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GIS Data and Geoprocess Modeling for Hydrologic Network Conservation Analysis in a Green Infrastructure Plan

Andrew Lorenz Wunderlich
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Andrew Lorenz Wunderlich entitled "GIS Data and Geoprocess Modeling for Hydrologic Network Conservation Analysis in a Green Infrastructure Plan." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

<div align="right">Bruce Ralston, Major Professor</div>

We have read this thesis and recommend its acceptance:

Thomas L. Bell, Mark DeKay

<div align="right">Accepted for the Council:
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GIS DATA AND GEOPROCESS MODELING
FOR HYDROLOGIC NETWORK CONSERVATION ANALYSIS
IN A GREEN INFRASTRUCTURE PLAN

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Andrew Lorenz Wunderlich
December 2008

DEDICATION

To my grandparents, the Almeidas and the Wunderlichs,

whose perseverance and hard work set an example to live by.

ACKNOWLEDGEMENTS

ABSTRACT

As urban sprawl swallows the areas around cities, planners are looking for alternative methods of development that help to protect and preserve the environment, enhance the lives of residents, and help reduce the skyrocketing costs of maintaining sprawling infrastructure. Green Infrastructure (GI) planning principles have gained in popularity due to their holistic nature and ability to balance preservation and development. A GI plan seeks to identify the critical "green" infrastructure in an area (the environmental resources that we rely on for clean air and water) and proposes complementary development strategies. One plan component of particular interest is the analysis of the hydrologic network, since it is water quality that drives many ecological and environmental planning issues. Over the last 30 years, riparian buffering has emerged as an accepted best practice for the protection and restoration of sensitive hydrologic features.

When creating a GI plan, the power of geographic information systems (GIS) is leveraged to help organize, analyze, and display the large datasets needed to synthesize the plan components. The plan components can be quite complex, and the need for solid, well-defined methodologies is great. In response, this thesis proposes a data model that defines the database structure and attributes needed for hydrologic network conservation analysis, based on research conducted during the creation of the Beaver Creek Watershed Green Infrastructure Plan in Knox County, Tennessee. The analysis methodology and some common hydrologic feature buffer practices are described. The specific methods chosen for this project are detailed and a geoprocessing model that generates the datasets necessary to visualize the hydrologic network buffers is presented.

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Chapter 1   Introduction

As long as humans have been living together in communities there has been infrastructure. In its most basic meaning, infrastructure is simply the foundation on which a system or organization is based. Webster also defines it more specifically as the system of public works of a country, state, or region; or the resources (as personnel, buildings, or equipment) required for an activity. This system, however primitive in the past, is the essential physical framework we have developed to support our daily activities. As populations have grown, so have our needs, namely, the need for this structure to continually provide connectivity and the services we demand now and in the future. This system of "gray" infrastructure is a concept that most people are aware of, if not by name, then by function. It consists of our roads, sewers, electrical utilities, communication networks, and structures of all types and uses.

This "gray" infrastructure that we rely on is the product of hundreds of years of growth and development. It is a large and complex system that requires constant attention and maintenance to keep it functioning smoothly. It is an interconnected system in which the components often rely on one another in order to perform their functions. For example, in order to keep roads functional when it rains, there must be adequate drainage provided by a storm sewer system. Infrastructure is usually associated with assets that are in continuous use over the long-term and due to their interconnectivity, individual assets can be difficult to repair or replace without affecting the entire system. This high level of interconnectivity, the high costs of construction and upkeep, and the

provision of public services make gray infrastructure necessarily a framework that is planned, organized and maintained by the government and funded by the people.

We rely on our gray infrastructure in some way every day: getting to work and school, communicating with each other, providing potable water and sanitarily disposing of our waste. What many do not realize, including planners and policy makers, is that there is also a critical "green" infrastructure, providing clean water, clean air and natural habitat for us and our fellow humans, upon which we also rely every day. However, ignorance of this critical companion to our gray infrastructure is becoming harder to maintain. As acres of land are gobbled up in our seemingly unceasing expansion into the hinterland around our towns and cities, people are beginning to notice the increase in intensity of "natural" disasters such as flooding, the continual degradation of the natural scenery, a staggering loss of wide open space and natural habitats, as well as the rising physical costs (in the form of taxes) of infrastructure maintenance coupled with a decrease in (or increased cost for) municipal services. This is, of course, an unsustainable situation and, increasingly, people at all levels in society and the government are calling for better management of our resources (gray and green) now and in the future. The goal is to make this transition in an informed and holistic fashion that takes into consideration our need to continue to grow and prosper while protecting the environment and maintaining quality of life for all. Our local governments and planning agencies are going to be the ones facing this challenge, and they need information, expertise, and tools to accomplish their goals of sustainable future development. Also, the term "infrastructure" itself implies a need, not an amenity. The fact is that properly

conserving and managing our natural resources is as important as keeping our roads paved and our utilities maintained.

Green Infrastructure

Green Infrastructure can mean different things to different people. Some organizations, such as American Forests, focus their definition on the importance of urban trees, while others focus on "green" structural applications for saving energy such as solar panels and green roofs. In keeping with the idea that new development and conservation ideologies should be more complete in their scope, several organizations and municipalities have made a more apt definition that mirrors in scope the gray infrastructure concept. For this project, I will use the definition coined by Benedict and McMahon (2002, 2006) of The Conservation Fund and adapted by DeKay and Moir-McClean (2006) for the Beaver Creek Watershed Green Infrastructure Plan. Green Infrastructure is an interconnected network of protected land and water that supports native species, maintains natural ecological processes, sustains air and water resources and contributes to the health and quality of life for communities and people. It is the natural life support system on which we all rely for clean air and water. This working definition outlines the major components of the Green Infrastructure plan and hints also at the nature of the analysis that will be needed to identify this interconnected network.

While conservation in general has been a hot topic in the last 30 or so years in the United States, most of the projects undertaken by cities and conservation groups have been ad hoc, single-purpose plans that don't account for sustainable growth and intelligent conservation. The ecologist Eugene Odum uses the example of forest

management increasing the number of trees, while wildlife management increases the number of deer, to the point that the deer graze down the seedlings. He suggests that it is time to "move up the scale" to more holistic methods of development and ecological management in order to avoid what he calls "the tyranny of small technologies" (Reimold 1998, p. xiii). Many conservation efforts have focused on individual parcels of land or bodies of water, with limited benefits to the whole environment and health of surrounding human communities. Experts have noted that it is the old system of development that continues to shape the manner in which decisions about conservation are made, such as the "preservation" of basically undevelopable land on steep slopes or in the floodplain, or creation of so-called "pocket parks" on unused parcels (Firehock 2007). That is not to say that individual or small initiatives such as "backyard" wildlife sanctuaries and public gardens to promote conservation and sustainability aren't productive; these are certainly useful in raising public awareness of green issues and getting people (especially young people) involved in the effort. But as a municipal plan, these piecemeal "solutions" to preservation are not going to be effective in the long term in providing the health benefits that a protected *system* of land and water can provide. Isolated goals tend to lead to isolated or even conflicting results. The key to Green Infrastructure planning is that it creates a systematic, multi-scale and multi-function plan that proactively addresses the most important environmental as well as human factors identified by the plan designers in an area.

Users of Green Infrastructure Plans

Local governments and planning agencies are the most common users of the information provided in a Green Infrastructure Plan (GIP). They are also often the providers of a large amount of the data used to create the plan. A GIP highlights protection of ecologically important land; the land that cleans our water and supports the trees that clean our air. Intelligent conservation is an increasingly important issue for governmental officials and the public, especially in areas facing heavy development pressure. Knox County is a good example of a rapidly suburbanizing metropolitan area that could (and should) be using a GIP to help identify areas for parks, open space preservation, and new corridors for greenways and blueways. Open space preservation and stream corridor preservation are known to be critical for mitigating flooding and maintaining healthy wildlife habitat. The GIP helps delineate the interconnected network of land of these sensitive hydrologic features and vital habitat corridors that need to be conserved while simultaneously identifying less sensitive areas where well-planned development can happen, thus preserving the character and heritage of the land while supporting the needs of a growing community.

Private landowners, land trusts and other groups should also be very interested in using Green Infrastructure planning principles. There are several federally sponsored programs designed to protect rural character by conserving large farm and grassland parcels. Within a Green Infrastructure plan, the habitat value of the land can be assessed and in turn, parcels can be ranked based on the size, quality and type of habitat that exists there. Concerned citizens and local leaders can then establish priorities for their land protection and restoration efforts.

The map products created for the plan, usually included in some sort of final report or publication, are also a vital component in a GIP. The ability to represent visually the interrelationship of lands in the Green Infrastructure network in a meaningful way is critical to justifying and acquiring funding for the purchase of easements and parcels that will help form the backbone of the network. Showing how parcels fit together spatially within an ecological landscape context is the key to making a Green Infrastructure network tangible to the average citizen. In other words, the case for conservation has to be made to the public in an understandable way, the same way any marketer has to advertise and promote a product, and maps are a key part of that marketing campaign.

Plan Component Development and GIS methods

In order for real planning decisions to be influenced by a Green Infrastructure plan, it must be based on good science, careful analysis and sound planning principles (Benedict and McMahon 2002). Using a GIS and "best practices" methodologies, planners and analysts can organize and process huge amounts of geographic data relatively quickly and easily to find solutions to complicated land use and planning questions. These problems may be in the form of an impact assessment for a proposed development, or documenting changes in land use over time to suggest updates to municipal zoning plans. Most major metropolitan areas have some sort of GIS group that manages and updates the spatial data for that municipality and a planner will usually have access to these datasets. What is not available digitally can be digitized or may be generated using GIS tools and publicly available data such as sinkhole delineation from a

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digital elevation model. Some of the more specific advantages of a GIS are its ability to be: 1) flexible and work at multiple scales; 2) use diverse data formats; 3) manage large datasets; and 4) complete complicated analysis tasks through geoprocess modeling. GIS is an invaluable tool for Green Infrastructure planning because it allows the user to integrate the sometimes disparate aspects of the plan and create a truly interconnected and functional analysis in which the components can be viewed together. Creating a complete picture that identifies these critical components is an important first step in facilitating the discussions among decision makers necessary to begin to create or update ordinance and synthesize a plan that integrates conservation and sustainable future development.

The first step in planning is making an assessment of the current situation. For the last 20 or so years, many metropolitan areas have made great strides in gathering and organizing vast amounts of geospatial data. What probably began in many places as a modernization of tax and property records has become a comprehensive system to store, analyze and distribute data covering many themes in the municipality. Many of these data are concerned with the aforementioned gray infrastructure, due mainly to the fact that many of the digital datasets were compiled from paper maps detailing the various components of that municipality's revenue generation through property taxes, utilities and other services, and general record keeping. The tax/property assessor, the public (water) utility, the transportation department and others maintained paper versions of the maps that documented the location and information about the entire built infrastructure of the city. Now, this information is digital and available to local planners for use in analysis of current conditions and for future development, but these datasets alone are not

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enough to tackle the planning problems facing a city. Often, they are of varying spatial and temporal scales, compiled from different sources, of questionable accuracy and/or origin, and may not be complete or up-to-date. These issues have to be taken into account when using such datasets, and usually compromises have to be made in order to make the best use of the readily available data, such as generalizing detailed data to match the scale of a comparable dataset in order to get complete coverage of a study area at an acceptable level of detail.

Another consideration is that the datasets commonly available in municipal GIS may or may not cover environmental themes, which are critical in creating a comprehensive GIP. There will certainly be data concerning some of the most pertinent surface systems, such as streams and swales, due, in part, to their relationship with the transportation network or public utilities, but not necessarily other important topics such as existing land cover or the locations of sensitive environmental features such as wetland areas and natural springs. Development and/or acquisition of these datasets is an important part of setting up the comprehensive database(s) upon which modern planning analysis needs to be based on in order to institute best practices. Today, there are many publicly available resources that can be acquired or derived that cover some of these important environmental themes, such as National Land Cover Database (NLCD) uniform land cover classification data or Federal Emergency Management Agency (FEMA) detailed flood study analysis maps.

Beyond the data that are necessary to undertake a comprehensive analysis, planners need the geospatial analysis tools and data processing techniques and data structure with which to work. Since the idea of more integrated planning methods such

as Green Infrastructure principles have come to light, the need for development of analytical best practices and tools to help visualize the implementation of these guidelines has become great. Synthesizing the geospatial components of the framework for a comprehensive plan is a daunting task, even for a group of experts, so having a template framework and sample tools for assisting in the process of making a preliminary investigation into the nature of the impacts of such a plan can be invaluable. Best practices on various topics that have been researched and designed by experts in a particular field can give guidance and take some of the guess work out of the more technical aspects of a plan component, such as inventorying habitat and ranking it for conservation. A data model, which defines the data structure, and associated geoprocess models, which describe the functions within the analysis to be performed, can give insights into the type, scope, scale and quality of the geospatial data needed to create the various "building blocks" of the plan. These tools are also flexible in design and can often be modified relatively quickly to work in different situations with customized attributes, inputs and outputs, usually corresponding to lower costs and faster initial results.

Of course, the true power of GIS analysis is limited by the knowledge of the user. Often, planners are limited in their ability to create and analyze the datasets necessary to create a Green Infrastructure plan because of a lack of practical knowledge of the process and components of the plan. It is important to get the right project setup and goals identified before commencing with the analysis. Again, having some solid, well-documented sample data models and geoprocessing tools to work with is going to be the best place for those new to the Green Infrastructure approach to get familiar with the

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process and the tools. In the end, having the appropriate datasets and a sound set of

principles and planning guidelines, and the tools to do the analysis, a comprehensive

Green Infrastructure plan can be developed that will be useful in informing future policy-

making decisions.

Case Study Area and Data Models

An important factor in creating a meaningful Green Infrastructure plan is to

choose a study area that is easy to define and collect data for. In many cases, the

watershed is a functional and convenient unit to work with, due to the significance of the

hydrologic network as a surface system to the overall GI plan, and the fact that it can be

delineated rather easily. Watersheds are connected ecologically by their hydrologic

network and the people living in them are often connected culturally (and historically)

due to the physical boundaries that define the area. In the case of Beaver Creek in Knox

County, the watershed is significant for several reasons. First, it is the largest watershed

in Knox County. It is entirely contained within the borders of the County, facilitating the

acquisition of uniform base data. Beaver Valley is also developing rapidly and virtually

unchecked, sprawling into previously undeveloped agricultural and forested lands,

increasing the amount of impervious surfaces that contribute to more frequent and

intensive flooding and nonpoint source pollution. Finally, the watershed is listed by the

state as having water quality too poor to support its designated uses, and some reaches are

in dire need of protection and rehabilitation (Moir-McClean and DeKay 2006). See

TABLE 1.1. Further discussion of the character of the Beaver Creek watershed and the

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specific hydrologic issues addressed in the Beaver Creek Watershed GIP can be found in Chapter 3.

A data model and associated geoprocessing models are the key components to the research carried out for this thesis. But what is a data model? What is gained by defining geoprocess models? GIS applications are known to be of great value when it comes to the representation and analysis of geospatial data. But as GIS software has become more powerful and the number of possible operations have grown, the complexity in practice of many analysis processes has eclipsed the practical knowledge of a lot of users. A model provides an abstraction of the data and processes defined within this complex system, which in turn allows for the simplification of ideas communicated within the model so they are easier to understand by all who need to use them, from professionals to the less-informed public who may have a need to grasp what is being presented (Batty 2005). In many definitions of modeling, future prediction or reduction in uncertainty about a process is usually a key component. But there are other reasons to model as well. In developing a data model and associated geoprocess models and applying them to an analysis project such as a GIP, the models take on the role of formalizing the thinking behind the concepts or specific components of the plan (Goodchild 2005). This is where the value of the model lies: it allows people to communicate in terms that are mutually understood (because the software environment in which the data and process models are based is the same for all its users) and it shows a clear and replicable method in spite of the complexity of the process. The other goal of data and geoprocess modeling for the GIP is to create a knowledge base.

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Table 1.1 Summary of issues and potential responses regarding water quality in the Beaver Creek Watershed (after Moir-McClean and DeKay 2006). These issues drove the analysis conducted under several components of the BCWGIP, not just the Water Network component, such as the farm and forest preservation that were covered in the Open Space Network component. The starred items are responses whose major spatial implications are identified by the Water Feature Network Protection model. Derivative data generated by geoprocessing of the Water Feature Network Protection model datasets were used in the synthesis of other responses, such as the identification of locations for proposed conservation neighborhoods.

Issue	Potential Response
Flooding in the Watershed 　Property damage 　Potential loss of life 　Reduced property value and property use	***Conserve land that mitigates flooding, through:** 　Farm and forest preservation 　Conservation neighborhoods 　*Protecting and reforesting floodplains 　*Protecting sinkholes and high-infiltration soils **Reforestation Anywhere in the Watershed**
Degraded Water Quality 　Silt and Erosion 　Pathogens 　Nutrients (fertilizers, etc.) 　Toxins (potential) 　Aquatic Habitat Impacts	***Relocate Conflicting Floodplain Activities,** 　such as those whose runoff needs special cleanup ***Protect and Restore Riparian Forests** 　along Beaver Creek and its tributaries ***Establish Vegetated Filtration Buffers** 　on streams and upland water features
Worsening Problems Due to New Development 　Increased impervious surfaces, thus runoff 　Needless removal of vegetation	**Promote Low-Impact Development Practices** 　that minimize impervious surfaces, slow runoff, filter 　water on-site, and increase local infiltration **Fit Development Intensity to Infiltration Capacity** 　Limit development on high-value conservation land 　(floodplains, headwaters lands)

In other words, I am taking existing knowledge and organizing and analyzing it to apply that knowledge to helping solve real policy questions pertaining to development in the watershed. In this sense, the data model is a formal representation of what is known about the Beaver Creek watershed, and this representation along with the associated geoprocessing methods was instrumental in the synthesis of new ideas by the Beaver Creek Watershed Green Infrastructure Plan (BCWGIP) designers for suggesting sustainable planning practices. Furthermore, Goodchild (2005, p. 15) states that "tested, operational models are among the most valuable forms of digital information since they encapsulate a wealth of practical and scientific knowledge in an easy-to-use form". He also notes that it is surprising how much effort has gone in to the development of huge amounts of data, digital libraries, and data sharing mechanisms, while very little has been done to expand the knowledge of methods for data use (geoprocessing) and modeling.

