feet. The scale of the data used was 1:24,000. The reference system for this DEM was North American Datum 83 (NAD83).

Within ArcView GIS, Spatial Analyst was used to import and view the DEMs. Six DEMs were downloaded for this project. The six DEMs are as follows: Story City, McCallsburg, Ames, Nevada, Ellsworth and Radcliffe. Because several DEM data sets were not connected, the DEMs were clipped by using an ArcScript from the Environmental System Research Institute (Appendix A). Using a mosaic script from ESRI (Appendix B), the DEMs were merged into a single coverage for proper analysis. Figure 2.4 is a DEM of the Bear Creek watershed after the clip and mosaic commands were performed. This image represents elevation changes. The darker images represent the higher elevations.

Creation of a Triangulated Irregular Network (TIN) from DEM

A TIN is a three-dimensional surface represented by interconnected triangles. A TIN is a significant alternative to the regular raster of a DEM. In a TIN model, irregularly spaced sample points can be adapted to a terrain and connected by lines forming triangles that represent a surface. The triangle's continuous surface defines elevations of the three corner points of the triangle (Mark 1975). A TIN was used in this project to determine the stream network within the watershed.

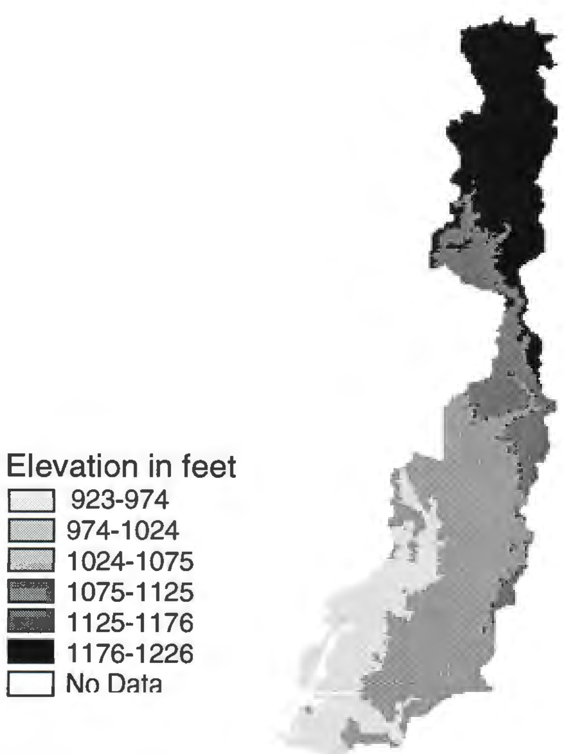

Figure 2.4 Digital Elevation Model (DEM) of Bear Creek watershed after the clip and mosaic.

Three-D (3-D) Analyst, an ArcView extension, was used to create the TIN. The TIN provides a more accurate three-dimensional static view of the land surface (Maidment 1993). Figure 2.5 is a TIN where the different shades of the TIN represent the changes in elevations.

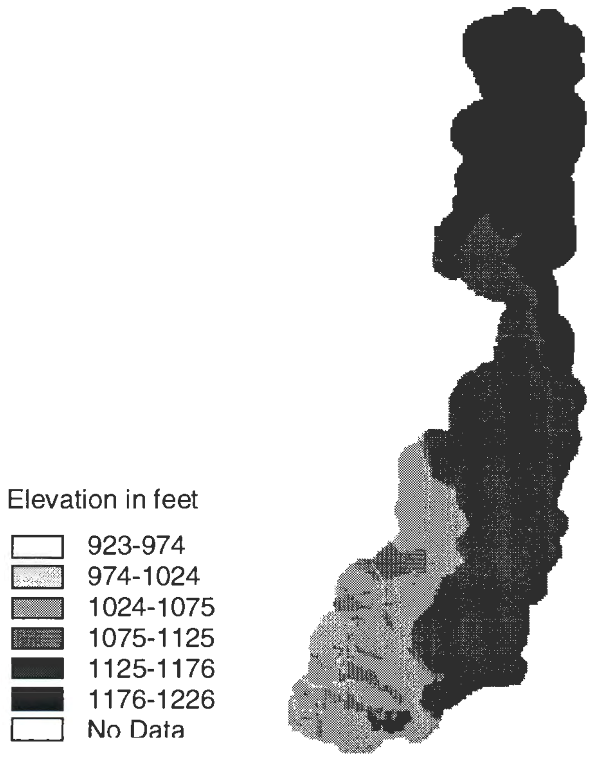

Figure 2.5 Triangulated Irregular Network (TIN) of the Bear Creek watershed.

Acquisition of Digital Orthophoto Quadrangles (DOQ)

An orthophoto is a photograph in which objects are shown in their true orthographic position. Thus, orthophotos can be used to make direct measurements such as distances, angles, positions and areas. Because of the true representation of all surface objects on the orthophotos, a direct correlation between surface objects and actual objects can be observed (Vision International 2001). The DOQs were used to view the Bear Creek watershed.

The DOQs were obtained from the USGS Global Information System (GLIS) as zipped files. The files were unzipped using WinZip. A similar clip grid command was used on the DOQs as for the DEMs. The ground resolution of the DOQs was 1-meter. This image was projected in the Universal Transverse Mercator (UTM) on the NAD83 (USGS 2001) with coordinates in meters. Figure 2.6 shows the Bear Creek watershed boundary superimposed on the DOQ.

Primary Data Layers

The watershed hydrologic processes began by downloading an Arc/Info coverage from the Bear Creek watershed research done by the Forestry Department. This coverage included soils, topography, land cover and stream centerline. Table 2.2 explains the significance of each of the data layers for this project.

Table 2.2. Data layers used for analyzing the landscape of the Bear Creek watershed (Miller 2000).

Soils	aids in modeling infiltration and runoff of the watershed
Topography	influences infiltration & flow direction
Land Cover	aids in assessing vegetation and the uses of the land
Stream	visualize stream centerline

Watershed Hydrologic Processes

Analysis of watershed hydrologic processes was necessary to achieve the objectives of this project. Those analysis were: (1) to simulate storm events (2) to calculate and display the changes in the discharge rates of the stream and (3) to find the soils in the watershed most prone to ponding and calculate the volume of water that each ponded area can contain. The first stage involved HEC-HMS and GIS. The second stage involved calculating and displaying the changes in stream discharge by using the HEC-HMS and GIS. The last stage involved extracting soil data from the soil coverage and a simple query within GIS. The last stage involved GIS Hydrology Modeling and Map calculator processes.

HEC-Hydrologic Modeling System

HEC-HMS is a modeling system designed to simulate the precipitation-runoff process of dendritic stream channel systems. In addition to unit hydrograph and hydrologic routing options, capabilities currently available in this system include a quasi-dimensionally distributed runoff transformation (grid format), precipitation and moisture depletion option that can be used for continuous simulation. This program features an integrated work environment, including database and data entry utilities, computation engine and result reporting tools. A graphical user interface (GUI) allows the transition from different parts of the program. Computation results are viewed from a basin model schematic map. Peak flow, total volume, time-series tables and graphs are included in the global and element summary table information (Dodson & Associates[a] 2001).

A hydrologic model, as used in this study, is defined as the equations that represent the behavior of hydrologic system components. In a situation that involves HEC-HMS, the known input is precipitation and the unknown output is runoff, or the known input is upstream flow and the unknown output is downstream flow (Hydrologic Engineering Center 2000). The HEC-HMS contains three models: the basin, precipitation and control specification. The Basin model represents the

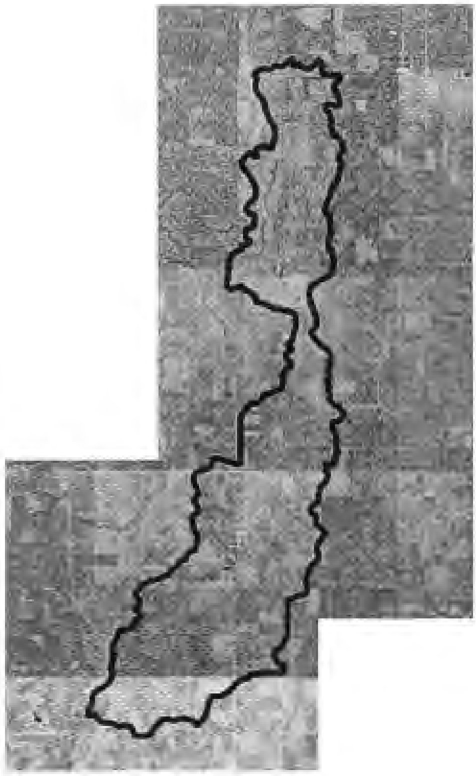

Figure 2.6 Digital orthophotos of Bear Creek watershed.

physical attributes of the model. The Precipitation model provides rainfall data. The Control Specification model is relevant to the timing of the storm event (Furnans 2000).

HEC-HMS uses different options to represent parameters within the basin model such as (1) computation of runoff volume, (2) determination of overland and interflow, (3) determination of baseflow and (4) determination channel flow (Hydrologic Engineering Center 1999).

Preprocessing GIS Data with HEC-GeoHMS

HEC-GeoHMS is a set of ArcView scripts developed using the Avenue programming language and Spatial Analyst (HEC 2000). Integrated data management and graphical user interface is included in this script. GeoHMS is used for many different analyses such as delineation of sub-basins and streams, terrain information and preparation of hydrologic inputs. HEC-GeoHMS provides the connection for translating GIS spatial information into hydrologic models (Doan 2000).

HEC-GeoHMS was used to process digital spatial data, obtain necessary hydrologic information and generate the hydrologic parameters for the use of HEC-HMS. These parameters included the sub-basins, reaches, sources, sinks and diversion in the Bear Creek watershed. HEC-GeoHMS uses a DEM to derive sub-basin delineation and prepare several hydrologic inputs. HEC-HMS then accepts these inputs as the beginning of hydrologic modeling (HEC 2000). The preprocessing involves an extensive step-by-step execution of each sub-routine (McPherson and Henneman 2000). The DEM was downloaded and prepared for analysis in GeoHMS.

Preprocessing with HEC-GeoHMS began with terrain preprocessing. Within the terrain preprocessing, drainage basin characteristics were established. These characteristics included filling the sinks, establishing the flow direction and accumulation, defining the stream and the stream segmentation. After the drainage basin was complete, sub-watersheds were defined and a new HMS Project was started. After the new project was started, the basin processing began. The basin processing included characteristics such as basin merge, stream merge, stream profile and split basin at confluences of each sub-watershed. The basin merge was a simple process that merged all of the contributing areas of the watershed together.

The stream merge function merged the stream as continuous flow. The stream profile allowed a visual view of the basin merge and the stream merge. The split basin at confluences separated the main channel from the tributaries. After this process was completed, basin characteristics were calculated including stream length, stream slope, basin centroid elevation, longest flow path and centroidal flow path. After the basin characteristics were defined, HMS was the final step of preprocessing before creating a schematic layout of the Bear Creek watershed using HEC-HMS. The result of preprocessing was the formulation of a basin model schematic map, which permits the inputs into HEC-HMS. Figure 2.7 is a schematic layout, a visual representation created by preprocessing the DEM of Bear Creek watershed using HEC-GeoHMS.

The elements of the schematic layout are as follows: the sub-basin, reach, reservoir, junction, diversion, source and sink. Two or more sub-basins converge and form a junction. For example, R10W10 and R20W20 are sub-basins. These two sub-basins connect at JR30, which is a junction. Within the different sub-basins the loss determination, runoff transformation and the baseflow are calculated. At the different junctions, the routing method takes place. The schematic layout shows the path that water flows from the source of the watershed to the outlet.

The Basin Model

Modeling with HMS involves four sets of calculations (1) quantifying rainfall losses into the soil, (2) converting excess rainfall to runoff (3) routing of runoff and

(4) baseflow determination (HEC 1999). HMS provides different methods for simulating precipitation-runoff process:

(1) alternatives in determining losses

(2) runoff transformation methods

(3) hydrologic routing options and

(4) baseflow determination.