To illustrate the concept of a data model and geoprocess modeling within a GIS environment and its use in a GIP, I will use the Beaver Creek Watershed Green Infrastructure Plan as a case study. The Plan was part of a larger effort by several local government and community groups to address environmental and developmental concerns in the rapidly suburbanizing Beaver Creek watershed located in Knox County, Tennessee. In this study, published in 2006, conservation scenarios designed by Tracy Moir-McClean and Mark DeKay of the University of Tennessee College of Architecture and Design based on Green Infrastructure principles drove the development of GIS geoprocessing methods to synthesize the map components necessary to analyze the current condition of community development, habitat and open space, and the hydrologic network. These map components, created by geoprocessing data from various civic and

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federal sources, were plotted and studied and a set of new maps showing potential future scenarios for the watershed's conservation and development were created. These maps were accompanied by additional illustrations and a detailed write-up and published in a report, which was submitted to the County for consideration in future planning decisions. I was responsible for organizing the datasets and helping develop the data processing methodologies for several components of the plan's analysis of the Green Infrastructure in the watershed. In the following paragraphs, I will use "we" to refer to myself and Professors Moir-McClean and DeKay. In this thesis I will be discussing the analysis of the hydrologic network in which we identified sensitive features and suggested a system of buffers, based on established best management practices, to protect those areas. The basic concept behind this system is a system of concentric buffers, divided into three zones: edge protection (undisturbed), conservation (managed uses), and stewardship (runoff control) (Welsch 1991; Brenner 1998). See **FIGURE 1.1** and **TABLE 1.2**. After the project was completed, it was my goal and the basis for this thesis to create a data model that identifies the datasets and attributes necessary to perform the associated geoprocessing tasks which replicate the processes we developed for hydrologic network protection buffers. I also plan to develop a geoprocessing model to define the method we used to create the derivative data that became the footprint of our suggested hydrologic feature protection areas. This is being done in the interest of having a well-documented and repeatable method for organizing the data and creating the buffer protection system suggested by the report, and storing the knowledge and experience gained during its development in a form that can be widely disseminated.
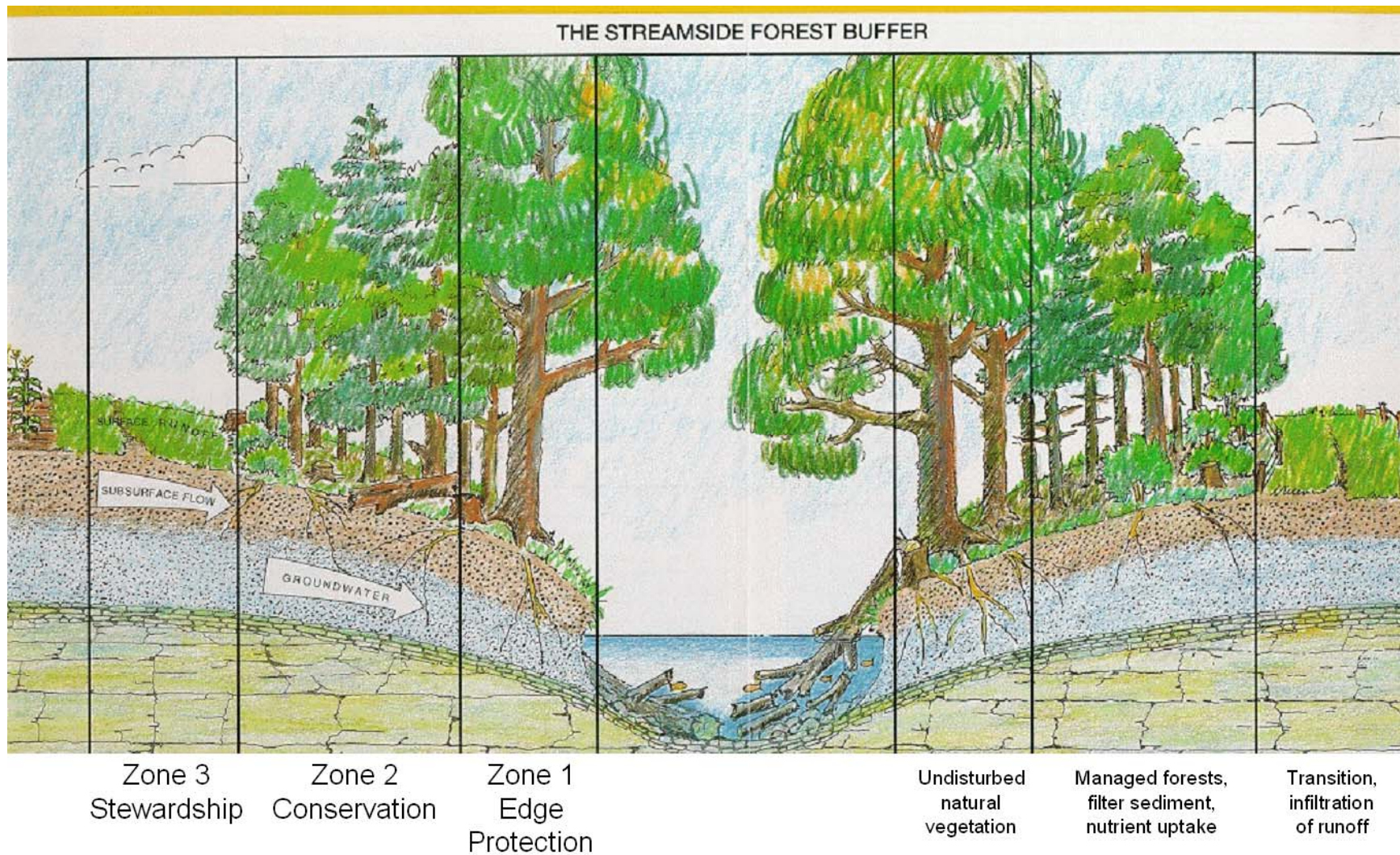
Figure 1.1 Conceptual drawing of the three zone riparian buffer system. Popularized by D. J. Welsh in the early 1990s, the zoned approach to preservation of riparian areas has emerged as a best practice for protecting and restoring the sensitive interface between terrestrial and aquatic habitats. Each zone has ecological functions as well as human benefits, such as pollutant filtering and flood mitigation. (Welsch 1991)

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Table 1.2 Sample of buffering BMPs identified during the planning stages of the BCWGIP for different hydrologic features, divided into EPA-recommended three zones. These buffer requirements became the basis for setting up the data and geoprocessing techniques necessary to build the Water Network Protection component of the plan. Adapted from unpublished research notes. (Moir-McClean 2004)

A. STREAM Buffer   ZONE 1: *Stream-Edge Protection*

IDENTIFY ZONE 1: STREAM-EDGE PRESERVATION		
1. *Identify* MINIMUM REQUIRED WIDTH for ZONE 1		
	Source/ Measure	*Output*
measure perpendicular from *FEMA FLOODWAY*	TN MS-4 Working Group (suggested) Buffer: Floodway (or stream) + 25'	*Zone 1: Edge Protection*
2. *Search* for SENSITIVE FEATURES and IMPACTS near Stream		
	Source/ Measure	
	Search Area: Floodway + 75' *for* wetlands, springs, sinkholes, steep slopes (no source for 75' EPA: 1,000' search hazards near source waters)	
3. *Add Buffer to* SENSITIVE FEATURES and IMPACTS near Stream		
	Source/ Measure	*Output*
a) Springs	Florida wellhead protection ordinance for drinking sources establishes a 500' radial setback around a potable well includes surface and subsurface area protection. –dividing this into the EPA '3 zones' **Zone 1: 25'** Zone 2: 450' Zone 3: 25'	*all land lying between spring zone1 and sinkhole zone1also becomes zone 1 buffer*
b) Wetlands	TN MS-4 Working Group (suggested) extent of wetlands +25' perpendicular to boundary	*zone 1*
c) Sinkholes	Catchments not available – so can't implement catchment-based rules - 'next best' strategy use: TN MS-4 Working Group suggestions for stream WQ –thus Zone 1 rule becomes area of sinkhole + 25' perpendicular to rim	*zone 1*
d) Steep Slopes	TN MS-4 Working Group (suggested) 15%-24% area of steep slope + 20' 25%+ area of steep slope + 50'	*zone 1*
4. *Add* *buffered* SENSITIVE FEATURES and *buffered* IMPACTS *to ZONE 1*		
	Source/ Measure	*Output*
Springs Wetlands Sinkholes Steep Slopes	min. Zone 1 buffer + + sensitive feature areas + sensitive feature buffers = ZONE 1	*Zone 1: Edge Protection*

STREAM Buffer   ZONE 2 *Conservation*

IDENTIFY ZONE 2: CONSERVATION		
1. *Identify* MINIMUM REQUIRED WIDTH for ZONE 2		
	Source/ Measure	*Output*
measure perpendicular from **ZONE 1 Boundary**	EPA (suggested) Zone 2: 50 first or second order 75 third order or larger	*Zone 2: CONSERVATION*

STREAM Buffer   ZONE 3 *Stewardship*

IDENTIFY ZONE 3: STEWARDSHIP		
1. *Identify* MINIMUM REQUIRED WIDTH for ZONE 3		
	Source/ Measure	*Output*
measure perpendicular from **ZONE 2 Boundary**	EPA (suggested) Zone 3: 25'	*Zone 3: STEWARDSHIP*

A discussion of buffering BMPs used in the GIP for riparian and other sensitive hydrologic areas can be found in Chapter 4.

A data model is usually disseminated in the form of a conceptual diagram that describes the structure, attributes, and relationships the datasets have with one another for the purpose of spatial analysis, as well as an empty "shell" geodatabase that can be populated by the user. See **FIGURE 1.2**. In my thesis, the diagram is derived from a geodatabase that has been physically constructed in ESRIs ArcGIS software package component ArcCatalog, which is designed for managing geographic data and data structures. The geoprocess model I created was developed using ModelBuilder™ process diagrammer for ArcToolbox geoprocessing tools, which is also part of ArcGIS. ModelBuilder is a software application that allows for the visual organization and linking of individual datasets and operators to create new software in the form of a geoprocessing model. See **FIGURE 1.3**. To use ModelBuilder, you drag-and-drop tools from ArcToolbox as well as datasets from ArcCatalog and chain them together in a logical sequence to build what is essentially a process flow chart. The model is then executed and the resulting dataset(s) can be displayed and analyzed in ArcMap.

For each GI plan component, scenarios were developed to identify the land that was important to it. A set of criteria were determined to identify this important land using GIS data and geoprocessing methods. From the datasets we collected during the initial stages of the project, we selected those that would help identify these areas and then formed GIS methods to process those data and produce a representation of that plan component. From there, these processes were tested, the results analyzed, and modified if necessary.

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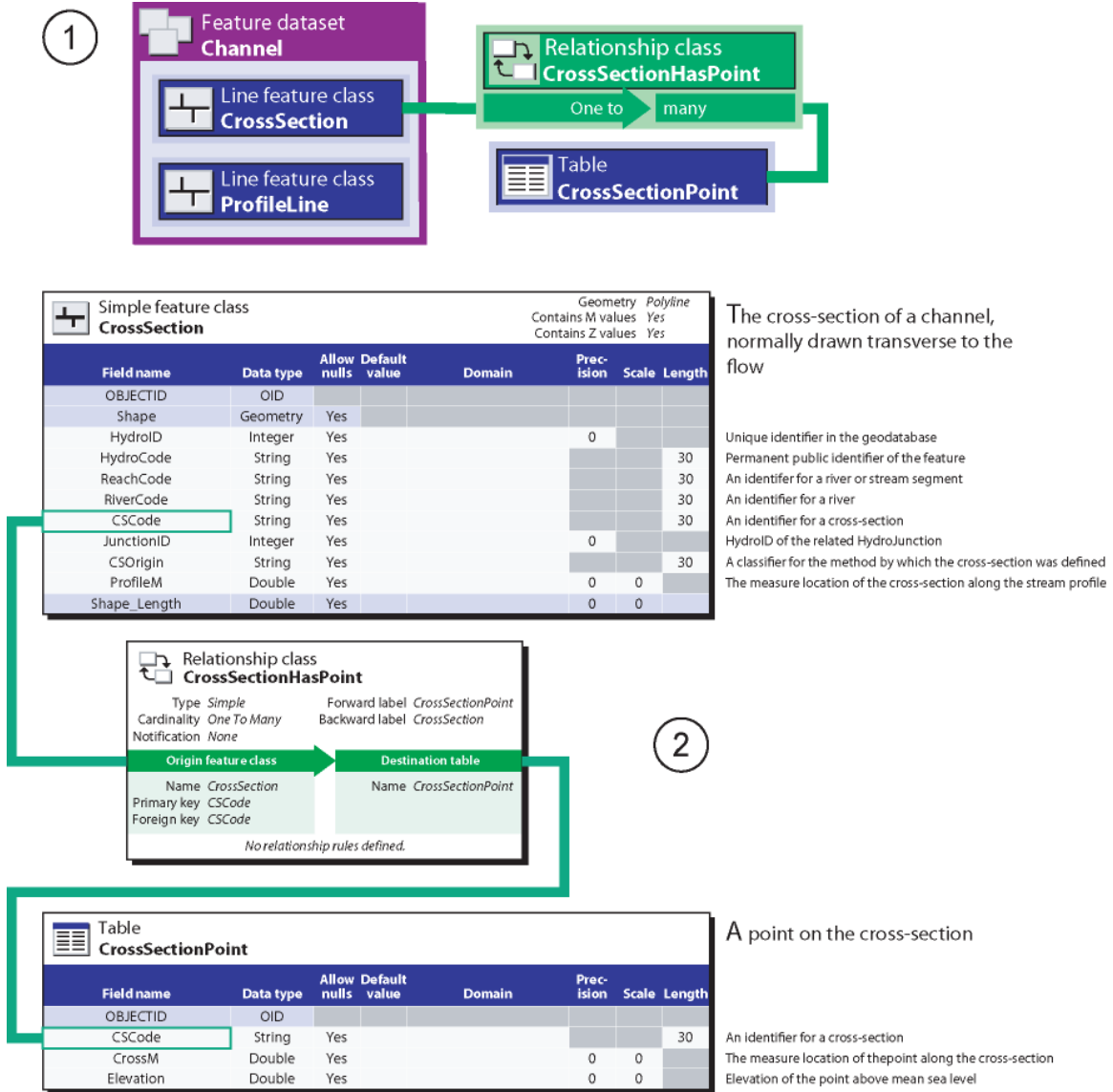
Figure 1.2 An excerpt from the ArcGIS Hydro Data Model as an example of a model diagram. 1) Shows the feature dataset name (Channel) and feature classes with topological type (line), along with a relationship from the CrossSection class to an attribute table. 2) Shows the details of the CrossSection class: the attribute definitions, and the details of the type, direction and destination of the relationship class to the attribute table. The feature classes and attributes are also given text descriptions to help identify their purpose within the model. (ESRI 2003)
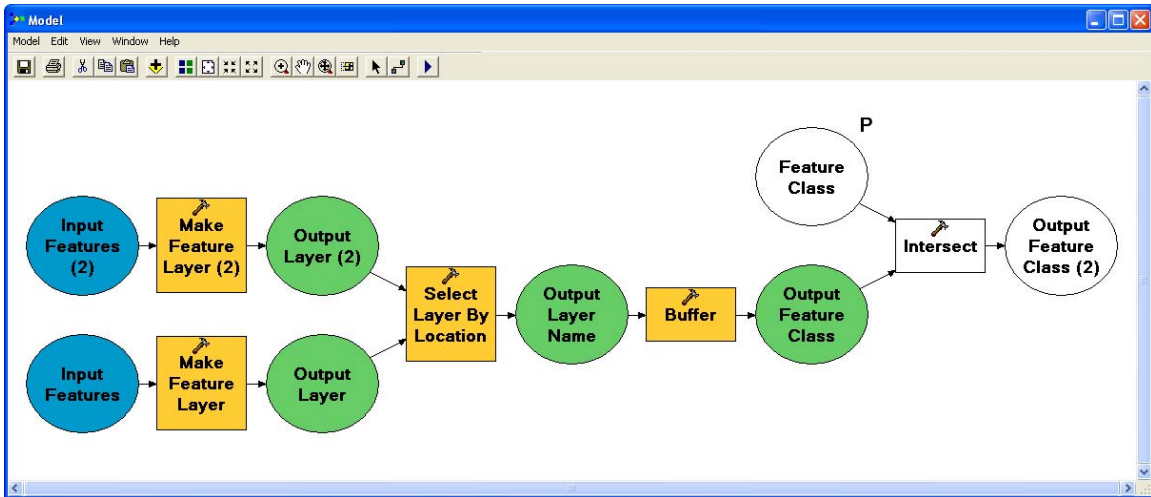
Figure 1.3 A sample ModelBuilder geoprocessing diagram. Model inputs (blue) are linked to operators (yellow) which perform a geoprocessing function (e.g. "Buffer") to create outputs (green). The outputs from one operation can be fed into the next to continue the geoprocessing. A white operator in the diagram (e.g. "Intersect") means that one or more necessary parameters ("Feature Class") has not been defined. This is often the case with parameters that are user-defined (P). The output will remain undefined until the user selects a feature class at run-time, at which point the model will validate and execute completely.

Once a component had been satisfactorily defined and the process for creating the spatial representation was established, the results were plotted, analyzed and joined with other components to help synthesize the pattern of land that became the basis for the proposals for development and conservation priorities in the watershed. After the BCWGIP was published, I began the task of designing a data model for each component of the plan and creating an associated geoprocessing model that replicates the analysis done within that component. I settled on the Water Network component as the best example of how to develop a data model and associated geoprocessing model that replicates the data design and processing methods used in one of the most critical components of our (or any) Green Infrastructure plan.