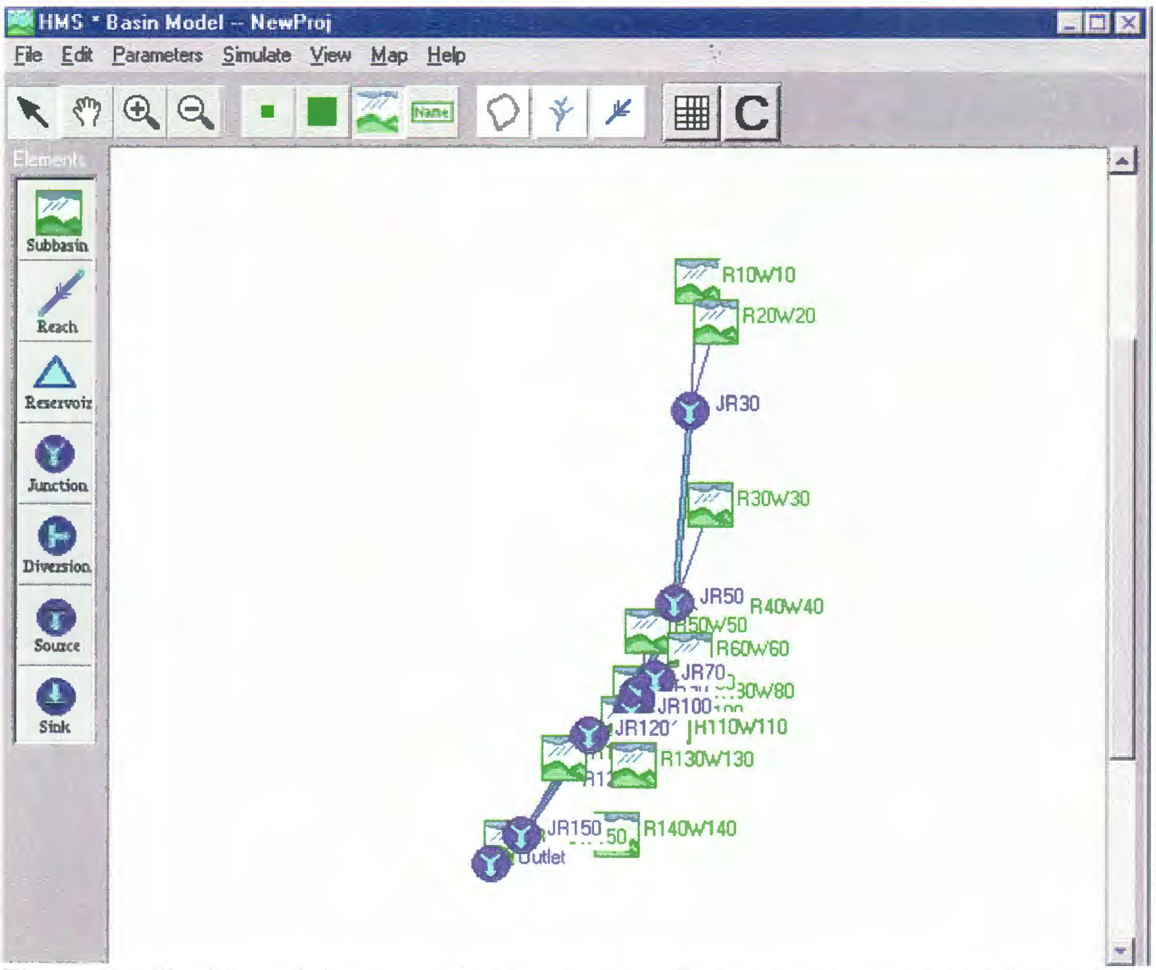

Figure 2.7 Basin model schematic layout of the Bear Creek watershed (HEC 2000).

Loss Determination

Loss rates are defined as the rainfall losses absorbed by the ground. Loss calculation can be achieved by several methods such as initial/constant, Soil Conservation Service (SCS) Curve Number, gridded SCS Curve Number, and the Green and Ampt (HEC 2000). These methods can be classified as lumped or linear-distributed methods. In the lumped method, losses are averaged spatially in a sub-basin while in linear-distributed method, losses are calculated for each individual grid cell (Boss International 2001). For this project, SCS Curve Number (CN) was used to measure runoff volume.

The SCS CN method was selected because of the data availability of the soil coverage and the land use for the Bear Creek watershed. The SCS CN is probably the most widely used of all the methods. Because of the fine resolution of the land use and soil data for the Bear Creek watershed, the SCS CN was the best choice for determining runoff losses within the watershed.

The SCS CN method estimates precipitation excess relative to total precipitation, soil cover, land use and antecedent moisture by using the following equations (Ponce and Hawkins 1996):

$q_P = (0.0021QA)/T_P$

where

q_P = peak runoff rate,
T_P = time of peak flow
Q = runoff depth and
A = area

$T_P = D/2 + 0.6\ T_C$

where

T_P = time of peak flow,
T_C = time of concentration and
D = the duration of excess rainfall.

For each hydrologic soil type (A,B,C,D), there is a corresponding curve number. From A to D, a decrease in the infiltration capacity of the soil occurs (Boss International 2001). A SCS CN was calculated for each soil type and the average for the sub-watershed was taken and used as the SCS CN. In Appendix C, the curve numbers for each sub-basin are documented.

Runoff Transformation

The runoff transformation method converts excess precipitation to direct runoff at a sub-basin outlet. This method describes water that has not infiltrated that moves over (overland flow) or just beneath (interflow) the watershed surface. This method is also achieved by either lumped or linear-distributed methods. In the lumped method, the amount of runoff is determined using hydrographs such as Clark, Synder, Kinematic wave or SCS (HEC 2000). In the linear-distributed method such as Modified Clark, the excess rainfall from each grid cell is “lagged” to the basin outlet. Because Bear Creek is an ungaged watershed, the SCS Unit Hydrograph as used to calculate the lag time using the SCS lag-time formula (Furnans 2000) as noted below:

$t_{lag} = 0.6\ t_c$

t_c = time of concentration

$t_c = L^{0.8}/190\sqrt{s} * \{(1000/CN) - 9\}^{0.7}$

where

s = watershed slope (ft/ft)
CN = Curve Number and
L = watershed length.

Routing

Routing is defined as the movement of runoff from sub-basin outlets. HMS's routing method options are Muskingum, the Modified Puls, the Kinematic Wave, confluence, bifurcation and the Muskingum-Cunge methods (HEC 2000). For this project, the Muskingum routing method was used to determine channel flow. This method is widely used and for this project, Muskingum method was used as a standard in comparison with the Squaw Creek watershed. These watersheds are in close proximity to each other and are similar in soil types, land uses and farming practices. The Muskingham method computed a downstream hydrograph based on a given upstream hydrograph as a boundary condition for each sub-watershed (Cunge 1969).

The Muskingum routing method uses a simple finite difference approximation of the continuity equation. This method estimates K and X. K is the travel time of the flood wave through the routing reach and X is a dimensionless weight ($0.5 \geq X \geq 0$). For an ungaged watershed, K and X can be estimated from channel characteristics. For this project, K is estimated as 0.4 and X is estimated as 0.2 with 22 subreaches taken from the Squaw Creek watershed.

Baseflow Determination

No baseflow, constant monthly, exponential recession, and linear reservoir are methods used to determine baseflow (HEC 2000). These methods simulate the subsurface drainage of water from the watershed into the stream. Because there was limited baseflow data in the Bear Creek watershed, the no baseflow model was used in this project. The subsurface tile lines with the Bear Creek watershed actually provides flow to the stream that can also be considered tile flow.

The Precipitation Model

The physical attributes of the HEC-HMS model are now complete, so the next step is to complete the model that deals with simulated rainfall. There are many methods by which to describe rainfall simulation such as User Hyetograph, User Gage Weighting, the Frequency-Based Storm, Inverse-Distance Gage Weighting, Gridded Precipitation, SCS Hypothetical Storm and No Precipitation (HEC 2000). The Frequency-Based Storm method was chosen for this model because of the lack of rainfall data that represents the entire Bear Creek watershed. This method allowed simulation to be based on rainfall data in inches from the United States Department of Agriculture (USDA)-National Resource Conservation Service (NRCS). In this project, five rainfall simulations were: a 100-year 24-hour rainfall, 50-year 24-hour rainfall, 25-year 24-hour rainfall, 10-year 24-hour rainfall and 2-year 24-hour rainfall. The precipitation depths in each of the simulations were obtained from USDA-NRCS. In this example of a 2-Year 24 Hour Rainfall, the precipitation depth was 1.51 inches. A 2-Year 24 Hour Rainfall describes a typical rainfall event that happens every 2 years with a duration of 24 hours. Table 2.3 shows the amount of rainfall in inches during the simulation events relative to the time.

Table 2.3 Rainfall in inches of the simulated storm event relative to time.

Time	100 Year	50 Year	25 Year	10 Year	2 Year
5 min	0.8	0.5	0.5	0.4	0.2
15 min	1.5	1.1	1.0	0.7	0.3
1 hr	2.3	1.8	1.6	1.3	0.4
2 hrs	3.0	2.6	2.4	1.7	0.5
3 hrs	3.5	3.2	3.1	2.1	0.6
6 hrs	4.9	4.0	3.7	3.0	0.7
12 hrs	5.8	4.9	4.5	3.5	0.9
24 hrs	6.5	5.8	5.3	4.5	1.5

The Control Specification

The final piece of the model involves time in which rainfall took place. In a hypothetical simulation, the number of days and the time of day are strictly up to the modeler. In an example of a 24-hour rainfall event, the time event begins at midnight on the 14th of July and ends at midnight on the 15th of July using sampling time intervals of 5 minutes. Using the set time interval, the unit hydrograph produces data after every five minutes. Five-minute intervals represent the time taken by the model to simulate discharge and display the results in a unit hydrograph.

Results

The results can be viewed in tabular or graphical form. For this model, an actual storm event was modeled to determine the accuracy of the HMS modeling process.

Within the Bear Creek watershed, a recording rain gauge is located on the Risdal Farm. Data were collected and analyzed from the summer of 1992. On July 15, 1992, the Bear Creek discharge after a storm event was noted as approximately 34.0 cfs. According to the conditions and based upon previous rainfall data, this discharge was associated with a 2-year 24-hour rainfall event. This rainfall data was entered into the HEC-HMS model and discharge at the Risdal weir was simulated. After the computation, the calculated model results were very similar to the observed discharge. Modeled discharge for the storm event was 34.5 cfs. In Figure 2.8, the graph indicates the result of the simulation at junction 90, the location of the Risdal weir, in cubic feet per second (cfs). Because the results are very similar to observed discharge at that location, the accuracy of this model to predict discharge of a storm event appears to be acceptable.

Stream Discharge Simulation

For this project, GIS was used to display the changes in discharge at each junction under different storm events. These discharges were computed during the HEC-HMS simulations. X Tools extension to ArcView GIS allowed the display of the changes in discharge by buffering different reaches based on the calculated discharge taken from HEC-HMS.

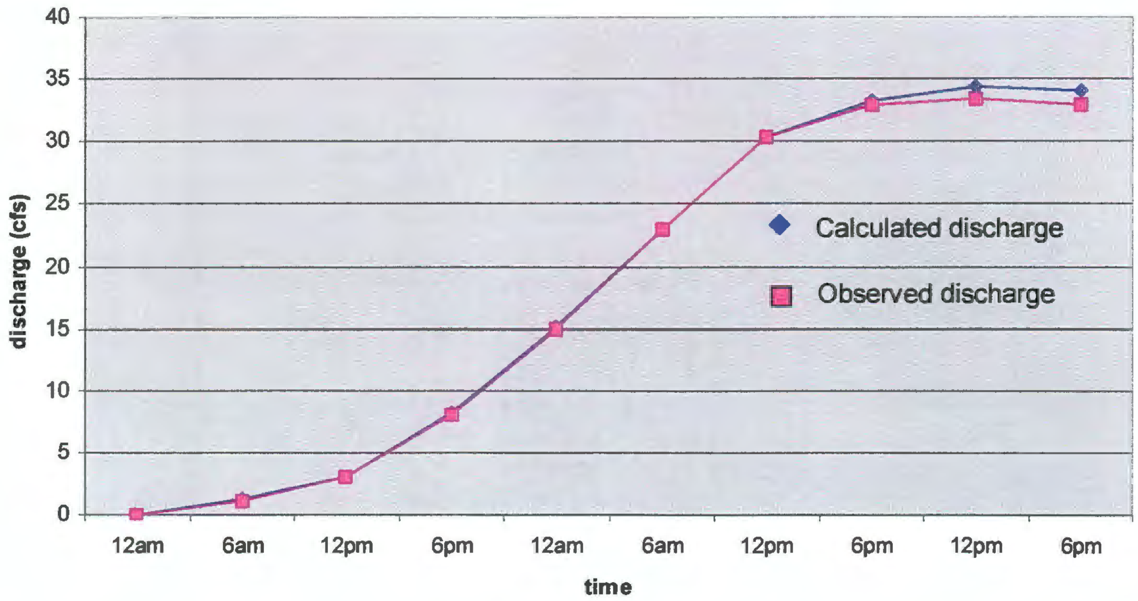

Figure 2.8 Results from the storm event of July 1992 (in cubic feet per second).

The changes in stream discharge are more noticeable from upstream to downstream as the elevation decreases and the water flow increases. Table 2.4 shows the discharges relative to the junctions. These discharges are used to buffer the stream showing the changes in the discharge under different storm events. Increasing buffered widths in Figures 2.9 to 2.13 represent increasing discharge rates. These buffered widths are not meant to represent the actual width of the Bear Creek.

Table 2.4 Discharges of the stream relative to junctions (cubic feet/second).

Junction	100 Year	50 Year	25 Year	10 Year	2 Year
30	290.7	251.5	220.2	161.6	16.8
50	338.4	292.1	255.1	186.3	18.4
70	219.4	191.4	169.8	125.2	17.0
90	557.2	482.7	423.8	310.4	34.4
100	599.5	519.2	455.4	334.3	36.7
120	657.0	568.0	497.2	364.0	38.5
150	912.5	786.7	686.7	499.5	49.2

Ponded Areas

The next step was to identify the areas within the Bear Creek watershed that are prone to ponding. This step was independent of any HEC-HMS modeling. The soil data were derived from the ISPAID database. ISPAID database includes a flood frequency code for each soil polygon. A query of the soil areas that are prone to ponding were identified by using the following flood frequency codes attached to the soil polygons:

NONE	=	Flooding is not probable
RARE	=	Flooding is unlikely but possible
OCCAS	=	Flooding occurs 50 times or less in 100 years
COMMON	=	Flooding is likely under normal conditions
FREQ	=	Flooding occurs 50 times or more in 100 years
PONDED	=	Water ponds on soils in closed depressions