The hydrologic feature protection data and geoprocessing models are based on the Water Network plan component of the Beaver Creek Watershed GIP. The goals of the water network protection component were to: 1) understand the existing condition; 2) identify the sensitive features in the network needing protection; 3) identify the best strategies for implementing protective measures for those features; and 4) identify priority areas of the watershed for protecting water quality and mitigating flooding (Moir-McClean and DeKay 2006). In broad terms, the importance of the data and geoprocess model development was reinforced by the findings of goal 1, namely impaired water quality, increased flooding, and degraded habitat. The geoprocess model I created generates the spatial representation of goal 4, guided by goal 3: identifying the areas that contribute to increased water quality and flood mitigation using best practices. In order to accomplish this task, the data model is based on part 2, where the datasets necessary to complete the analysis are identified. The geoprocess model uses as its inputs the features

identified for protection in goal 2 (such as the streams, wetlands, sinkholes, and springs) that are included in the data model, and implements the strategies identified in goal 3 in the form of the selection and buffer tasks performed by the geoprocessing model to create spatial representation of the buffer zones. **FIGURE 1.4** illustrates the concept of the three-zone buffer in map form. A more detailed discussion of the specifics of the Water Network component in the BCWGIP and the development of the data model, its parameters, design, and execution of the geoprocessing model can be found in Chapter 5.

Summary of Research Focus

This thesis has several goals. The first is to discuss some of the important issues associated with GIS analysis for a Green Infrastructure Plan. The second is to focus on one critical aspect of the Green Infrastructure Plan: the hydrologic network protection analysis. The most common riparian buffer methods are discussed and the specifics of the methods chosen for this project are described. The third is to present a data model that defines the structure and attributes needed for this analysis. In conjunction with the data model, a geoprocessing model that replicates the methods designed for the water network analysis component of the BCWGIP is presented. The original process will be supplemented and updated with new data and improved methods for the delineation of the hydrologic feature buffers that were not available at the time the original analysis was carried out. Finally, I will compare the final results of my improved modeling method and the results of the original BCWGIP analysis.
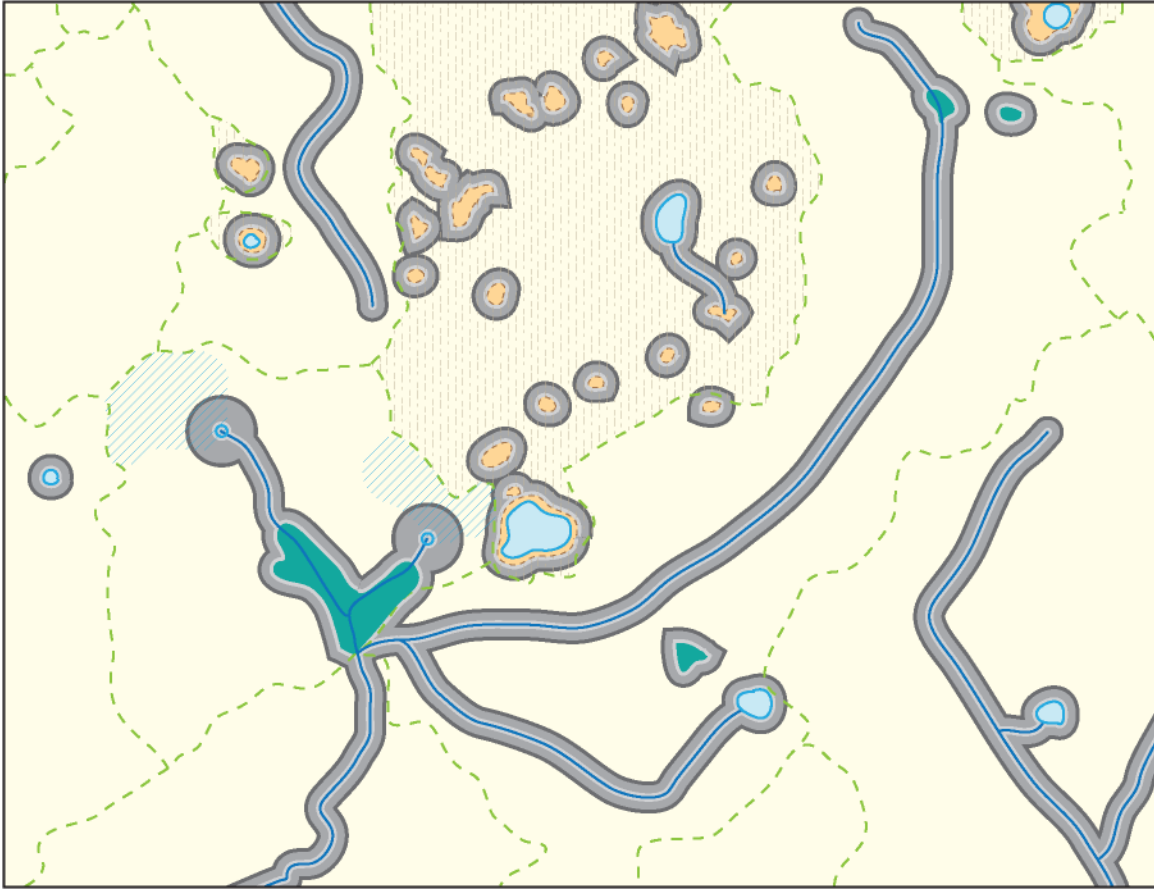
Figure 1.4 Conceptual diagram of a zoned hydrologic feature buffer system. The streams (dark blue lines), springs (blue open circles), water bodies (light blue fills), wetlands (blue-green fills), and sinkholes (tan fills), are buffered linearly with a three-zone system (similar to the BCWGIP). Like features are buffered the same distance on each side (line) or along the outer edge (polygon) and the buffers combine to form a composite buffer zone. The green dashed lines are the sub-basins that form the watershed. Brown hatchings indicate a sub-basin that is drained by sinkholes. Blue hatchings indicate surface area that drains to a spring location. These additional data, along with floodplain, slope, and soil data, can be used to advance the methods used and enhance the buffers.

Additionally, I will relate some of the most important lessons learned during my experience in designing and researching the development of the data and geoprocessing models for this thesis and make some suggestions for future development of GIS analysis methods for GI planning.

Chapter 2   Green Infrastructure and GI planning

Since the start of the BCWGIP project in 2004, there has been a surge in the popularity of Green Infrastructure (GI) principles and their implementation in planning projects. As the amount of documentation regarding the subject has increased and helped to flesh out the definitions, uses, and implications of using GI principles in real-world planning applications, it has also become more clear what the defining principles of Green Infrastructure and GI plans should be. Green Infrastructure is an interconnected system of protected land and water that supports native species, maintains natural ecological processes, sustains air and water resources and contributes to the health and quality of life for communities and people (Benedict and McMahon 2002). It is a development strategy born from the realization that our current sprawling development pattern is unsustainable and unhealthy and needs to be addressed with progressive and holistic approaches to our future growth (Firehock 2007). A working definition of GI, along with a few other key principles, make up the core of what an effective Green Infrastructure plan (GIP) should address. The next few paragraphs will summarize the important principles of Green Infrastructure plans from the most recent and currently available literature on the subject. All of these principles were also leveraged in the creation of the Beaver Creek Watershed GIP.

While the term "green infrastructure" is relatively new in the vocabulary of planners and developers, the basic concepts behind the major principles of GI are not. The ideas of connectivity and the interactions between humans and the environment are two of the most basic and important in geography. The emphasis of GI on ecological

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stewardship and sustainability can be traced back to the earliest planners of cities and their understanding that parks and open spaces in urban areas were essential in improving the health of and interaction between humans and nature. In more recent times, the concepts of Landscape Ecology and Urban Forestry have emerged. Landscape ecology is a discipline that takes a multi-scaled view of human and natural influences on the development and planning of landscapes (Davies *et al.* 2006). Urban forestry is a broad term that covers everything from street trees and wooded urban parks to suburban or urban fringe forest management (Davies *et al.* 2006). These concepts have helped to re-establish some of the more traditional ideas of conservation and renew them in the form of academic discipline-based concepts that can be applied by professionals to resource management. The most recent developments have been community forests and the greenway/blueway movement, in which many local and state governments and eco-groups have cooperated to try and build a system of linkages between urban fringe forests, parks and open spaces, and waterways (mainly for recreational benefit) and in doing so have begun to create the backbone of what might become a larger, more well-defined network of green infrastructure (Davies *et al.* 2006). All these concepts are still important in guiding new thinking about conservation and sustainable development and were critical in influencing the development of green infrastructure principles.

Multi-functionality is also one of the key principles of a GIP. In other words, the benefits of a GIP are not related solely to one aspect of the landscape or another or to one community's development or one vision of the future. Green Infrastructure plans should address issues such as: 1) the aesthetics of development, i.e. the type of development pattern planned for an area should be appropriate and of good quality; 2) the potential

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conflicts with existing land uses and dealing with the impacts by suggesting solutions; and 3) the viability of GI in that the plan must be attractive in principle and sustainable in practice (Davies *et al.* 2006). This concept of multi-functionality is also illustrated by the flexibility of the GI planning process. It allows the same principles to be applied in different areas and to different degrees based on the need of the community and the environment, as defined by the plan designers. Less-flexible methods of land use planning, such as traditional zoning, have resulted in development that is out of context within the landscape or doesn't resonate with residents, which one could say makes it unsustainable ideologically, not to mention environmentally.

At its core, a GIP should be a strategic approach to land and water conservation that links lands for the benefit of nature and people. It should help the community identify conservation priorities, and provide planners with a framework on which conservation and development decisions can be based (Benedict and Drohan 2004). Identifying the various networks is one of the most important parts of creating a GIP. The ecological network that GI seeks to protect is that critical zone of open space, riparian corridors, and ridge tops that give wildlife a safe and healthy environment in which to thrive by reducing unnecessary habitat fragmentation, which is damaging to many species, and preserving and even enhancing biodiversity. These areas also provide necessary (and valuable) cultural and ecological services. Open space (grasslands and pastures), forests, and working farms provide local economic benefits by sustaining natural resource-based industry as well as preserving rural heritage. Likewise, natural filtration and flow of water in forested riparian areas and floodplains saves municipalities money on storm water treatment and flood mitigation projects. For example, New York

City found that the cost of purchasing and protecting watershed land in the Catskill Mountains (green infrastructure) was less than one quarter the cost of developing and building water treatment facilities (gray infrastructure) that could treat the same amount of water (McMahon 2000). These networks also provide communities opportunities for recreation by linking parks and open spaces. Some communities along the Mississippi River have saved taxpayers millions of dollars in flood damages and disaster relief by purchasing some of the properties most at risk in the floodplain and returning those areas to a more natural state while adding greenways for the residents to enjoy (Benedict and McMahon 2002).

The Green Infrastructure ideology is fundamentally different from conventional approaches to conservation because it can be used to help assess the *monetary* value of conservation efforts and actions as they relate to the costs of traditional infrastructure (McMahon 2000). It is a system in which land development and growth management are handled *in concert* with conservation efforts: planners can identify land that should be preserved or restored or have its use changed based on the context in which the land exists in the real world, while simultaneously delineating areas that are appropriate for development or redevelopment. This is not a conservation plan that seeks to stop all human activity to preserve a specific species of bird or piece of land, nor is it a mitigation plan used as a ploy by developers to foist an unsustainable development on the public. This is truly a new approach whereby the realities of our needs to protect our natural resources while continuing to grow and prosper are addressed. No longer do outdated zoning and land use control practices have to guide new development, nor do we have to earmark haphazardly land for protection just because it's there. In the end, the

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identification of areas to be protected and those to be developed should really be the most important part of any comprehensive planning effort, and when planners and policy makers implement GI principles in their designs, this goal can be achieved. While it is outside the scope of this thesis to propose a system of monetary valuation of the hydrologic network or any other BCWGIP component, it is certainly a concept that can be modeled and assessments made using tools similar to those I am proposing.

While developing a GIP, the plan organizers need to be aware of all the players in the area, from potential developers to government officials to residents, because different people have different ideas of what is valuable to them. Green Infrastructure projects should bring public and private partners together to work collaboratively toward a common land conservation goal (Benedict and McMahon 2002). The more involved these parties get in the process of the plan development, the more successful and meaningful the plan will be. An experts panel with representatives from different levels and groups within the community can help transcend jurisdictional and political boundaries and often provide the means to gather the necessary human and data inputs for the planning process. Here in Knox County, the Beaver Creek Watershed GIP was overseen by a diverse taskforce made up of community representatives, government planners and engineers, parks and recreation managers, and water quality experts. Another necessity of the inclusion of these diverse groups is that the GIP will have to be tailored to fit into or complement the existing plans already adopted by a state or local government, such as a greenways plan or a water quality improvement plan (Firehock 2008). If these types of ancillary plans are not in place, the GIP can be designed to work as a guide for creating the ordinances that will form such plans which will function in

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concert with one another. An example of this concept in practice comes from the Maryland Green Infrastructure Assessment (GIA) completed in 2003. The GIA laid the groundwork for identifying the most critical lands for protection in Maryland. Now, state and local governments and private organizations can work with the Maryland Department of Natural Resources through the GIA and the state's various land conservation programs towards clear and common goals of protecting the most ecologically valuable and vulnerable lands. Several other Maryland programs, namely the Rural Legacy Program, Program Open Space, and GreenPrint program, are being coordinated to focus on the state's highest priority conservation lands, many of which were identified in the GIA (Benedict and Drohan 2004). This high degree of implementation indicates an acceptance and growing institutionalization of the GIA results in Maryland, and sets an example for others to follow.

Funding is another issue for Green Infrastructure planning. Since this type of planning is relatively new, many in government and policy making are not very familiar with the costs and benefits associated with GI. This makes it very important to try and educate policy makers and legislators at various levels within the state and local government about the benefits to their constituents as well as the cost savings in gray infrastructure maintenance and environmental impact mitigation of new development. The initial GI planning has costs, as do the conservatory suggestions of the final GIP. Some states, such as Maryland, Virginia, and Florida, have been earmarking funds for conservation and protection of water resources for years. Maryland's Program Open Space has been in operation for over 30 years thanks to the dedicated funding it receives from real estate transfer taxes (Benedict and Drohan 2004). Funding can also come in the

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form of grants and private monies, or from local governments seeking to develop greenway or park plans. The Beaver Creek project was funded through several sources, including Knox County Stormwater Department, Knox Land and Water Conservancy, the Tennessee Valley Authority, and the University of Tennessee, Knoxville (BCWGIP 2006). Securing funding for the initial analysis is necessary to get the plan off the ground, but continued funds for making the necessary purchases of easements and lands to flesh out the network and fulfill the goals set forth by the GIP is the greatest challenge facing those who wish to bring a plan to full implementation. Education about and promotion of GI planning brings it into the consciousness of the government and the people so they can appreciate the more immediate benefits it brings as well as the long term savings for the taxpayer.

While sound principles, the right team of experts, and adequate funding are important to creating an effective GIP, it is my opinion that sound science and well-designed methods based on best practices are the real key to making a comprehensive and defensible plan. This opinion is based on the fact that without a foundation in geospatial sciences, it is actually not possible to create a GIP. Many experts have seen the benefits of using powerful geospatial analysis for inventorying and analyzing all sorts of patterns and relationships of the landscape, and a GIP is just a focused extension of that idea. The availability of diverse data and the development of methods to process those data is at the heart of the GIP and what it tries to accomplish: namely the identification of the interconnected system of land and water that comprise the plan's "footprint". Geographic information systems (GIS) provide the computational environment and the tools to process geospatial data. A solid understanding of the tools plus the creation of

methods that implement those tools is as critical to the plan as are the plan managers and the funding that sustains it. GIS data analysis and the outputs form the core of a GIP and their influence on the results of the plan findings are critical. A more detailed discussion of the use of GIS in a Green Infrastructure Plan will be covered in Chapter 3.

Green Infrastructure needs to be a vital component of our future development decision making process. This type of planning is comprehensive in scope and aims to identify and protect the most important and ecologically sensitive areas while also providing a framework to identify developable land. The Green Infrastructure approach appeals to people concerned about biodiversity, habitat, and land conservation as well as people interested in open space and land use planning. It engages stakeholders at the community, region, or statewide level, and seeks the input and knowledge of local experts. It is interested in the quality of natural resources rather than solely on the quantity, and seeks to improve the diversity of these areas to better serve the needs of the community and the environment. It uses the latest geospatial analysis techniques to analyze and interpret vast amounts of complex data, and the results can be used to help form the basis for legislative and community action. It appeals to advocates of smart growth and sustainable development because of its potential to lessen human impacts and reduce the costs of building and maintaining gray infrastructure through informed development decisions.

GI planning: Plan Scale, Functional Analysis Unit, and Data Scale

When discussing scale and green infrastructure, map scale may be the first thought in many people's minds. But the "scale" of the plan should refer more to the

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level (or hierarchy) at which the plan is being designed and should be differentiated from the "map scale" that the plan data are designed for. They are of course related, but it is important to note the difference because the principles of Green Infrastructure are meant to be geospatially scale-independent. The plan principles can be seen as local in scope when it comes to affecting the development of a particular piece of land, but it is these implementations of plan principles to form GI units and the linkages created to foster interaction between these local units that form the spatial pattern (network) the plan represents at a higher level. So, the hierarchy can be defined, from lowest to highest, as: a) individual elements (parcels, neighborhoods, etc.), b) networks (cities, watersheds, etc.), and c) infrastructure (regions or "networks of networks") (Davies *et al.* 2006). Thus, the plan's scale is a function of the level at which the principles are to be applied. The plan will need to be augmented to meet more specific needs at a lower level (large spatial scale), or generalized to address regional concerns (small spatial scale). In this context, the Beaver Creek Watershed GIP can be viewed as a plan designed at the second level, since it was designed to identify the system of land and water that are of the highest value in the Beaver Creek watershed.