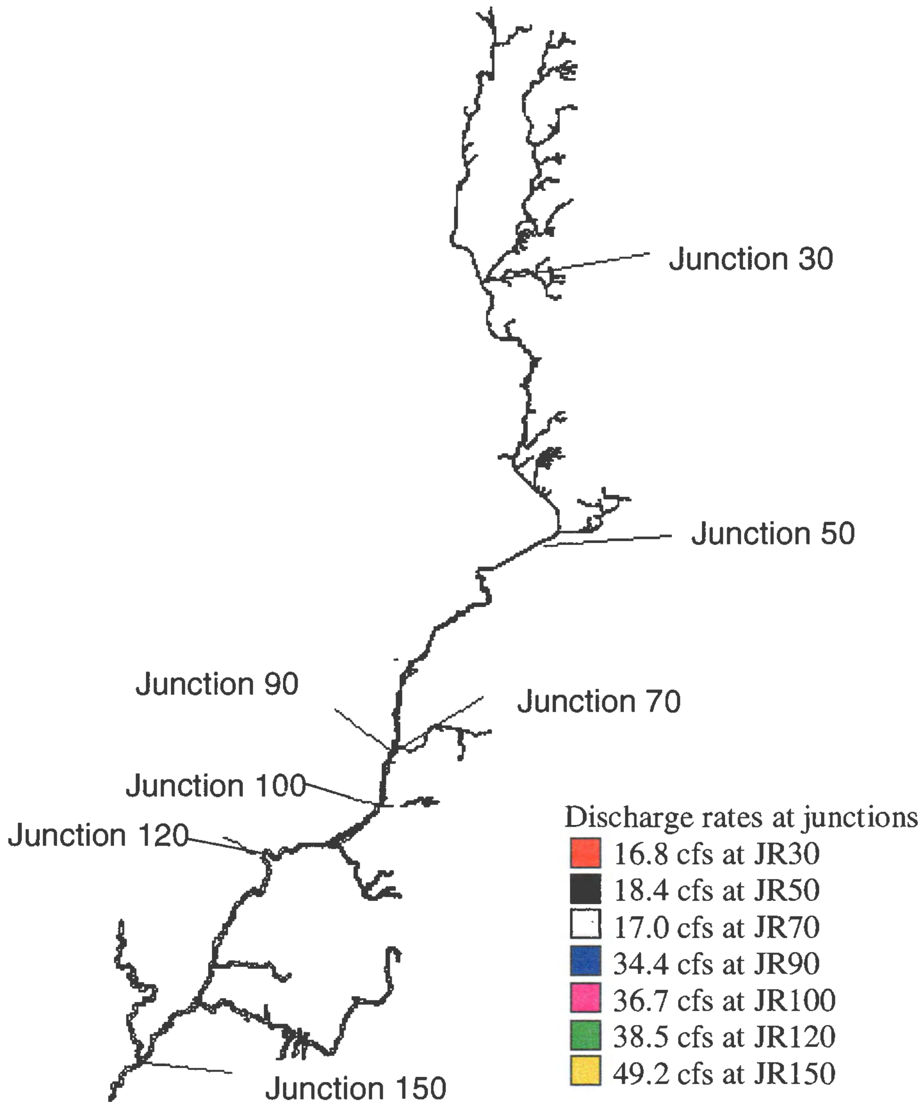

Figure 2.9 Discharges of the stream during a 2-year storm event.

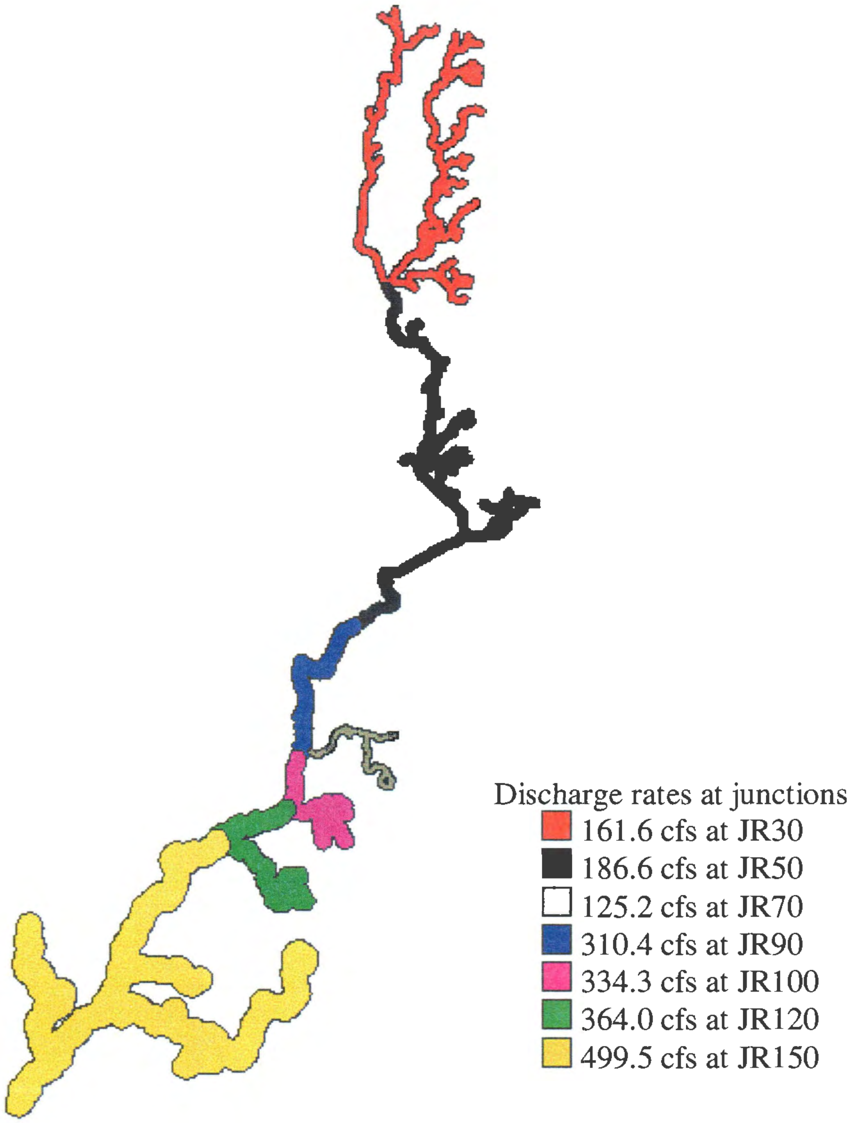

Figure 2.10 Discharges of the stream during a 10-year storm event.

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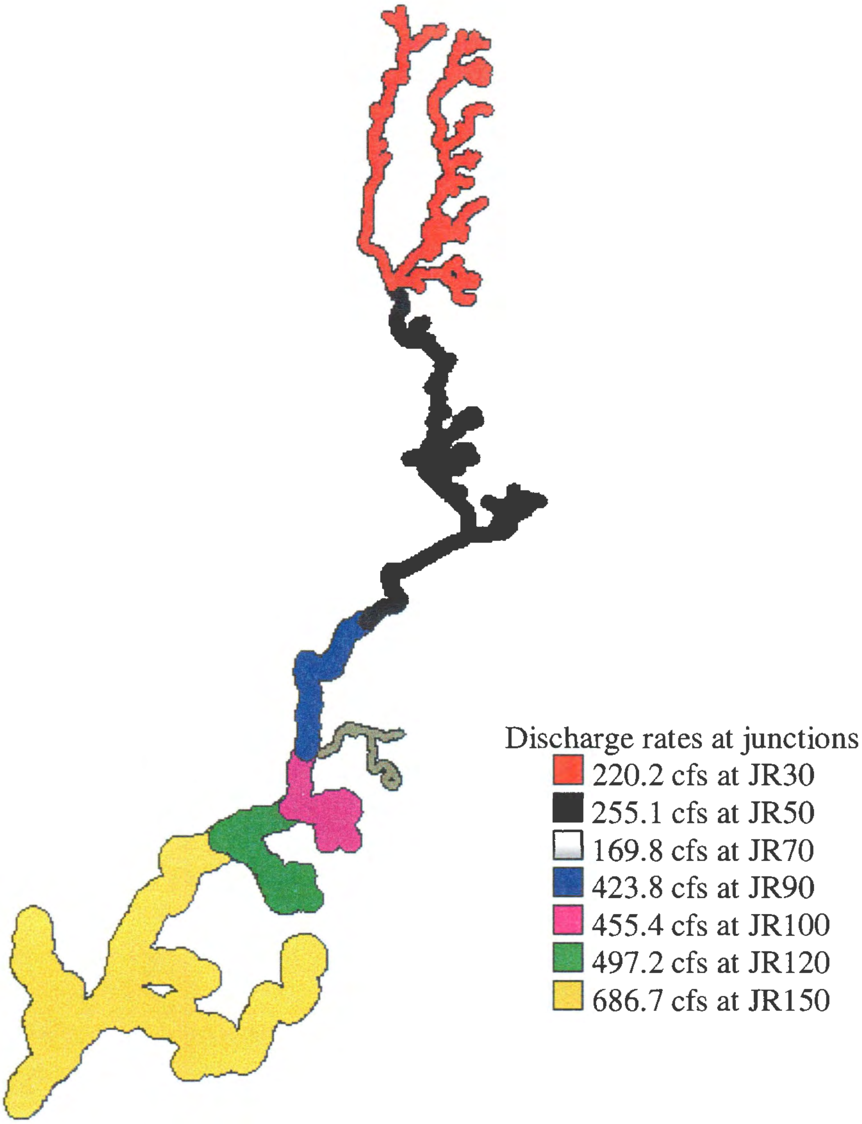

Figure 2.11 Discharges of the stream during a 25-year storm event.

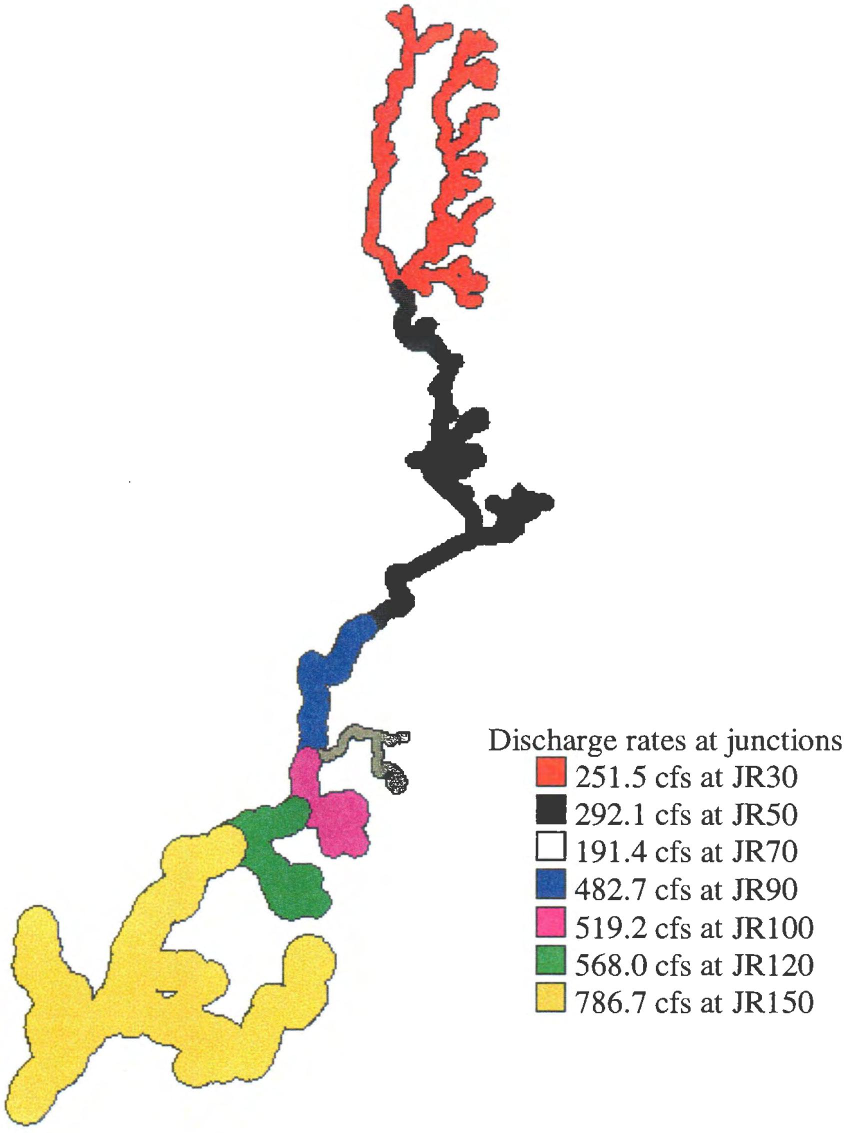

Figure 2.12 Discharges of the stream during a 50-year storm event.

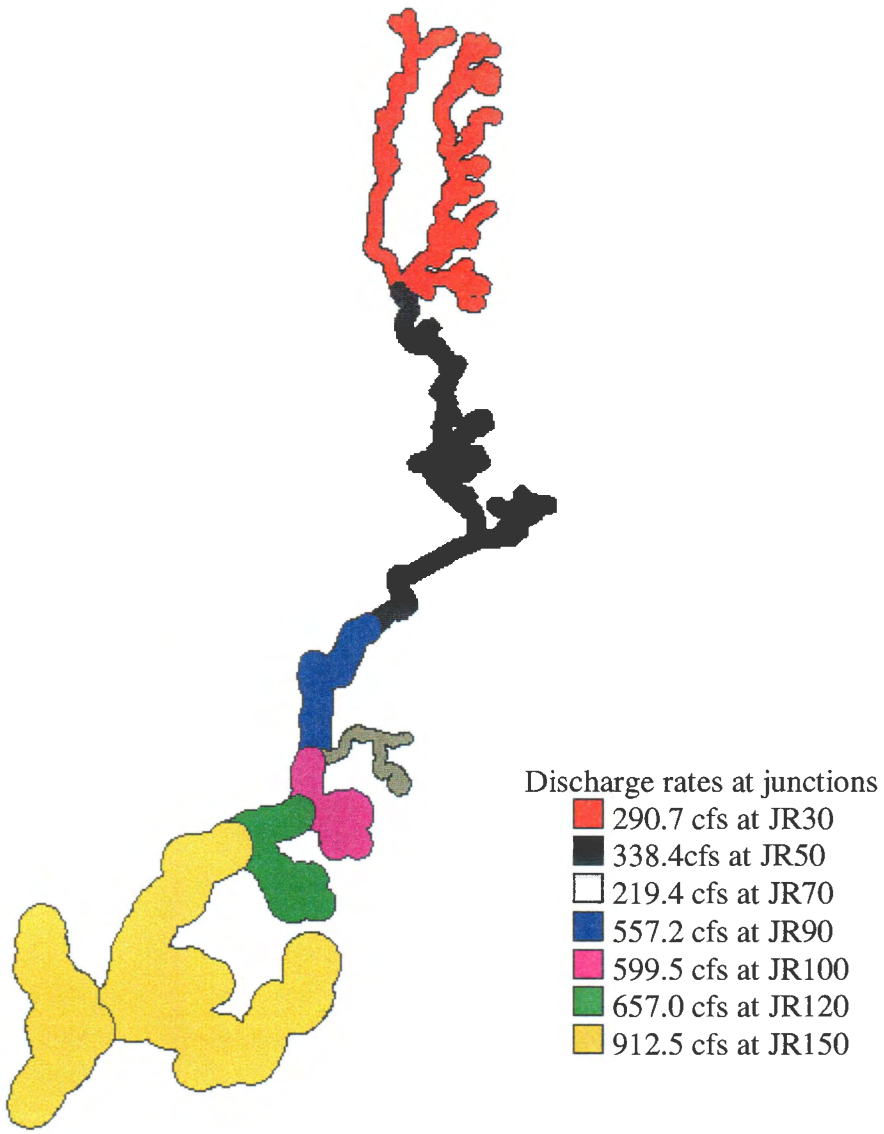

Figure 2.13 Discharges of the stream during a 100-year storm event.