Since the level and area of interest that a GIP is designed to be used for is one of the first decisions that has to be made when beginning the plan, there will necessarily be constraints on the spatial scale at which the analysis is carried out, and decisions about the appropriate data sources will need to be made (which I will discuss later). Beyond the spatial scale and data conformity issues there is also the consideration of the *unit* of analysis within the study area. If the mandate for the plan is to cover a state, counties might be an appropriate analysis unit. If the plan is for a county or large city, it might be

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more meaningful to look at the analysis in terms of a collection of ecologically functional units, such as watersheds.

Watershed as an Analysis Unit

Ecosystems are composed of all the organisms (including humans) living in them and their habitats. But an ecosystem may be hard to define geographically since it rarely has finite boundaries. A watershed can be thought of as being composed of a network of ecosystems. The floodplain in the valley bottom connects to the forested ridges that bound the watershed by way of the open spaces and riparian corridors that cross the valley. Also, the watershed is usually easy to delineate geographically, making it a landscape unit ideal for resource management. The ecologically important factors that make and keep a watershed healthy can easily be linked to the primary principles of Green Infrastructure. Watersheds include the surface and groundwater, soils, vegetation, and animals, as well as humans and our impacts (Reimold 1998). These all fall under one part or another of the landscape that GI plans seek to protect and manage. Being an ecologically functional unit, watersheds can be broken down further into subwatersheds for more detailed analysis, or agglomerated with neighboring sheds for a broader study. That is a great benefit of the watershed as a geographical base unit in a GIP: once the plan objectives and methods have been worked out and executed at the watershed level and the results checked, those methods can be simplified to a work at a higher level, or expanded and executed with more detailed data on a local level.

This scalability of the Green Infrastructure methods also makes them a good choice when funds are only available for an exploratory or pilot assessment. A well-

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crafted plan on a pilot study area, such as a single watershed within a county, can be a crucial step to helping educate those decision makers responsible for continuing funding for developing a plan that covers the entire area, perhaps as part of a comprehensive county master plan. By the same token, a plan that has been developed to cover an entire state or large basin (such as the Chesapeake Bay watershed) can be enhanced with additional or more detailed methodologies and data sources to target specific conservation and/or development goals at the local level (larger spatial scales).

Data Scale

In a GIP, once the analysis unit for the project has been determined, the spatial scale of the data for the analysis will need to be determined. As with any geospatial analysis, choosing an appropriate scale at which to work is probably as important as knowing the extent of the analysis. A GIP may cover a town, a water conservation district, a county, a region, state, or multiple states. To be clear: the area covered by the plan will be important to selecting the scale at which the analysis methods will be developed, but there is some flexibility. The main factor to consider is the uniformity of the data being used to carry out the analysis. The scale at which the most data are available may become the scale at which the analysis has to take place. Suppose, for example: a GI plan is to cover a small county which is comprised of about 20 USGS topographic quadrangles. Hydrologic data for the more rural quadrangles in the county are available, but data at the same scale for the urban core are unavailable and would need to be digitized from existing maps, in turn increasing costs. This kind of issue may mean that data from a different source or at a smaller scale will have to be used to

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complete the analysis, which may effect the methods used. Similarly, a GIP may cover an MSA comprised of an urban county and the five counties that surround it. Detailed five-meter resolution land cover data may be available for the urban county, but such detailed analysis has not been carried out for the less-developed surrounding counties. The only uniform data available are the National Land Cover Dataset at a resolution of 30 meters. In this example the methods may have to be modified to work with the coarser data, or planners will need to develop a method that will yield meaningful results if the datasets were to be integrated with one another. These kinds of issues will be common in the development process of a GI plan and require some careful consideration.

Choosing the unit and scale at which a Green Infrastructure plan is designed is critical to the overall process. The plan's viability and defensibility depend on the use of data that are of an appropriate level of detail and of similar scale within a plan component, and that the components are of comparable scale for the purpose of combining them to find composite relationships. Also, within the GIS software used for processing the data, the analysis methods that are developed must be executed with appropriate parameters and with the right spatial environment options set so the results are accurate and don't compromise subsequent operations.

Chapter 3   BCWGIP Component Development and GIS Elements

Once a Green Infrastructure plan has been commissioned and the details of the study area and scope of the analysis have been defined, work can begin on designing the project. In a comprehensive plan like this, many aspects and details will have to be considered when designing the plan components. Green Infrastructure is the interconnected system of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks, and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to health and quality of life (McDonald *et al.* 2005). This definition is slightly expanded from the one used in Chapters 1 and 2, and for good reason. It is being presented here because it helps highlight some of the important features that the GI plan will need to address more specifically and hints at the data themes that will be required to do the analysis. So it is an appropriate expansion of the definition as it applies in this chapter which discusses the use of GIS to analyze data and generate the spatial representations that will be used to synthesize a complete Green Infrastructure plan.

Green Infrastructure plans are not all the same. Some choose to emphasize certain ecological aspects over others. For example, a plan may be based around urban tree canopy, or it may focus on a greenways plan, like the Charlottesville, Virginia GIP (Firehock 2008). A GIP could also be structured around stormwater treatment issues or habitat management. This type of focused effort might seem contrary to the holistic approach suggested by the experts, but it is important to point out that these are just

components that are being emphasized. The plans, if executed under the principles described in the previous chapter, will still encompass a full range of considerations and the final result will be a framework upon which better development decisions can be made. The reasons for these differences are varied, but generally, the plan components need to be structured in such a way that they take into account the important factors in an area. For instance, a Green Infrastructure plan created for an area along the Mississippi River is not going to contain a ridge corridor protection component as part of a larger open space initiative. These differences create a need to be flexible with the plan components while still achieving the same overarching Green Infrastructure principles. Generally, the plan should minimally address: 1) the value of existing green infrastructure and prevention of deterioration; 2) linking these areas to create a network that becomes more valuable than the individual pieces; and 3) consider all green areas in the plan coverage, regardless of public or private ownership (Davies *et al.* 2006). Due to the number of detailed variations in components from different plans, the components discussed in my thesis will be referenced from the Beaver Creek Watershed GIP, since it was in the creation of this plan that the initial research for the design and implementation of the data and geoprocessing models that I am proposing was carried out. Also, the Beaver Creek Watershed GIP is an excellent example of a completed, comprehensive plan based on sound landscape planning and GI principles and executed using the best available data and well-defined geoprocessing methods.

Beaver Creek Project Background

The Beaver Creek Watershed Green Infrastructure Plan (BCWGIP) was carried out from 2004-2005 and published in early 2006. It was a project of the Green Vision Studio at the University of Tennessee, Knoxville's College of Architecture and Design. Professors Tracy Moir-McClean and Mark DeKay were the principal investigators and project managers. I managed the GIS data development and analysis, and was responsible for much of the cartography in the final plan document. The BCWGIP was sponsored by the Beaver Creek Task Force. Some of the Task Force members include the Beaver Creek Watershed Association, Knoxville-Knox County Metropolitan Planning Commission, Tennessee Valley Authority (TVA), Knoxville Utilities Board and KGIS, Hallsdale-Powell Utility District, and National Association of Conservation Districts. Roy Arthur, Knox County Watershed Coordinator, was responsible for project oversight. The fiscal agent was Knox Land and Water Conservancy, and funding came from Knox County and TVA. The project was influenced by a diverse group, with interests ranging from storm water treatment to flood control to recreational opportunities to future development strategies.

The BCWGIP was developed at the "network" level within the GIP hierarchy, and as such, the plan was not designed to be a specific proposal at the parcel level for exactly what should happen in the watershed. Rather, it was conceived as "a visioning exercise intended to create a reference document that can be used by a variety of individuals and institutions to guide decision-making about preservation, conservation, and development patterns" (Moir-McClean and DeKay 2006, p.11). The driving issues in the Beaver Creek watershed were (and still are) increased flooding, poor water quality

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and pollution, and the desire by the county and residents to investigate acquisition of conservation easements in the watershed. The plan was designed around the needs of the Beaver Creek watershed, and a method to guide the plan development was outlined. The basic method was broken down into six steps: 1) document existing green infrastructure elements and networks; 2) analyze each element to understand the current conditions; 3) generate "corridor" proposals (components) for ridge preservation, water feature protection, and heritage preservation; 4) synthesize these into a composite stewardship pattern; 5) establish priorities for land conservation programs; and 6) design proposals for future conservation-minded development and a network of parks and greenways to link it all together (Moir-McClean and DeKay 2006).

Plan Component Overview

From an analysis perspective, the BCWGIP is comprised of three major components: the settlement network, open space network, and water network. These key components are used to synthesize the backbone of the plan's "corridor" framework, which defines the spatial implications of the plan's proposals. Each of these components is composed of multiple elements that address the factors important to each, i.e. the open space network component contains an assessment of the value of a) existing forests and b) farmlands. In this section, the primary objectives of each component and some of the important elements and their data processing methods will be discussed. More detailed descriptions of each element and how they were generated and then synthesized into the three major plan components can be found in the published BCWGIP and will not be restated here. The purpose of this brief summation of the components and their elements

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is to relate the context in which the hydrologic network protection analysis was carried out within the BCWGIP and where my research and development of the data and geoprocessing models is based. In the discussion of the BCWGIP throughout my thesis, the use of "we" refers to myself and Professors Moir-McClean and DeKay.

All three of the major components identified in the plan are of course underlain by the land itself. The first part of the project was to inventory and organize the huge amount of data that was available for the study area and assess the existing condition of the land. From that point, the organization of the plan elements took shape. Each component was defined in terms of its elements, so, for example, the land and settlement pattern plan component was composed of an elevation model, an inventory of existing forested land (land cover), the existing land use patterns, etc. To create these individual elements, our GIS's ability to manage and display the large, complicated datasets was leveraged to analyze the data we had collected and create base maps of the basic elements of each component (i.e. a topographic base, a parcel map base, etc.). These base maps (basic elements) were then studied for patterns and clues to the direction of further analysis, and derivative elements were created. For example, the land and settlement component had a basic element of the existing land use (a zoning map), and from that the elements of development intensity (clustering of similar types and levels of use) and neighborhoods and centers (analysis of the location of related uses) were derived using GIS analysis tools. Also, during this stage it became clear that there were datasets that were either incomplete or missing altogether, and those would need to be sourced or created from scratch by digitizing or deriving them from other data in order to define an element.

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Land and Settlement Component

With an initial overview and organization of the patterns on the landscape, work on the three major components began. The first component was the land and the existing settlement pattern. This component was intended to reveal the pattern of and relationship between existing settlement and open space in the watershed. The land and settlement pattern plan component was composed of an elevation model and derivatives (slope, hillshade), an inventory of existing forested land (land cover), the existing land use patterns, intensity of development, and an analysis of the type and size of neighborhoods and service centers. This component is an excellent example of the diversity of data used to build a plan component. Data for the topographic base was from the United States Geological Survey (USGS) National Elevation Dataset (NED) digital elevation model (DEM) at a resolution of 10 meters. The land cover data was from the Environmental Protection Agency (EPA) Gap Analysis Program (GAP) at a resolution of 30 meters. The elements relating to settlement patterns and intensity of use were based on a land parcel dataset used with permission from Knox County's KGIS.

Analysis of the data included comparing the locations of existing forests to the landforms (overlay, intersection). This analysis showed that while the ridge top forests were relatively intact, the bottomland and riparian forests have been severely affected by development in the valley. The analysis of the settlement pattern required selecting and categorizing parcels based on use and grouping similar uses to reduce the number of detailed use classes. The intensity of use was then determined by looking at the existing zoning of parcels, and then determining the proximity of like uses with each other and with other uses. This was accomplished by buffering parcels and then intersecting the

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buffers to determine where like uses were in proximity (200 feet) of one another.
FIGURE 3.1 shows an excerpt from the map of the results of our analysis of the existing development pattern in the Beaver Creek study area.

The conclusion drawn after the construction of the elements in this component of the plan was that the intensity of use in the watershed was very low, i.e. typical suburban sprawl development, where the land is cleared of forest and agricultural uses and covered with low-intensity residential developments that are automobile-oriented and poorly connected to each other and to the commercial centers designed to serve them. Corridors of strip-commercial and mixed office and light industrial uses are located along major roads while residential development fills the spaces between them. These analyses showed a distinctive pattern that Moir-McClean and DeKay referred to as "centers with no neighborhoods; neighborhoods with no centers" (BCWGIP, p.25). See **FIGURE 3.2**. It is a development pattern that is unfriendly to modes of transport other than driving and causes the arterial streets and intersections to be overloaded by cars funneled from residential developments with inadequate outlets. The low-intensity construction of houses increases infrastructure costs (both for their installation and maintenance) and creates more impervious surfaces that lead to increased flooding and storm water treatment costs. Suggestions for the future stemming from the assessment and analysis of the current settlement situation included increasing the density of residential development near centers, discouraging development in open spaces, and the protection of working agricultural lands.
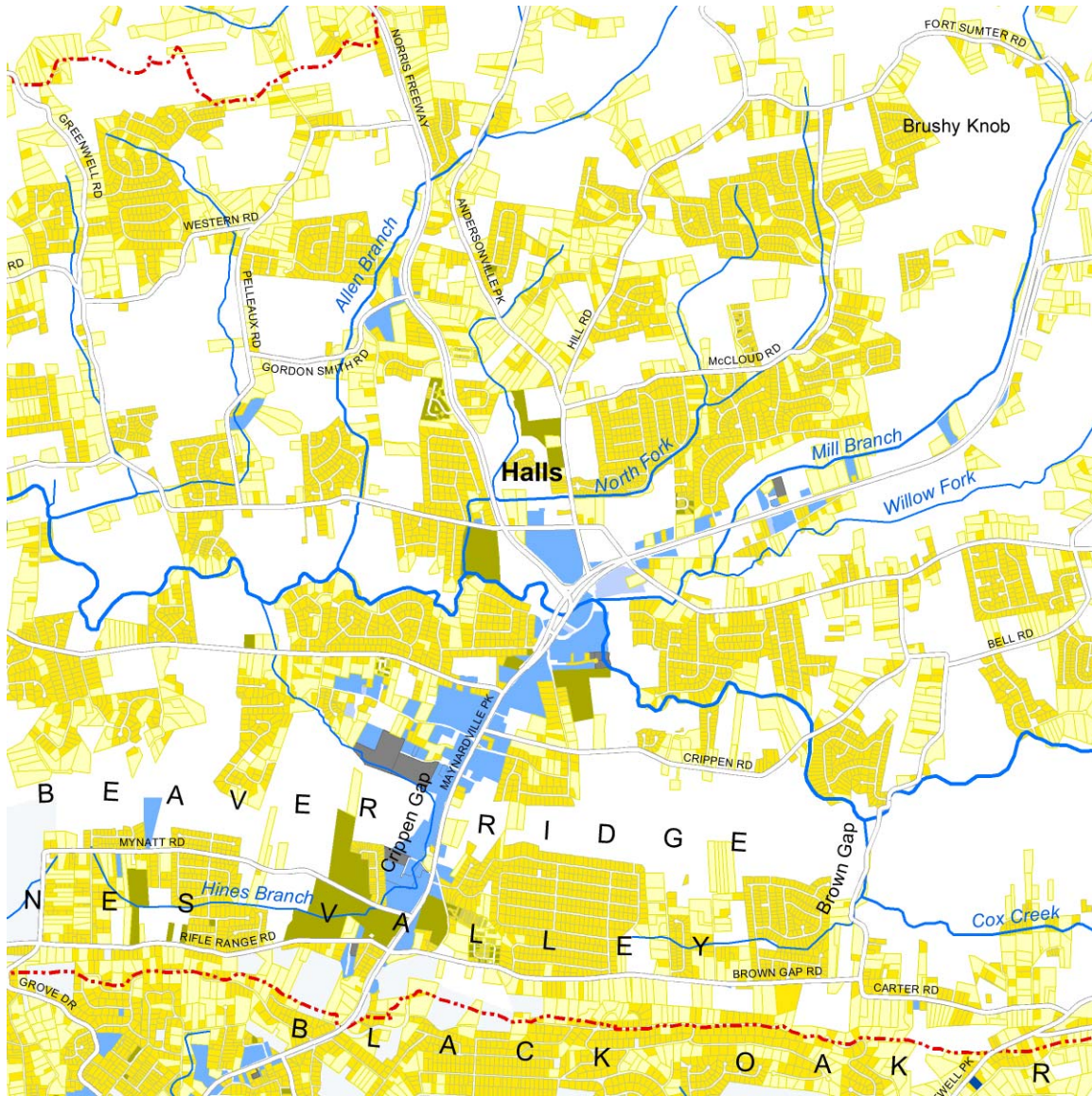
Figure 3.1 Excerpt from the Existing Development Pattern map. Residential development is shown in yellows from light to dark: Very Low Density (Single Family, 1-5 acres); Low Density (Single Family < 1 acre & 2-4 Family); Medium Density (5+ Family & Parcels < 1/4 acre). Commercial and mixed-use development (such as churches) are shown in blues from light to dark: Commercial / Mixed Use, Vacant; Commercial / Mixed Use, Occupied. Gray color indicates an industrial or office site, in this example dark gray is Industrial/Office, Occupied. The empty areas are undeveloped forest or agricultural lands. The map shows the general settlement pattern of developed areas in the watershed. Clusters of adjacent residential, commercial, and industrial parcels are identified. This has the effect of simplifying the pattern to show significant groupings of each use. (BCWGIP, p. 23)