For this project, soils classified as PONDED were identified and displayed using GIS. GIS functions, Hydrology Modeling and Map Calculator, were used to calculate the total volume of water that can be held by soil polygons that was labeled PONDED. Figure 2.14 shows the Bear Creek watershed and the areas that are prone to ponding. These soils are prone to ponding without any flooding or disruption. Most of the ponded soils are located on the outer fringes of the watershed. If wetlands are constructed and used for storage of water within the Bear Creek watershed, the areas that are closer to the stream should be selected first. This concept works best in a watershed without a tile drainage system. Because the Bear Creek watershed includes tile drainage systems, the decision to construct wetlands to help minimize the impacts of flooding must be further examined to weigh the pros and cons.

The total amount of water that can be held by the ponded areas is 8,650,300 cubic meters within the Bear Creek watershed. The total amount of water that can be held by soils that are within 250 meters of the stream is 501,500 cubic meters. This is important because these are the areas that are most likely to be used for storage of any surface flow if wetlands are constructed.

The amount of storage available within these ponded areas that are within 250 meters of the stream is an important concept. In order to simulate the storage-holding capacity of these ponded areas, the time (in hours) that it would take each rainfall event to produce 501,500 cubic meters of discharge was calculated. Results are shown in Table 2.5.

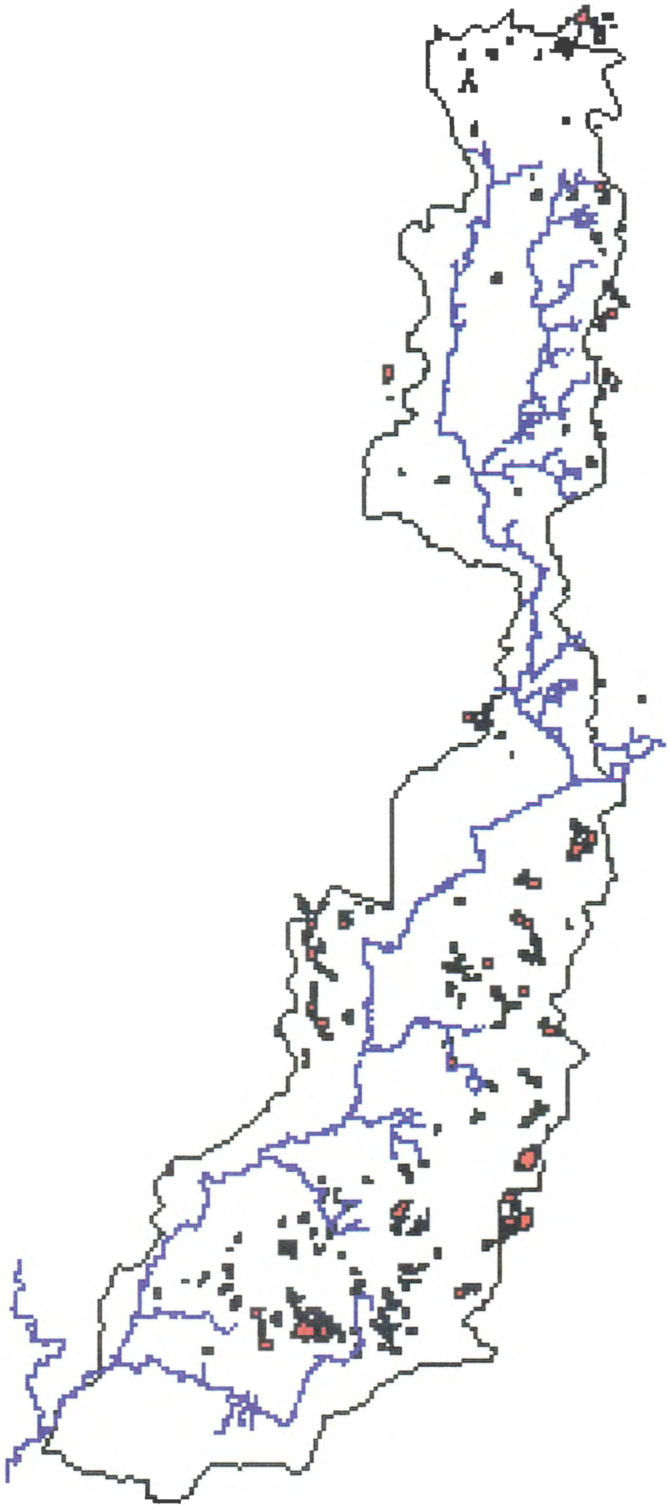

Figure 2.14 Soils of the Bear Creek watershed that are prone to ponding.

Table 2.5. Time (in hours) to produce discharge of 501,500 cubic meters.

Rainfall event	Time (in hours)
100 year	5.5
50 year	6.5
25 year	7.5
20 year	10
2 year	100

Conclusion

Completion of this research project shows that the future of hydrologic modeling of the Bear Creek watershed is promising. Currently, rainfall data are being collected and hopefully more accurate hydrologic modeling can be done in the near future.

Within the Bear Creek watershed, hydrologic modeling of hydrologic processes was completed, the stream discharge rates were calculated and displayed and the ponded areas were identified and also displayed. Future research is needed to accurately assess the actual locations where flooding will occur for a given storm event. This can be accomplished by using HEC-RAS and Virtual Reality software. This information would provide more substantial evidence for the landowners of the benefits of taking some ponded areas out of production and possibly constructing wetlands to help minimize the impacts of flooding.

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CHAPTER 3. GENERAL CONCLUSION AND PERSPECTIVES

Completion of this research project indicated the need for future work in the area of flood modeling within the Bear Creek watershed. This project also demonstrated the growing capabilities of technologies such as HEC-HMS and GIS. The continued advancement in technology will continue to revolutionize the area of hydrologic modeling. No other flood hydrologic modeling research has been conducted for the Bear Creek watershed. This project could be the initial step to spark the interest in hydrologic modeling.

The major advantage of using HEC-HMS for this project is that it allows the use of hypothetical storm events within the Precipitation Model for any basin. This is important because of the fact that the Bear Creek watershed has limited rainfall data applicable that represents the entire watershed. Additional rainfall gauges are now being added to the Bear Creek watershed. With the addition of these gauges, more information will be available to more sufficiently represent the Bear Creek watershed.

Because this project dealt with the modeling of hydrologic processes within the Bear Creek watershed, identifying the soils that are prone to ponding and calculating and displaying changes in discharge rates of the stream channel under different storm events, steps in the area of hydrologic modeling within the Bear Creek watershed has been taken. However, much more work is needed to ensure the validity of HEC-HMS and GIS to accurately assess flooding conditions of Bear Creek.

There are research opportunities in this area in the future. This research can be used as a basis to determine the exact locations of water flowing onto the landscape under flood conditions using HEC-RAS. HEC-River Analysis System incorporates several aspects of hydraulic modeling, including water surface profile computations, bridge hydraulics, unsteady flow and one-dimensional steady flow. HEC-GeoRas, as HEC-GeoHMS, is a precursor to the actual modeling system. HEC-GeoRAS is an ArcView GIS extension designed to process geo-spatial data for use within HEC-RAS. In order for research results from this project to be taken into HEC-RAS, additional work is need such as identification of the flow path centerlines, cross-sectional stream attributes, main channel banks and land use in order to develop Manning's n coefficient. HEC-GeoRAS preprocessing begins with the development of HEC-RAS steady-state simulations. This is accomplished by using geometry data, flow data, open-flow data, reach boundary conditions and steady-flow conditions. The HEC-GeoRAS post-processing incorporates the water surface profile derived from the HEC-RAS model into a spatial environment into GIS. The water surface profile data is used to develop a water surface TIN. The water surface TIN is then intersected with the terrain model TIN and this is how the flood visualization within HEC-RAS occurs. The results can be shown in 2 or 3 dimensions. Virtual reality technology can also be used to show the results.

Using the discharge data from this project coupled with areas that are prone to ponding, HEC-RAS can be used to show the exact locations on the landscape that the water will go during flood conditions. This continued research will present more evidence of the benefits of taking some ponded areas out of agricultural production to help minimize the impacts of flooding by using the ponded areas as water storages.

APPENDIX A. CLIP GRID SCRIPT

```
DiskFile   : clipgrid.ave : Clip Grid
' Programmer : Tom Van Niel
' Created    : 03-Nov-99
' Revisions  : 05-Nov-99/Tom Van Niel/ Allow user to specify whether
'              Clip Theme should be a Grid or a Feature Theme.
'            : 15-Jun-00/Tom Van Niel/ add in SetAnalysisExtent
'              command to output grid extent equal to extent of
'              input FSrc or Grid - eliminates lots of nodata vals.
'
' Function   : Clips all Input Grids by the Clip Theme.  OUTPUT Grid
'              matches the INPUT Grid geographically (pixels line up).
'              All non-zero areas in CLIP theme are used to "clip" out
'              the INPUT Grid.
'
' References : None
' Called By  : GUI
' Calls      : None
' Sister Code: None
' ----------------------------------------------------------------------
' Initialize Variables
theView = av.GetActiveDoc
If (not (theView.GetClass.GetClassName = "View")) then
  MsgBox.Warning("A View must be active to use this function.","Exiting")
  Return Nil
End
thePrj = theView.GetProjection
Counter = 0
TypeList = {Grid,FSrc}
theNumFields = {}

' Get Input Grid to be Clipped
InSrcList = SourceDialog.ShowClass("Select In GRID(s). Grid(s) to be
clipped.",Grid)
  If (InSrcList.Count = 0) then return NIL end
  theCellSize = Grid.Make(InSrcList.Get(Counter)).GetCellSize
  theExtent = Grid.Make(InSrcList.Get(Counter)).GetExtent

' Get Data Source Type (i.e. Grid or Feature)
DType = MsgBox.ListAsString(TypeList,"Select Data Source Type for CLIP
Theme"+NL+"(Select ""Grid"" to select from GRID Themes"+NL+"or ""FSrc"" to
select from Feature Themes)","Data Source Type Input")

' Get Clip Theme
```

```
NullSrcList = SourceDialog.ShowClass("Select CLIP Theme. Non-zero areas in ClIP
Theme will be retained in the OUTPUT Grid.",DType)
If (NullSrcList.Count = 0) then return NIL end
If (NullSrcList.Count > 1) then
   msgbox.ERROR("Must Select only one CLIP Theme","Clip BOUNDING THEME
SELECT ERROR")
   return NIL
End

' Make Clip Grid (Convert Shape to Grid if DataSourceType is Feature Source)
If (DType.GetClassName = "Grid") then
  NullGrid = Grid.Make(NullSrcList.Get(0))
  NullRect = GTheme.Make(NullGrid).ReturnExtent
Elseif (DType.GetClassName = "FSrc") then
  NullFtheme = Theme.Make(NullSrcList.Get(0))
  NullRect = NullFtheme.ReturnExtent
  NullFtab = NullFtheme.GetFtab
  theFields = NullFtab.GetFields
  For each Fld in theFields
    If (Fld.IsTypeNumber) then
      theNumFields.Add(Fld)
    End
  End
  theFld = MsgBox.ListAsString(theNumFields,"Select Field containing values to
retain in Clip","Field Selection")
  NullGrid = Grid.MakeFromFtab(nullFTab,thePrj,theFld,{theCellSize,theExtent})
End

' Loop through all In Grids Selected

For Each Grd in InSrcList
  InGrid = Grid.Make(InSrcList.Get(Counter))
  ' Clip Ingrid with Clip Grid
  Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE,NullRect)
  OutGrid = nullGrid.Con(InGrid,nullGrid)
  ' Save Output Grid
  InBase = InSrcList.Get(Counter).GetFileName.GetBaseName
  InBase = InBase.left(4)+"cl"
  OutFN = av.GetProject.GetWorkDir.MakeTmp(InBase,"")
  OutGridStrng = msgbox.Input("Enter Output Grid File Name","GRID
NAME",OutFN.asString)
  If (outGridStrng = NIL) then return NIL End
    OutGridStrng = OutGridStrng.Trim.Substitute(" ","")
    OutGridFN = FileName.Make(OutGridStrng)
    OutGrid.SaveDataSet(OutGridFN)
```

```
  If (OutGrid.HasError) then
    msgbox.ERROR("Out GRID HAS ERROR, MIGHT BE INVALID GRID NAME
EXITING","SaveDataSet ERROR")
    return NIL
  End

  ' Ask User if Want to Add Grid to View
  AddGrd = msgBox.YesNo("Add OutPut Grid to the View?","Add GRID",FALSE)
  If (AddGrd = TRUE) then
    OutGTheme = GTheme.Make(OutGrid)
    theView.AddTheme(OutGTheme)
  End
  Counter = Counter + 1
End 'For Loop
```

APPENDIX B. MOSAIC SCRIPT

```
' Description: Mosaics multiple grid themes, making a smooth transition
' over overlapping areas.
'
' Name: Spatial.GridMosaic
'
' Requires: Spatial Analyst
'
' Self:
'
' Returns:
'
' FileName: ggmosaic.ave
'


' GET THE ACTIVE THEMES
theView = av.GetActiveDoc
gl = theView.GetActiveThemes

' FIND THE OUTPUT NAME FOR GRID
gridFN = SourceManager.PutDataSet(GRID,"Output Grid :" ,
"newgrd1".asFileName,TRUE)
if (gridFN = NIL) then return NIL end

' ADD THE GRIDS OF ACTIVE THEMES TO A GRIDLIST
gs = {}
x = 0
for each gg in gl
  x = x + 1
  if (x > 1) then
    gx = gg.GetGrid
    gs.Add(gx)
  end
end

gy = theView.GetActiveThemes.Get(0).GetGrid
 MOSAIC THE GRIDS IN THE GRIDLIST AND SAVE THE RESULTING
' GRID IN THE WORK DIRECTORY
av.GetProject.GetWorkDir.SetCwd
n_g = gy.mosaic(gs)
n_g.SaveDataSet(gridFN)
ngt = GTheme.make(n_g)

theView.Addtheme(ngt)
```

APPENDIX C. CURVE NUMBERS FOR HEC-HMS SUB-BASINS

Sub-Basin	Curve #
R10W10	78
R20W20	78
R30W30	69
R40W40	78
R50W50	75
R60W60	85
R70W70	78
R80W80	75
R90W90	75
R100W100	75
R110W110	75
R120W120	69
R130W130	69
R140W140	78
R150W150	98

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Remember: "Today, I'll do what other people won't do so tomorrow I can do what other people can't do." -----Rodney Jones

ONE LOVE, HOTEP (Peace)