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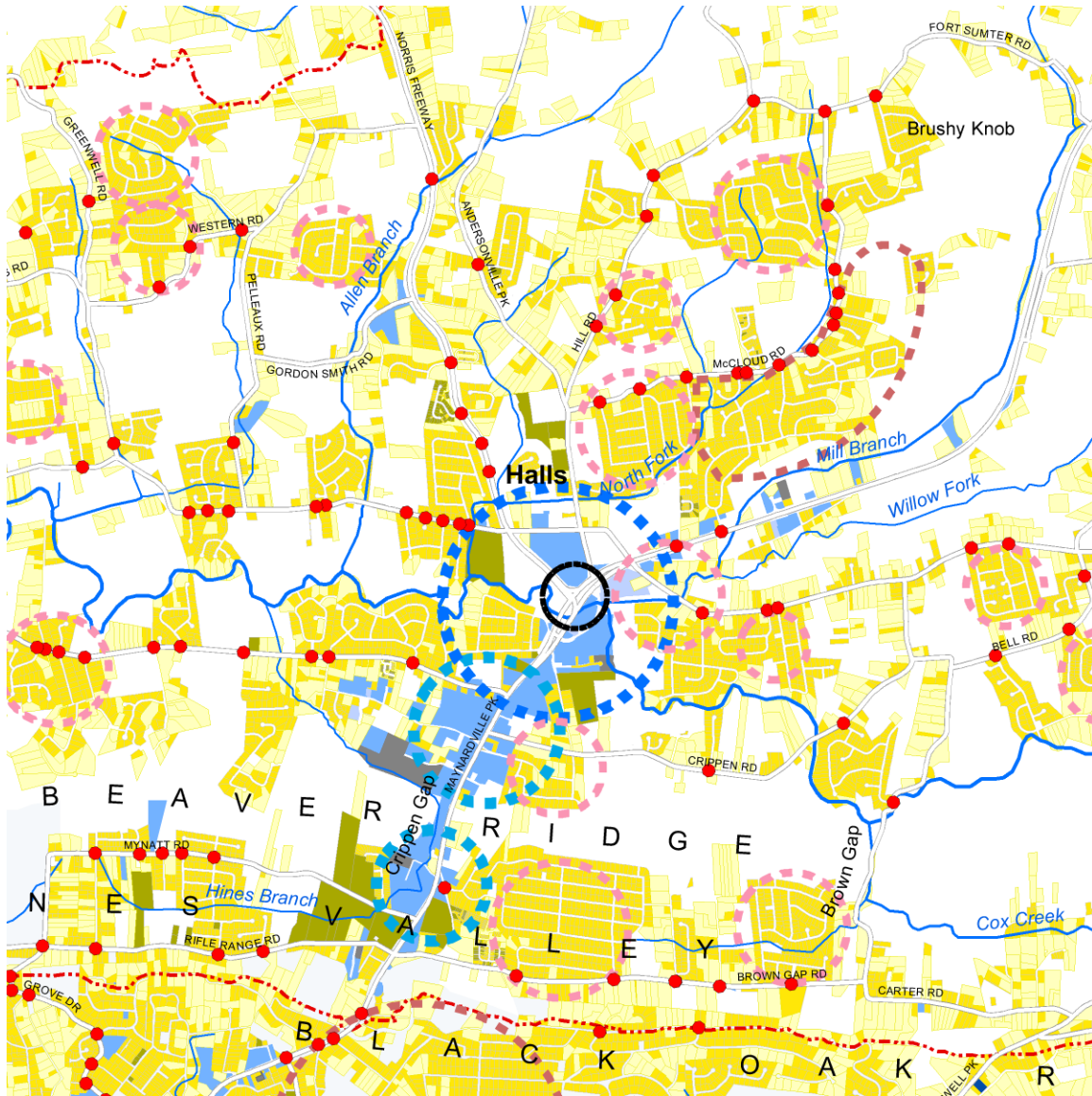
Figure 3.2 Excerpt from the Neighborhoods and Centers map. The colors assigned to parcels on the map are the same as Figure 3.1. The red dots signify the location of a residential development outlet to a main road. The dashed rings signify the different types of centers. Blue rings correspond to commercial centers of local to regional significance (light to dark), and red rings correspond to neighborhoods of different relative sizes (light: ~1/2 mile across; dark ~1 mile across). The black ring signifies a community center. The pattern of "centers with no neighborhoods; neighborhoods with no centers" refers to the obvious detachment of the different uses. Instead of seeing many concentric or overlapping rings, they are spread out, isolated from one another, highlighting the sprawled, automobile-oriented development of the last several decades. (BCWGIP, p. 24)

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Open Space Component

The second component of the Beaver Creek watershed analysis was the open space network. In this component, the goal was to identify valuable open space areas and the corridors that connect them, based on criteria that supports GI principles by the design team, in the interest of developing a network of land that provides ecological as well as economic benefits, such as pollution and sprawl mitigation, recreational opportunities for residents, and native habitat protection. The open space network component was much more GIS analysis-intensive than the settlement component, and was arguably the most complicated analysis from a GIS standpoint. The open space component was comprised of an assessment of existing parks and recreational lands, an analysis of the "richness" of native species in the watershed, a ranking of the value of the land in the watershed for habitat and agriculture, and a weighted comparison of the value of land for habitat preservation versus agricultural uses. The purpose of the comparisons between these types of land use (habitat vs. agricultural) was that most of the open space in the watershed, developed and undeveloped, is held in either agricultural or large parcel low-density residential use that is mostly grassed or forested. The goal was to compare what the value of these lands were in terms of their size, land cover, connectivity to water, and soil type (value for agriculture).

The datasets used for the analysis of the open space network were numerous, and I will not list them all here. See the published BCWGIP Open Space component maps (pp. 28-35) for information on the datasets used in the various analyses. The most important sources of data were the parcel and road datasets from Knox County's KGIS, a dataset of power line right-of-ways we digitized from USGS 7.5 minute topographic

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maps, the species richness and land cover datasets derived for the EPA GAP Analysis Program, the Knox County soil map prepared by the Natural Resources Conservation Service (NRCS). The existing parks and recreation centers in the watershed were assessed to determine the extent to which they were able to serve the communities around them. While the larger parks and sports complexes served the community well, there were insufficient smaller parks and greenways to serve and connect individual neighborhoods (BCWGIP, p.29).

The species richness dataset, which predicts the count of unique species of four types of vertebrates (amphibians, reptiles, mammals, and birds) in 100-meter cells, was used in a comparison of the Beaver Creek watershed and the Oak Ridge Reservation to determine the relative impacts of development on species counts. Amphibians and reptiles were most adversely affected by suburbanization, so those species gained priority when looking at the value of those habitat lands. The next step was to rank land for its value as habitat. This was the most complex analysis in the open space component. The watershed and surrounding study area was taken and cut it into "patches" using the road and overland utility network and "erasing" those areas, as well as removing land classified as "developed". These patches were then classified based on predominant land cover, either forest or grass. The patches were then weighted based on five criteria: size, interior habitat area, connectivity to patches with similar characteristics, species richness, and distance to water. Two iterations of the process were done, one on the upland areas, and another on riparian areas (those within 300 feet of a stream). The results were studied and the weights were designated either prime, good, or marginal upland or riparian habitat. Agricultural and large (10+ acre) residential parcels were assessed for

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agricultural value based on the suitability of the soil for agricultural use, according to NRCS recommendations. The final element of the open space network component was to combine the outputs of these analyses (the habitat and agricultural value) and compare their weighted values and assess which held the higher priority: habitat or agriculture. See **FIGURE 3.3**.

The results of the open space component indicated that there is a serious need to protect and link the remaining valuable habitat and open space in the watershed. The ever-increasing development pressure on the area has led to damaging fragmentation and degradation of natural habitats and the destruction of valuable agricultural lands by unchecked sprawl. The riparian forests are almost completely gone from the valley floor, and ridge-top areas, where much of the intact forests remain, are at risk of being developed. The analytical outputs from this analysis were also used extensively in the construction of the composite heritage protection and stream protection corridors, which will be discussed later.

Water Component

The third and final major component of the BCWGIP analysis was the water network. In many ways it was the hydrologic issues that drove the plan, since it was the poor water quality and flooding problems that were the main justification for the project and its funding. That said, the goals of the water network analysis were to identify lands that contribute to increased water quality and provide protection to sensitive hydrologic features and their contributing lands.
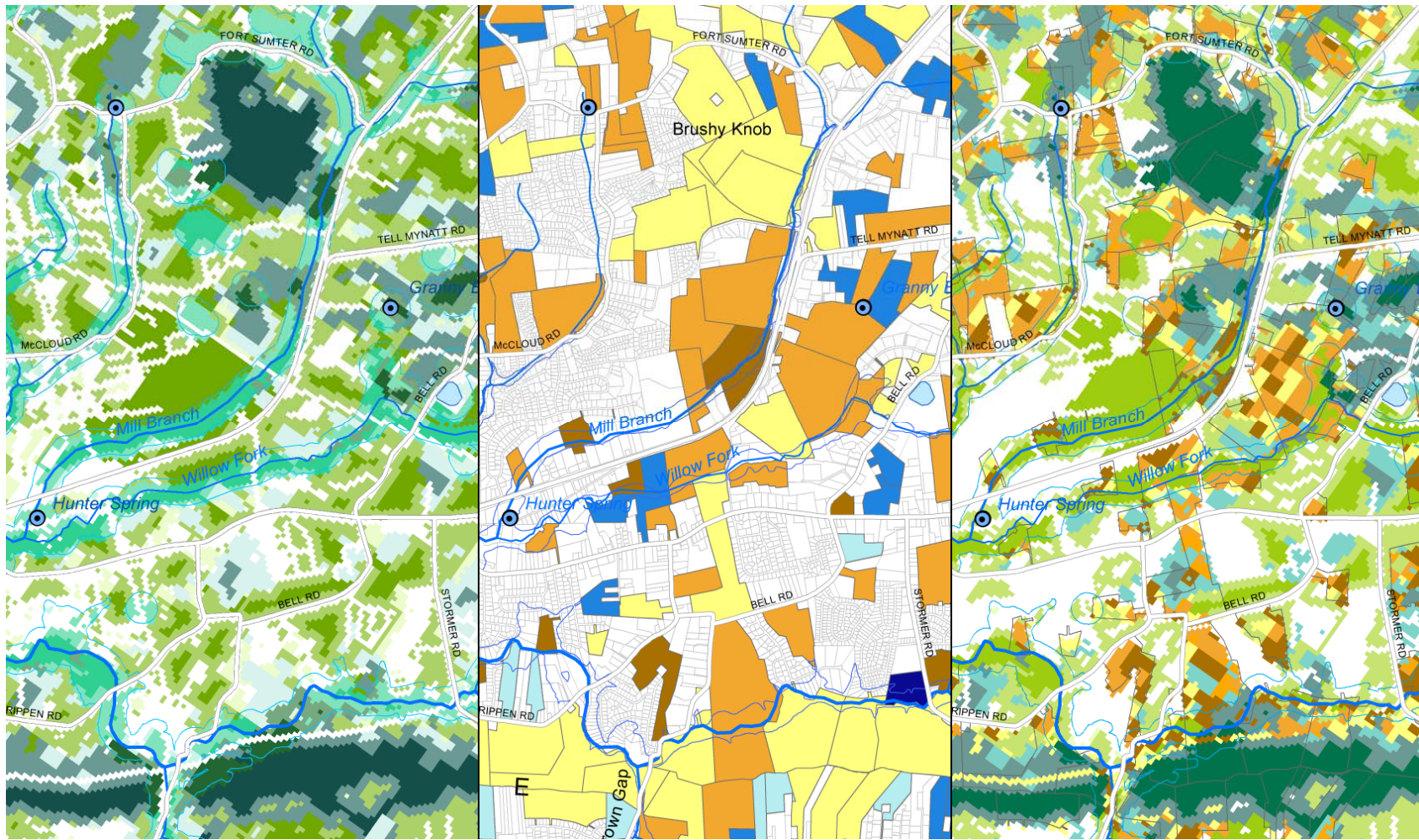
Figure 3.3 Excerpts from maps of the Open Space analysis. The left map shows the results of the habitat value analysis (lighter colors indicate lower values). The bluish-greens represent riparian values, the yellowish-greens represent upland areas. The lighter hues represent grassy areas and the darker hues forests. The middle map shows agricultural land value based on soils (darker is higher). Yellows-oranges represent parcels zoned for agricultural use, blues are residential parcels over 10 acres. The map on the right shows the composite, with significant parcels outlined. Here, yellows-oranges represent the valuable agricultural lands and greens represent the valuable forest (darker hues) and grassland habitats (lighter hues) in both riparian and upland areas. (BCWGIP, pp. 32-34)

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The biggest problem in the watershed is that development has increased the amount of impervious surfaces and crowded the natural floodplain with development that keeps it from working properly. The headwaters are experiencing rapid growth and the surface's natural ability to slow water and allow for infiltration has been diminished. Riparian forests, which protect the banks from erosion, slow water and allow for infiltration, and provide an important ecological function by helping regulate water temperature, have been all but destroyed in many areas of the watershed. As traditional development continues, these problems worsen.

To combat these problems, a strategy was devised that utilizes a system of riparian and sensitive feature buffers, divided into three zones. This plan was based on a series of best management practices gleaned from government guidelines and model ordinances, then enhanced to provide protection to the various sensitive features we identified within the watershed. The features identified for protection were of two kinds: features that represent surface water, and features that relate to groundwater. The datasets included streams from the USGS 100k Digital Line Graphs (DLGs), springs, spring catchments, and sinkholes digitized from USGS 24k Digital Raster Graphics (DRGs), wetlands and water bodies from the National Wetlands Inventory (NWI), floodplain area delineation by the Federal Emergency Management Agency (FEMA), and slope information derived from USGS 10 meter DEMs. First, a map of the watershed and all the features was made to show the features identified for protection. See **FIGURE 3.4**. Criteria were then set to define the minimum buffer for each kind of feature, based on best practices guidelines. The buffer was divided into three zones based on EPA recommendations (from closest to furthest from the feature): protection (of

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edge), conservation, and stewardship. The basis for the buffers was first and foremost the stream itself. Sensitive features (springs, wetlands, steep slopes) adjacent to the streams were added to the buffer, and features not adjacent to streams (upland wetlands and sinkholes) were buffered individually. Once the first zone of the buffer was defined, the second and third buffers were added. The second zone added the critical floodplain, and the third zone was a buffer of the completed second zone. See **FIGURE 3.5**.

The completed buffer system had two main implications. The first was to identify the sensitive hydrologic features and map the related lands and show where development should be avoided in order to help rectify the water quality issues in the watershed. The method developed was rational and repeatable and could be used in other similarly situated localities with very little adjustment. The second was to use this system to help identify links between the bottomland and the ridges to facilitate the synthesis of composite green infrastructure patterns in the watershed.

The water network protection methodology is the topic of the research carried out in this thesis. Further discussion of the best practices for riparian buffering, including the zoned approach described here, will be covered in Chapter 4. The GIS method developed for the BCWGIP will be explained in more detail and a data model and associated geoprocessing models for developing a similar hydrologic network protection analysis will be covered in Chapter 5.
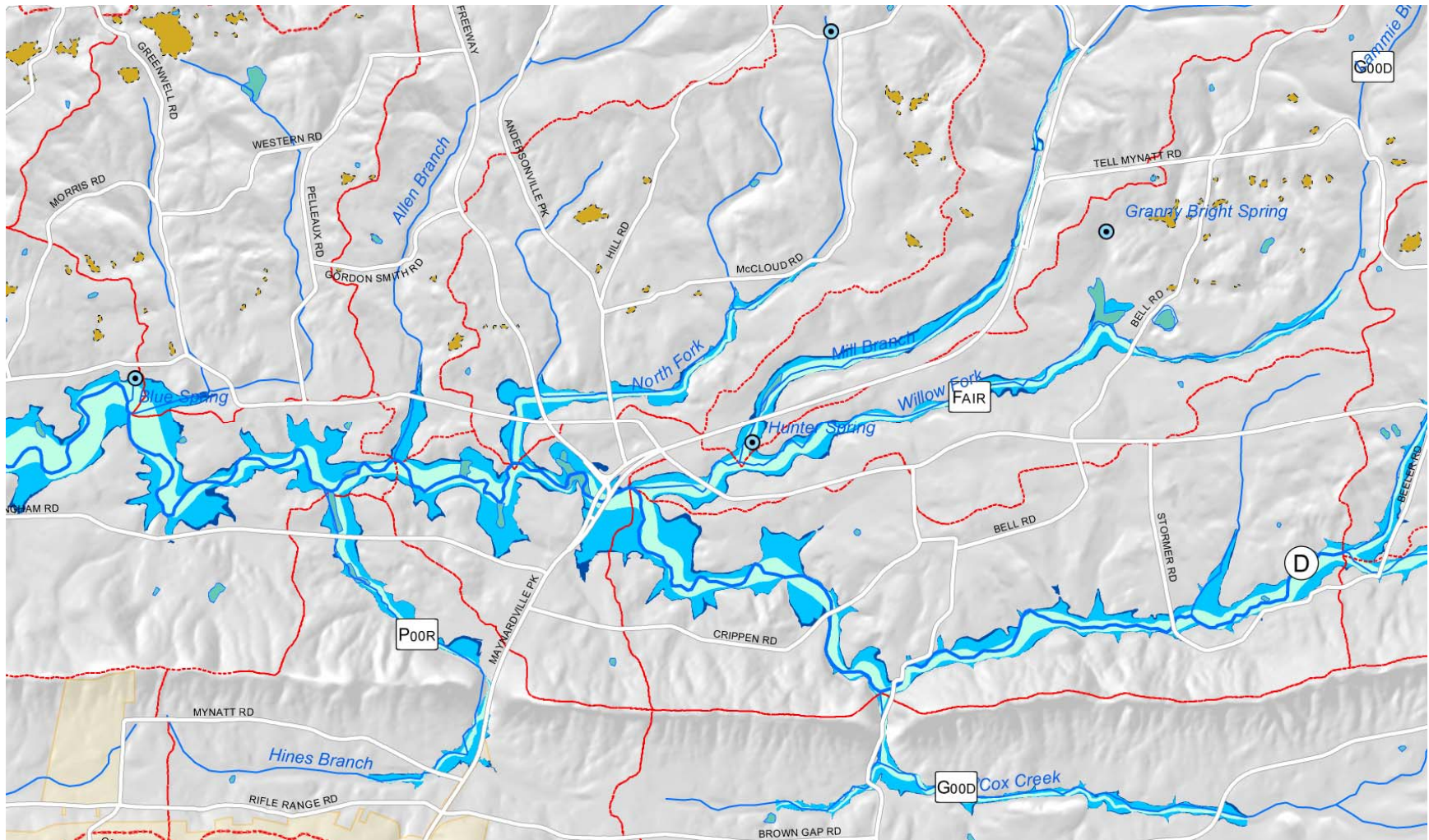
Figure 3.4 Excerpt from the Existing Hydrologic Features map. The stream network is underlain by the FEMA floodway (light blue) and 100- and 500-year floodplains (medium and dark blue, respectively). The blue-green areas are wetlands and water bodies from the NWI. Springs (black and blue rings) and sinkholes (light brown) were digitized from USGS topographic maps. Red lines show the catchments of the tributaries of Beaver Creek. The labels indicating tributary condition ("good", "fair", etc.) and the Beaver Creek Water Quality Report Card ("D") were defined by a TVA water quality study. (BCWGIP, p. 40)

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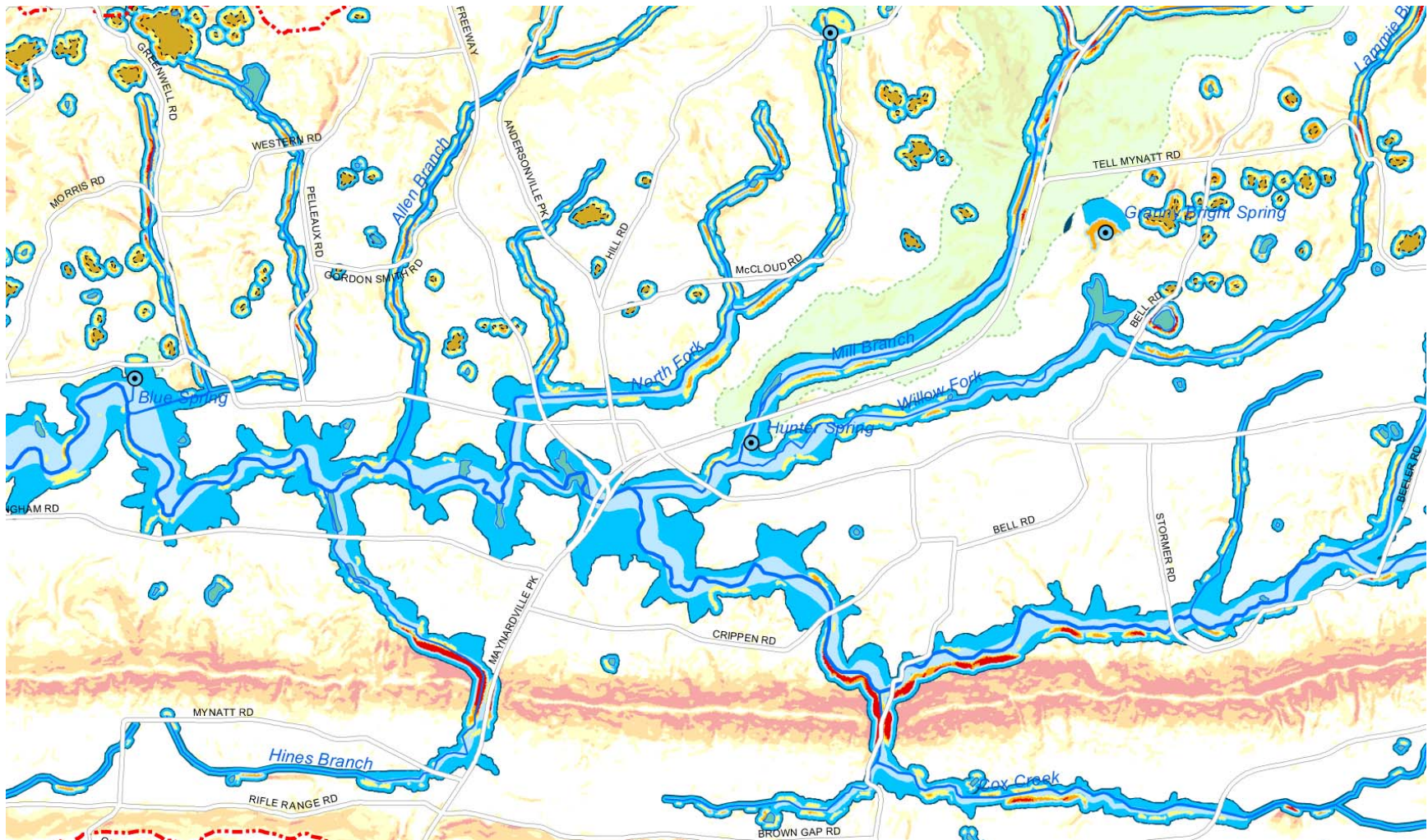
Figure 3.5 Excerpt from the Water Feature Buffers map. This composite shows the three-zone buffer system and the features considered when buffering. Map features are the same as Figure 3.4, with the addition of the slope zones (reds and yellows) and spring catchments (light green). Also, the floodway and the 500-year floodplain are now part of the buffer. The zones are 1 thru 3, light to dark blue. The streamside (riparian) buffer is a continuous feature while sensitive upland feature buffers form a more discontinuous pattern. (BCWGIP, p. 42)

Composite Patterns in the BCWGIP

Once all three components of the plan had been completed, composite relationships between the components were identified. This was done to begin the process of synthesizing a framework of green infrastructure called the "Land Stewardship Network" for the final GI plan (BCWGIP, p.49). The composite component was created by taking the other three major components (or elements thereof) and combining them to create a complete Green Infrastructure framework. Our GI framework was comprised of the stream protection corridors, ridge protection corridors, and heritage protection corridors.

The stream protection corridors were defined by taking the water network component and intersecting it with the habitat value versus agricultural value element from the open space component. Parcels with high value for riparian and grassland habitat and parcels with high agricultural value that intersected the water buffer system were added to the stream protection corridor. See **FIGURE 3.6**. The ridge protection corridor was delineated by taking the slope element from the land and settlement component and the habitat value versus agricultural value element from the open space component and intersecting them. Areas with 25% slope that were larger than 2 acres were selected. Adjacent areas with over 15% slope were then added to the steeper areas and the combined area intersected with the forest habitat to create the ridge protection corridor. See **FIGURE 3.7**. The heritage protection corridor was created a bit differently than the other two. Since its purpose was to link the stream corridor and the ridge corridor, it required some hand-selection of the parcels that defined it. The choices for inclusion in this corridor were based mainly on the habitat value versus agricultural

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value, but others may have been included. The idea of this corridor was that it provided the linking land for the other two corridors. It also created natural "barriers" to sprawling development by separating existing communities with wide swaths of open space that cross the valley, connecting the bottomlands to the ridges. See **FIGURE 3.8**. The three corridors were combined to form the Green Infrastructure Corridors map and the composite land stewardship network identification was complete. See **FIGURE 3.9**. The next step in the plan was to take the proposed land stewardship network and intersect it with all parcels in the watershed. There were three main reasons for doing so: 1) to determine if there were any conflicting environmental uses within the protected areas; 2) to identify parcels where more detailed assessment of best management practices and use of protective easements might be done; and 3) to find parcels that have significant environmental benefit and identify them as potential acquisitions if they become available (BCWGIP, p.51). The resulting parcel selections were classified and mapped in two parts: parcels that intersect the stream corridor, and parcels that intersect the ridge corridor.

Finally, a master plan for future development was outlined that had three major parts. The first was a proposal for the locations of town, village, and neighborhood centers. Since the watershed has developed so quickly, the existing community boundaries have been degraded and the once independent communities are in danger of losing their identities. The purpose was to better delineate the boundaries of communities (in the context of the land stewardship network) and identify the centers that serve them in order to try and steer development in a direction that concentrates development in these places, effectively strengthening their identities and improving their functionality.

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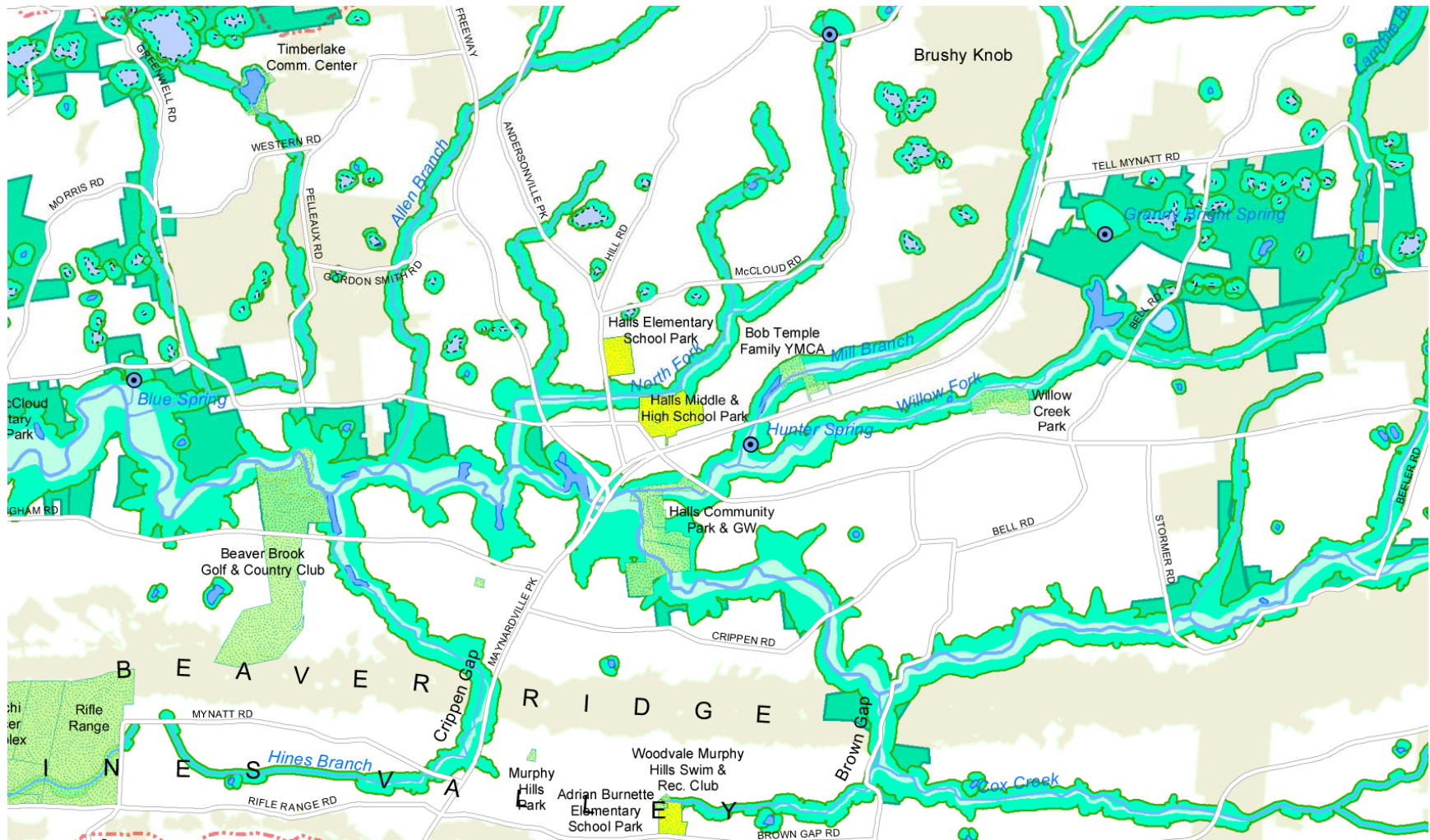
Figure 3.6 Excerpt from the Stream Protection Corridors map. The Stream Corridors expand the Water Feature Buffer concept to include adjacent land with high open space value. Adjacent lands that were found in the Open Space analysis to have high value as riparian wildlife habitat, prime upland grassland habitat, and prime or good agricultural soils were included. Also, parcels that linked nearby upland hydrologic features to the stream network and linked chains of features (such as wetlands and sinkholes) together into "groundwater corridors" were included to make the protected uplands more continuous. (BCWGIP, p. 49)

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Figure 3.7 Excerpt from the Ridge Protection Corridors map. Areas protected include slopes above 25% plus adjacent forested areas with slopes above 15%. Areas with slopes above 25% that were larger than 2 acres in size were identified, along with adjacent areas with slopes greater than 15%. These 15% slopes were then intersected with a land cover dataset to find those that had significant forests. The yellow hatched areas show areas of 15-24% slopes and the wide, light brown hatches indicate areas over 40% slope. The green fill shows the final Ridge (and Slope) Protection corridor. (BCWGIP, p. 49)

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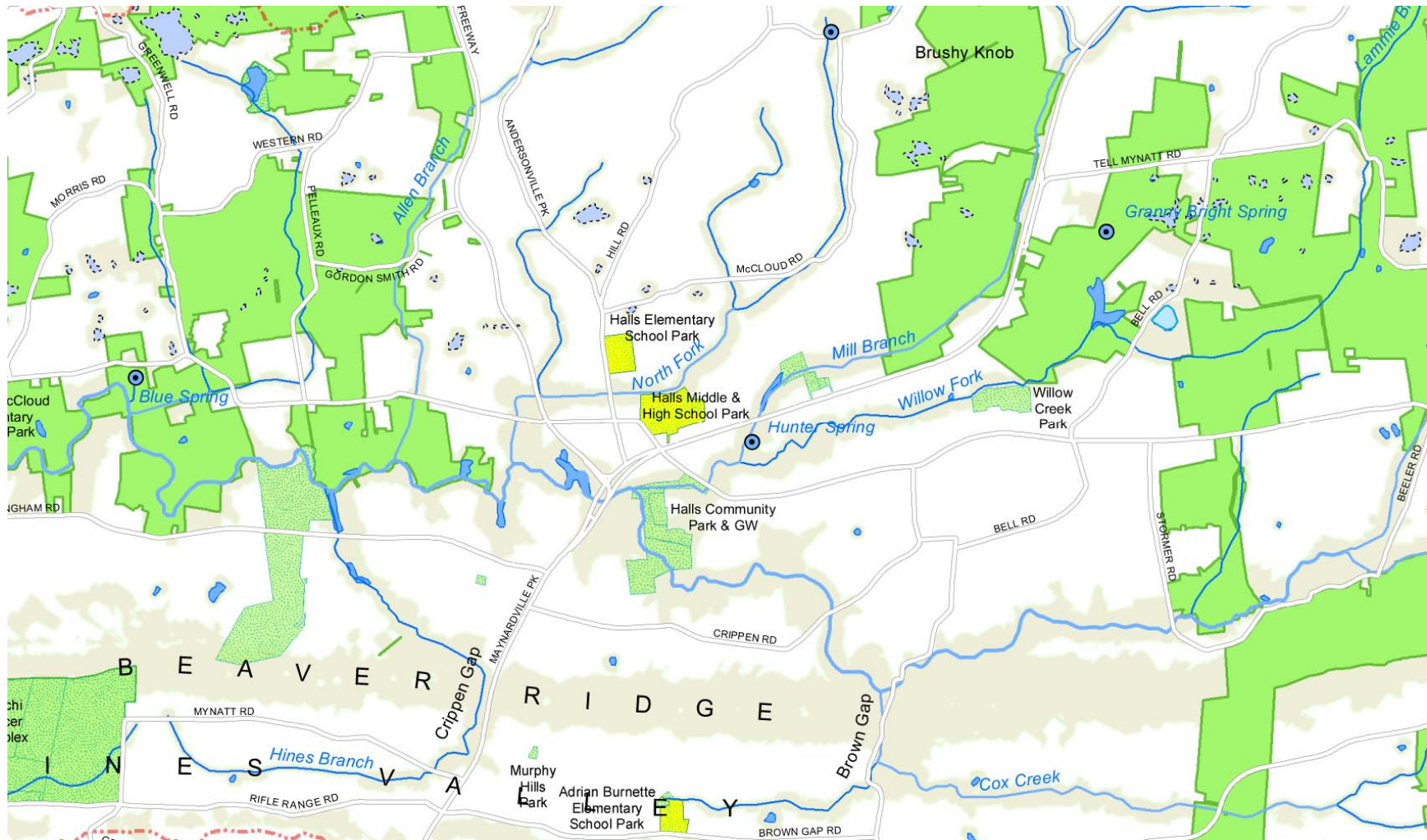
Figure 3.8 Excerpt from the Heritage Protection Corridors map. This map shows land (green areas) recommended for preservation in its rural character, allowing for agricultural and rural residential development. Good farmland and good habitat areas were identified from the agriculture vs. habitat value analysis. Undeveloped land that was considered prime and good farmland, especially over 20 acres, remaining forests, prime grassland habitat, and riparian habitat areas were considered. Finally, parcels that connected the ridges and valley in relatively wide swaths that would also help to create community edges were hand selected. Where possible, stream routes and parcels that provided the best network continuity were chosen. (BCWGIP, p. 49)

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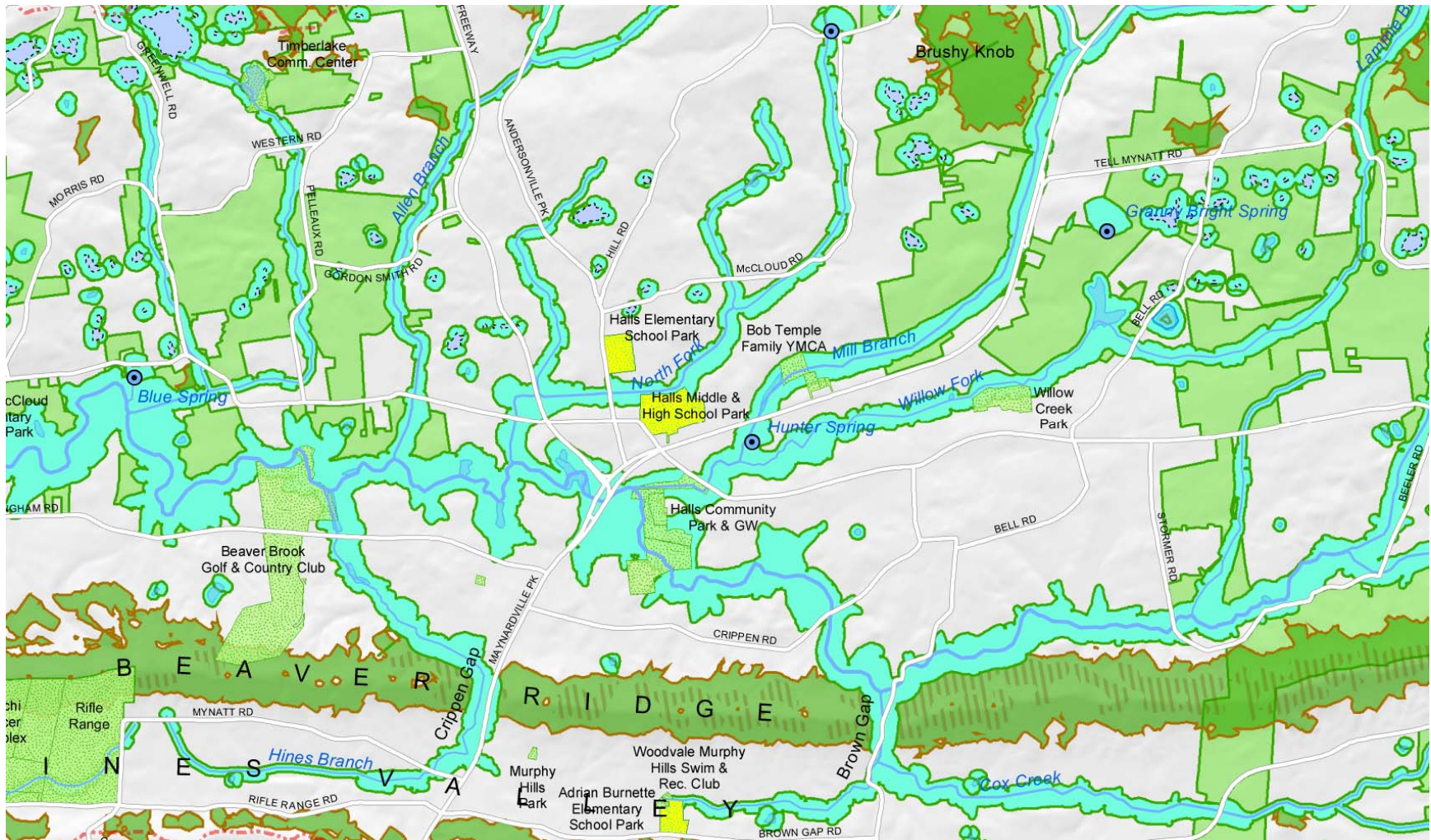
Figure 3.9 Excerpt from the Land Stewardship Network map (GI Corridors map). This is the sum of the three corridors types: Stream, Ridge, and Heritage. It represents the land most valuable for conservation to both the community and to natural processes. Levels of conservation and development recommended by the BCWGIP vary as appropriate for each area's open space value, existing land use, and other characteristics. This network forms a framework within which (in the gray areas) more intense development, such as neighborhoods and village centers, can be targeted by planners and developers. See the BCWGIP for more information. (BCWGIP, p. 50)

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The second proposal was for a park and soft transit network. The town, village and neighborhood centers were examined along with the existing parks and the other corridor maps. Knox County's parks and recreation plan was also consulted, and a proposal for a system of parks, greenways, hiking trails, and other pedestrian-friendly paths was developed. This system also included suggestions for streetscapes, such as tree-lined boulevards and pedestrian routes within each community to improve safety and beautify the area. The third proposal was to identify lands for preservation through conservation easements and programs. Two programs were investigated, one for grassland preservation and one for farm preservation, both sponsored by the NRCS. In each analysis, the program requirements were used to identify parcels that were suitable. For grassland preservation, areas over 40 acres that intersected an agricultural land use were identified. For farm preservation, agricultural parcels over 40 acres with more than 50% prime soil coverage were identified. These three proposals along with the concluding remarks completed the Beaver Creek Watershed GIP.

GIS Method Development and Research Foundation

The methods for developing the representations using GIS data and analysis techniques of each element were often time consuming and tedious. The simplicity with which I have described the components should not be construed as simplicity of analysis or methodology. This plan was, after all, nearly a two-year project with many hours of work devoted to researching and developing the best methodologies to analyze the conditions in the watershed using the best available data. So, while the generation of some elements was rather straightforward, such as deriving slope from a DEM, many

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required a considerable amount of research into the meaning and usefulness of each attribute of the data, and what could be gleaned from them, as it was with the habitat value analysis. At each step in the process, other projects and model ordinances were used to help establish which best practices were applicable and could be integrated into the BCWGIP. But in many cases, new methods had to be developed where there were no previous examples. This was a natural progression whereby the knowledge of others was collected and leveraged and supplemented with new ideas to create a better, more holistic approach to the analysis carried out for the BCWGIP.

The purpose of this thesis is to take that process one step further. The methodologies developed during the creation of the plan were well-crafted, but were done essentially "by hand" in that a specific data model to describe and house the datasets was not created, nor were any of the processes automated to facilitate later repetition. Not automating the processing was a pragmatic decision: dealing with the reality of limited funding, time available, and staff. So while the methods were well documented, there is no convenient way of disseminating those methods and describing the data required to accomplish the analysis. This is why I chose to research and develop these tools for the hydrologic conservation buffer method. The data model and associated geoprocessing models that I have created since the completion of the BCWGIP are intended to be the concrete representation of that method and all the knowledge gained during that investigation. I chose this particular component, not only for its importance to the GI plan, but for its relevance as a stand-alone method for identifying land that contributes to increased water quality that could be used elsewhere. It also offered unique challenges for the geoprocessing and data model development. The

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rest of this thesis will cover the research I did into the various riparian buffering methods, the development of the datasets, data model, and geoprocessing tools, and how the results of my research have supplemented and improved upon the methods and results of the BCWGIP.

Chapter 4   Riparian Buffering: Principles and Review of Best Practices

The water network analysis for the Beaver Creek Watershed Green Infrastructure Plan suggests a system of buffers to protect the land that contributes the most to water quality. The idea of protected buffers is not a new one and has been suggested time and again as a best practice when it comes to dealing with non-point source pollution (Welsch 1991; Reimold *et al.* 1998; Fischer and Fischenich 2000; Benedict and McMahon 2002; Benedict and Drohan 2004; Davies *et al.* 2006). But the style, width, method of delineation, and features considered when buffering are varied and there are no decisive rules when it comes to any of these buffer attributes. This can be problematic when trying to implement a buffer system: what are the best practices and how can they be implemented? These and many other considerations have to be taken into account when designing a method for riparian buffering. In this chapter I will discuss: 1) the importance of riparian areas for ecological health and watershed function; 2) the basic principles of riparian buffers; 3) what some established best practices are and compare them; and 4) implementation methods using GIS analysis tools. The first two items will be more general in scope: an overview of the basic functions of riparian areas and of their management. The third and fourth will be more specific: referencing model ordinance and specific strategies to defining riparian buffer zones. There will also be a complete rundown of the methods chosen for the Beaver Creek Watershed GIP and a description of the updates that I made to the buffer method based on additional research conducted after the BCWGIP was finished.

Before delving into the specifics of riparian buffering principles, I will define what a riparian area is. Simply put, a riparian area (or zone) is the interface between terrestrial (land) and aquatic (water) (Hunter 1990). Most definitions follow this simple principle. Since scale and defining an appropriate scale at which to work have been issues throughout this research, it should be noted that the spatial definition of a riparian zone is also scale-dependent. When speaking about a riparian area at a specific place along a reach, a stream sample station, for example, the riparian zone may be defined as the immediate edge of the water where some very specific plants or animals are living (Swanson *et al.* 1982). At the next level, the riparian area might include the area along a reach inundated at flood stage or its floodplain. On the largest scale, the riparian zone can be thought of as the area that has a significant influence on the stream and vice versa, which may include sensitive upland areas (Hunter 1990). When working with an entire watershed like Beaver Creek, the latter definition is probably the most meaningful, in spite of its broad scope. Since the purpose of the buffering system in the BCWGIP was to identify the most important land that contributes to the health of the hydrologic network, including the floodplain and additional sensitive areas where floodplains aren't defined, the broader definition allows for the addition of these lands. Other important lands that were identified in the BCWGIP as "upland" features of the hydrologic network, such as wetlands and sinkholes, while not considered part of the traditional riparian zone, were included in the buffering system. This was done in an effort to be holistic in the approach taken to hydrologic feature protection, but they are identified separately because of their unique contribution to the hydrologic network as areas of groundwater recharge. The following overview of riparian buffering will not cover those

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features, as they are not riparian per se, but their function and inclusion in the complete buffering plan will be discussed later.

Riparian Areas: Ecosystem Health and Watershed Function

Riparian areas are often regarded by experts as the most important and valuable part of the landscape because of the important, often critical, functions they serve for streams and the entire watershed (Hunter 1990; Welsch 1991; Reimold *et al.* 1998; Benedict and McMahon 2002). The riparian ecosystem, when healthy, supports a large and diverse group of plants and animals, some of which are unique to that habitat (Hunter 1990). These areas are also quite rare when compared to the vast oceans or the lands beyond the riparian zone, which in and of itself increases their importance. Riparian areas are responsible for several important ecological functions and overall stream health benefits. Since these areas act as an interface, they can be looked at from two perspectives: one terrestrial and one aquatic.

For aquatic life, healthy riparian areas provide several critical functions. First, a stream itself is usually not very productive as a stand-alone ecosystem. The movement of water in a stream carries microorganisms away, and plants struggle to root even in shallow water if there are currents (Hunter 1990; Hynes 1970). Therefore, streams rely on the contribution of adjacent areas to supply biomass and materials to feed organisms and create dynamics in the streambed. Riparian trees provide most of this biomass in the form of leaves and twigs that are broken off by animals or that fall naturally. The decomposition of this material by small organisms starts the climb up the food chain to larger species, eventually making its way back to terrestrial predators. Second, trees that

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fall into and across creeks provide long-term food supply for microorganisms and shelter for larger aquatic animals. The changes that theses blockages create in the streambed alter the flow of the water and create pools and eddies that slow the water and allow for the deposition of sediments and the creation of still water habitat for fish and other aquatic life. There are also benefits of stream side trees as erosion control mechanisms, as rooted banks erode less severely and more slowly that barren ones (Hunter 1990; Heede 1985; Richards 1982). Third, when trees in a healthy riparian zone are maintained, the negative impacts of erosion away from the stream are also mitigated as the forest slows the overland flow and provides filtration of the sediment. Less turbidity in the stream means more light for aquatic plants and lower amounts of fine sediment coating streambed gravel, which is a prime area for mussels, spawning fish, and other organisms that require water to percolate through the gravel to remain healthy (Hunter 1990). Finally, trees provide shade to streams, especially smaller, shallower streams, which equates to lower water temperatures. Cooler water holds more dissolved oxygen than warmer water, which is necessary for many amphibian species to remain healthy (Hunter 1990; Barton *et al.* 1985). These are the most important benefits of healthy riparian areas to aquatic life.

For terrestrial life, the most obvious benefit of streams is water itself. Access to a clean supply of drinking water is a necessity of all terrestrial creatures, including humans. But aside from the obvious function of supplying fresh water, riparian areas are a haven for many types of plants and animals like amphibians and aquatic mammals. The humid microclimate in a healthy riparian area, often characterized by moist soils and open water or groundwater near the surface, supports many unique species of plants (Swanson *et al.*

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1982). The floodplain of a creek also offers a unique landscape for certain types of plants that may be swept away when flooding is present, but are quick to reestablish after inundation (Hunter 1990). The riparian diversity of plant species contributes to the variety and diversity of animals as well. In many areas, studies have found that the vast majority of terrestrial vertebrates are dependent on riparian areas or at least prefer riparian habitats (Thomas *et al.* 1979; Brinson *et al.* 1981). The namesake of the Beaver Creek watershed is also a noted architect of stream morphology. Beaver dams and the subsequent shaping of the stream channel provide unique benefits to the beavers and other aquatic inhabitants. Beaver dams control flooding just as human dams do, by holding water during a surge and allowing it to discharge at a lower rate after an event. The dam material is biodegradable, so other plants and animals benefit from the nutrients that decomposition adds to the ecosystem. Some estimates show that a healthy beaver population can contribute over two tons of woody material per mile of stream; 75% of which will decompose, while the remainder will be consumed and discharged as feces (Hunter 1990). And so it is thus that the root of much of the biological diversity and ecological health of streams is dependent on terrestrial activities in the riparian areas. By the same token, human activities in riparian areas over the last few centuries have severely degraded the health and reduced their functionality, and that is what the movement to protect and restore riparian areas aims to reverse.

Riparian areas also serve some more general functions that promote ecological health and provide human benefits throughout the watershed. Along the length of a creek, the types of plants and animals will change, from the headwaters down to the mouth of the watershed (Hunter 1990). These different habitats are dependent on one

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another, as the impacts of those in the upper part of the watershed may provide benefits

to those in the lower part. The beavers mentioned above are a good example of that

phenomenon: their addition of biomass to the creek provides nutrients to animals

downstream. Riparian areas lower in the creek valley are naturally susceptible to

flooding, and as such are usually quite fertile due to the deposition of nutrient-rich

sediments. If this natural process of flooding and deposition is impeded by human

development, the results are the degradation and eventual loss of use of prime agricultural

lands. Healthy riparian areas promote species richness among terrestrial birds and

reptiles as well as amphibians and mammals. Studies have shown bird populations in

riparian forests are denser that those in upland areas. These forests provide water and

shelter to migratory birds and provide the same functions to breeding birds. The natural

vegetation cover along streams also provides corridors for animals to move and creates

connections between the upland and ridge tops to the valley floor (Hunter 1990).

Protecting Riparian Areas Through Buffering

After describing the functions that riparian areas serve, it is clear that these areas

are critical as green infrastructure and require special consideration for their value as

habitat and as natural water management systems. But what are riparian buffers? In this

section I will discuss the basic principles of riparian buffering and some of the criteria

used when defining buffers and their attributes.

The use of buffers to protect streams and wetland riparian areas is a well-

established practice (Fischer and Fischenich 2000). Castelle *et al.* (1994) defined riparian

buffers as "vegetated zones located between natural resources and adjacent areas subject

to human alteration" (p. 879). It is a simple concept that states that there should be a zone, of some specified width, on either side of a creek or around bodies of water or wetlands (or other sensitive feature) for the purpose of protecting that feature from the negative effects of human activities and/or protecting or restoring the associated aquatic/terrestrial ecosystems. The most important factor, and the most contentious, is the width of the buffer zone. Keller *et al.* (1993) stated that "the effectiveness of riparian forests to perform ecological functions including acting as dispersal corridors between forest fragments, enhancing the biodiversity of agricultural landscapes, and helping to improve water quality depends upon the width of the riparian forest" (p. 138). Should the buffer be fixed-width or variable-width? Should it be divided into sub-zones (Zone 1, Zone 2, etc.) with different degrees of regulation and land use? Should different features be buffered different distances? These are the main issues facing planners and policy makers when trying to establish a model for riparian buffering. In order to focus the discussion of best practices for riparian buffering, I am going to answer some of these general questions. This should help clarify the type of buffering methods that are applicable to the issues in Beaver Creek that drove the research into creating the data and geoprocess models that will be discussed in Chapter 5.

Best Practices in Riparian Buffering

There have been many buffering plans created in the interest of preserving habitat and improving water quality in an effort to elevate the health of watersheds and their inhabitants. The designers of these plans range from small cities to entire states to the federal government. In almost all cases, the term "best practices" is thrown around quite

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a bit, but what defines a best practice? In general, a best practice asserts that there is a certain way to accomplish a task that is more effective at producing a particular result than any other way. According to Wikipedia, best practices can also be defined as "the most efficient and effective way of accomplishing a task, based on repeatable procedures that have proven themselves over time for large numbers of people" (2008). In effect, a best practice is a consensus by experts on a method for dealing with a particular issue. Many of the methods for riparian buffering have come from agricultural researchers, foresters, and ecologists who have been looking at ways to solve problems with erosion and pollution caused by poor farming and grazing practices or poor forest management. David J. Welsch, who is often cited for his 1991 work "Riparian Forest Buffers, Function and Design for Protection and Enhancement of Water Resources," was working with the Forest Service when he detailed the three-zone system of buffers for application in the Chesapeake Bay watershed that is now widely accepted as a best practice. Additional research by other experts led to the inclusion of multiple variables that have been observed to be critical factors in the healthy function of riparian areas. Some of these variables include soil type, plant nutrient uptake, subsurface and overland flow rates, and appropriate management of uses (e.g. grazing and harvesting) in riparian areas. The conclusions drawn by this additional research have led to the formulation of guidelines that suggest solutions to the questions of effective widths, types, and methods of buffer implementation. These suggestions have been tested and compared to areas where problems exist, and the suggestions that have been observed to be consistently beneficial have been generalized and included in best practices guidelines. In order to be widely accepted, a best practice is usually general enough to be effective in a variety of

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situations. The specific conditions on the ground in the assessment area will have to be examined in order to choose which practices and implementations are going to be appropriate. See **TABLE 4.1** for a summary of the general width requirements for key buffer functions based on extensive literature reviews on the subject by Fischer and Fischenich (2000).

Riparian Buffering Practices Compared

With all the available information, it would seem that designing a buffer model would be relatively straightforward. But the devil is in the details. Suggestions for best practices are just that: suggestions. Fischer and Fischenich in a study conducted by the U.S. Army Corps of Engineers in 2000 found that the "criteria for determining the proper dimensions of buffer strips for some [riparian] functions is not well-established and recommended designs are highly variable" (p. 3). The report identified over 30 different recommendations for buffer widths based on criteria ranging from water quality improvement to habitat for individual vertebrate species (summarized in **TABLE 4.1**). How does one choose from the available guidelines which implementations will be of the greatest benefit? First, the primary objectives of the buffer plan should be determined. Is the goal to protect water quality? Stabilize eroded or erosion-prone stream banks? Attenuate flooding? Protect wildlife habitat? All of the above? The question of primary objective will need to be answered before any buffers are delineated. The Beaver Creek Watershed GIP was driven mainly by water quality and flooding issues, so these factors primarily drove the choices regarding the buffer criteria for the data model.

Table 4.1 Summary of important buffer functions and recommended buffer widths (after Fischer and Fischenich 2000)

Buffer Function	Description	Recommended Width[1]
Water Quality Protection	Buffers, especially mixed forest and dense grassy or herbaceous buffers on gradual slopes, intercept overland runoff, trap sediments, remove pollutants, and promote ground water recharge. For low to moderate slopes, most filtering occurs within the first 30 ft, but greater widths are necessary for steeper slopes, buffers comprised of mainly shrubs and trees, where soils have low permeability or are highly erodible, or where nonpoint-source pollution loads are particularly high.	15 to 90 ft
Riparian Habitat	Buffers, particularly diverse stands of shrubs and trees, provide food and shelter for a wide variety of riparian and aquatic wildlife.	90 to 1500 ft or more[2]
Stream Stabilization	Riparian vegetation moderates soil moisture conditions in stream banks, and roots provide tensile strength to the soil matrix, enhancing bank stability. Good erosion control may only require that the width of the bank be protected, unless there is active bank erosion, which will require a wider buffer. Excessive bank erosion may require additional bioengineering techniques (see Allen and Leach 1997).	30 to 60 ft
Flood Attenuation	Riparian buffers promote floodplain storage due to backwater effects: they intercept overland flow and increase travel time, resulting in reduced flood peaks.	60 to 450 ft or more[3]
Detrital Input	Leaves, twigs, and branches that fall from riparian forest canopies into the stream are an important source of nutrients and habitat.	10 to 30 ft

[1] Ranges based on synopsis of values reported in the literature.

[2] Some wildlife species require much wider riparian corridors; research to determine specific needs will be required.

[3] Inclusion of the floodplain is highly desirable for improving overall buffer function.

But that is not to say that the other factors are being ignored, because the buffers that are effective for water quality and flood mitigation are also quite effective in addressing erosion and riparian habitat factors. Specific species habitat issues are the most difficult to attenuate, due to the high variability in the patterns of land and water use of different species. If the driving issue in a hydrologic protection assessment is habitat, then detailed studies of the movements and needs of the native species in an area will have to be conducted in order to help identify appropriate buffers (Fischer and Fischenich 2000). In the Beaver Creek assessment, the habitat issues were handled separately from the general water quality buffer requirements. By taking a more general approach to the treatment of the hydrologic network protection, a method was created that is more flexible and can be more widely applied. So, in the following discussion of the creation of a buffer plan, the issues will focus on the general requirements of water quality, flood mitigation, and habitat stabilization (i.e. reduction of disturbances) in riparian areas. I will review a selection of the model buffer ordinances and suggested regulations that fit these criteria and compare their major aspects.

When selecting buffering practices, I began my search at the top, i.e. I started with the highest authority on environmental policy in the country: the U.S. Environmental Protection Agency (EPA). The EPA has created model ordinance and suggested methods for buffering sensitive hydrologic features to protect riparian areas and to restore their primary functions of water treatment and flood control. They also provide references to other state and municipal plans that they feel have the design and attributes necessary to be effective. (In fact, the EPA plan is based heavily on the Baltimore County, Maryland plan). I then looked at some ordinance regarding water quality buffers suggested by

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eastern states and municipalities, since the topography, soils and geology, climate, and settlement patterns are comparable. Note that the purpose of this discussion is not to debate the legal and legislative issues associated with the implementation or enforcement of buffer zones; the ordinance is merely the source of the parameters used for determining the buffer size and the features considered, which is the primary concern of the development of the data model and methodology for delineating the buffers with GIS geoprocessing tools.[*]

I decided to use the EPA general guidelines as a reference point for comparing the different buffer widths and the features that the buffers protect. I did this because many of the ordinances reviewed have taken after the EPA guidelines and then been modified or expanded to include additional features or buffer rules. I selected other ordinances and reference documents and assessed them for their recommendations as well. In order to keep the comparison focused on references that meet the basic water quality improvement and flood mitigation goals, I only compared buffer ordinances that meet the following general criteria, based on EPA recommendations: 1) the buffer must be based on measurable criteria that identify the type of feature and the buffer distance; 2) the buffer must maintain a minimum width; and 3) the buffer must use the "zoned" approach to allow for variability in buffer size, function, and allowable uses, which maximizes their operability. In addition to the expert buffer recommendations, I am including in this comparison the parameters used in the Beaver Creek Watershed GIP and my selections for analysis in the water protection data model. The results can be seen in **TABLE 4.2**.

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[*] For more information regarding legal issues and buffer enforcement, see "A Stream Corridor Protection Strategy for Local Governments" prepared by the University of Virginia Department of Urban and Environmental Planning of the School of Architecture, Institute for Environmental Negotiation.

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Table 4.2 Comparison of riparian/water quality buffer best practices from model ordinance and suggested regulations

			Source of Model Ordinance or Reference Document						Beaver Creek Watershed GIP[g]	ALW Proposal for Hydrologic Conservation Model
			U.S. Environmental Protection Agency[a]	Baltimore County, Maryland[b]	David J. Welsch (1991) Chesapeake Bay Watershed Recommendations[c]	North Carolina State Proposed Buffers[d]	VA & MD Dept. of Forestry Buffers (from NRCS guidelines)[e]	Tennessee Dept. of Environment & Conservation (TDEC) MS-4[f]		
Zone size (min. ft) from edge		Zone 1	25	75	15	50	35	25	25	25
		Zone 2	50	25	60	50	15	25, 75	50	50
		Zone 3	25	n/a	20	n/a	n/a	n/a	25	25
		Total (min.)	100	100	95	100	50	50-100	100	100
Primary features considered for protection			streams (SO); (Z1, SO3+, 25ft)	streams (SO)	streams	streams	streams	streams (SO)	streams (SO); (Z2, SO3+, 25ft)	streams (SO); (Z2, SO1-2, 40ft; SO3+, 20ft)
			springs	springs	bodies of water	bodies of water	bodies of water	springs	springs (500ft)[3]	springs (500ft)[3]
			bodies of water	bodies of water	wetlands	wetlands	wetlands	bodies of water	bodies of water	bodies of water
			wetlands	wetlands				wetlands	wetlands	wetlands
Secondary features (zone of inclusion, additional buffer width requirement)[1]			floodplain: 100 yr. (1, 25ft)	floodplain: 100 yr. (1, 25ft)	steep slopes (1)			floodway (1)[2]	floodway (1)[2]	floodway (1)[2]
			steep slopes (1, 10-100ft)	steep slopes (1, variable)	soils (2, 25-75ft)			steep slopes (1, 20-50ft)	floodplain: 500 yr. (2)	floodplain: 500 yr. (2)
			land use (2, 100-300ft)	land use (1, variable)				land use (2, 50-250ft)	steep slopes (1, 20-50ft)	steep slopes (1, 20-50ft, catchment)
				soils (1, variable)					sinkholes (1)	sinkholes (1)
										soils (1, catchment)
Search Distance			200ft	100-500ft	n/a	n/a	n/a	50-100ft	75ft	75ft
Plan scale			variable	1:1,200	n/a	n/a	n/a	variable: site scale	1:24,000 (up to ~100k)	1:24,000

[1] Secondary features found within the search distance of the stream are added to the buffer. The features are given the same buffer requirement as the specified zone (unless noted otherwise), and the final width of the buffer in that zone is the greater of

[2] Where floodway is defined, the buffer should be floodway + 50ft or stream + 100ft, whichever is greater. Where floodway is not defined, the buffer should extend a total of 100ft from the edge of the stream (all three zones combined). In the Beaver Creek p

[3] Increased buffer around springs is applied within the overland catchment of the spring. The minimum distance required by Zone 1 is still enforced around the entire feature.

References:

[a] U.S. EPA. 2007 (last update). *Model Ordinances to Protect Local Resources: Aquatic Buffers*. http://www.epa.gov/nps/ordinance/mol1.htm (accessed July, 2008)

[b] Baltimore County, MD, Environmental Protection and Resource Mgmt. 2002. *Buffer Protection and Management Ordinance*. http://www.epa.gov/owow/nps/ordinance/documents/A2a-Baltimore.pdf (accessed July, 2008)

[c] Welsch, D. J., 1991. "Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources". USDA Publication NA PR 07 91

[d] Environmental Defense Fund. 2003. *Riparian Buffers: Common Sense Protection of North Carolina's Water*. http://www.edf.org/documents/2758_NCbuffers.pdf (accessed July, 2008)

[e] Natural Resources Conservation Service. 2006. *Conservation Practice Standard: Riparian Forest Buffer*. ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/391.pdf (accessed July, 2008)

[f] Tennessee Department of Environment and Conservation. 2004. *Tennessee MS4 Working Group Water Quality Buffer Zone Policy*. http://www.franklin-gov.com/engineering/STORMWATER/ms4.htm (accessed July, 2008)

[g] Moir-McClean, T., and M. DeKay. 2006. *Beaver Creek Watershed Green Infrastructure Plan*.

Buffer Methods: The Zoned Approach

All of the surveyed methods provide for the establishment of buffers with a zoned approach. The zoned buffer approach, popularized by David J. Welsch and his work to design a buffer strategy for the Chesapeake Bay watershed in the early 1990s, has been widely implemented and found to be a sound method (EPA, Baltimore County). This approach provides a framework through which water quality, habitat, and other objectives can be accomplished with variable-width buffer zones, each with different prescribed functions and allowable uses. The following summary of the three zones and their functions is based on the work of Welsch (1991) and supplemented by the review of riparian buffer best practices documents by Fischer and Fischenich (2000).

Zone 1 begins at the stream centerline or edge (depending on stream order and mapped scale) and provides bank stabilization and habitat for both aquatic and terrestrial organisms. Other primary functions of this zone include stream shading and contribution of biomass and large woody debris from mature forest vegetation, which is the most desirable type of vegetation for the zone. The natural vegetation in this zone also helps reduce flood effects, reduces bank erosion, and removes some sediments and nutrients. Generally, the vegetation should be composed of native trees and shrubs at a density that permits understory growth, and it should be able to tolerate frequent inundations. The width of this zone typically varies between 15 and 25 feet and can be expanded to include additional features such as adjacent wetlands or the floodway.

Zone 2 extends upslope from Zone 1 from a minimum of 15 feet up to several hundred feet, with 50-75 feet being generally sufficient, depending on the buffer objectives. This zone has the most flexibility in design, and is primarily the zone to

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consider any additional critical lands such as the floodplain (50- to 500-year) or areas of steep slope, or for making variations to the buffer based on specific attributes like stream order. The main objective in this zone is to provide a managed riparian forest with a vegetation composition and character similar to that of natural riparian forests in the region. The primary function of Zone 2 is to remove sediments, nutrients, and other pollutants from surface and groundwater. This zone, in combination with Zone 1, if made wide enough, also provides most of the desired habitat benefits by limiting disturbances, and allows for some human benefits as well in the form of low-impact recreational uses such as greenways.

Zone 3 typically contains grass or herbaceous filter strips and provides the first line of defense of the riparian area's water quality by dispersing and slowing runoff, allowing for infiltration, and filtering sediment. The minimum recommended width of Zone 3 is 20-25 feet. The primary concern in this zone is the protection of the stream from overland flow of non-point source pollution such as herbicides and pesticides applied to lawns and agricultural fields, and runoff from roads and parking lots. Properly maintained grassy and herbaceous buffer strips may also provide quality habitat for upland wildlife species. This zone can also support limited, low-impact human uses, usually dominated by residential yards or light agricultural uses such as haying or controlled grazing.

Primary Features Considered when Buffering

At the core of each of the buffer models reviewed is the stream and the associated riparian wetlands and bodies of water. While it may seem obvious that the stream is at

the heart of all riparian buffering methods, there is quite a bit of contention in the literature as to who defines a stream and what parameters should be used in their definition. Most of the model ordinances employ the definition of perennial or so-called "blue line" streams from USGS 7.5-minute topographic maps (1:24,000 scale). This is a common convention since these streams are clearly defined and marked on quadrangle maps, and in many cases, digital versions of these maps are available. In some areas, though, the USGS maps may be outdated or just plain wrong and there may be a need to derive a stream dataset from current aerial photos and/or a hydrologic analysis of a DEM. In other instances, a buffer plan may include intermittent streams or natural swales (ephemeral streams) that only flow during rain events. If this is the case, these features will need to be defined accordingly. All of the buffer documents referenced in this review are based either on USGS "blue-line" streams (perennial and intermittent) or on a map of the hydrologic network derived locally. Optionally, the NRCS soil maps tend to have a more detailed stream network than the USGS maps (at the same scale) and, if available, may provide a more suitable level of detail in the delineation of intermittent and ephemeral streams.

Another important aspect of streams that many of the model ordinances take into consideration is stream order. Methods that prescribe stream order be considered when delineating the buffers are denoted by "(SO)" in the comparison table (**TABLE 4.2**). Stream ordering is a system by which reaches are assigned a number to denote their relative size and position within the larger hydrologic network hierarchy. The most common method of stream ordering was first proposed by Horton (1947), then modified and popularized by Strahler (1952, 1957). The Strahler method (as it is commonly

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referred to) considers perennial or recurring (intermittent) streams and assigns values beginning with 1 for a headwater stream (no tributaries) up to 10 (for the Mississippi River) in the United States. When two streams of the same order join, the resultant stream is of the next higher order. If a lower order stream joins a higher order stream (e.g, a 1st order stream joins a 2nd order stream), the stream remains of the higher order. In this way, the stream hierarchy can be determined and different buffering strategies can be applied at each level within the network.

Assignment of stream order can be done programmatically or manually within a GIS software environment. In the BCWGIP, I manually assigned stream orders to the USGS 100k hydrology dataset that was used in that analysis. In the dataset developed for the testing of the data model I designed for this thesis, a new, more detailed stream network was delineated and stream order assigned programmatically. Because the level of detail in the new stream dataset is higher and more tributary creeks are identified, the stream order attribute is the one major difference when the BCWGIP and thesis datasets are compared. In the thesis stream dataset, which is comparable in level of detail to a 1:24,000-scale topographic map, the highest stream order of Beaver Creek is 5 while in the original 100k assessment it was only a 3, which creates some major differences in the spatial implications of the plan, which I will discuss more in Chapter 6.

For plans that prescribe the use of stream order as one factor in determining buffer width, there are two common implementations. The first is to add an additional buffer, in the first zone, of around 25 feet to streams of the third order and higher, bringing the total Zone 1 buffer to 50 feet for those streams. This increase in the buffer size on streams of a higher order is usually associated with flood mitigation strategies that prescribe lower

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levels of disturbance in the flood-prone lower reaches of the stream network. The second

implementation strategy is basically the opposite. Lower-order streams, which can make

up more than 75% of the total stream length (and if proportional to inflow, of total

pollutant loading) in a watershed (NRC 2002), have an obvious impact on water quality

and flooding downstream. These headwater streams are collectors of the majority of

overland flow and are impacted the most by contributing factors such as steep slopes or

erodible soils (Gilliam 1994). For these reasons, some plans call for a larger Zone 1 or

Zone 2 buffer on the first- or second-order streams, and may stipulate buffers for

intermittent or ephemeral streams that only flow seasonally or during storm events for

increased protection.

After streams, other surface waters are the primary features for consideration in

the buffer models. All of the model ordinance and reference documents I surveyed,

including the many that are not referenced directly, call for the inclusion of surface

waters such as ponds, lakes, and wetlands. The buffer requirements for these features is

generally the same as for a stream, and the buffer is measured from the mapped extent of

the feature. Where the feature buffers intersect, as would be with the case of a stream

running through a marshy (wetland) area, the buffers are combined so to maintain

continuity and keep the related features protected as a unit. Sources for these features can

be similar to those for streams. The USGS 7.5-minute quadrangle maps are a popular

source, as well as the National Hydrography Dataset, and the National Wetlands

Inventory. As with the streams, there may be some contention as to the delineation of

wetlands and bodies of water, as they are dynamic features that change over time due to

natural and man-made causes. In the case of wetlands, their delineation can be aided by

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detailed soil maps, as hydric soils are generally associated with wetland areas. In my review of the literature, not much discussion was dedicated to how different types of ponds or lakes (man-made, natural, etc.) should affect buffering. Generally, there was no differentiation, so these features get the same treatment as streams if they are in proximity to one another.

Springs or seeps are another important part of the surface and groundwater system, as they are often the origin point of headwater streams and sources of drinking water for humans. They can also be the outlet of hydrologic sinks in upland areas and thus can be the source of reemergence of pollutants that have drained to the sink and flown through the subsurface. Major springs are denoted on USGS maps and have often been identified locally for their use as sources of drinking water. Not all the buffer plans called for protection of springs and seeps, and if they do, their buffers are not treated differently. Some areas may have separate wellhead or drinking water source regulations and do not include springs in the buffer ordinance. In Florida, for example, their wellhead ordinance calls for large 500 foot setbacks to protect springs and wellheads. The Beaver Creek Watershed GIP looked to model wellhead and drinking water source protection ordinance to get better information about the protection of these critical hydrologic features. Others may not have considered these features for inclusion if the buffer plan was geared more towards habitat protection or riparian forestry applications. In many cases, it may be that the spring is included in the buffer by default, since a stream (whose origin is a spring or seep) would have a buffer that covers that source point as well. In the EPA, Baltimore County, and Tennessee models (as well as the

BCWGIP), spring buffers are considered part of the critical Zone 1 and the size may be modified if desirable.

Secondary Features Considered When Buffering

Once the primary and most critical features for buffering have been identified, the buffer plan can be expanded to make the buffers more effective at achieving their plan goals. For the buffer methods I reviewed, water quality and flood control were issues of primary concern. In general, most of the plans make provisions for two important secondary features for consideration: areas of steep slope and the floodplain.

Slope is defined as the ratio of vertical distance (rise) to horizontal distance (run). The two ways that slope is commonly expressed are degree of slope and percent of slope. Degree of slope (θ) is measured by taking the inverse tangent of the rise over the run [$\theta = \tan^{-1}(\text{rise} / \text{run})$]. Percent of slope is calculated by dividing the rise by the run and multiplying by 100 [$\% = (\text{rise} / \text{run}) * 100$]. The range of values for degree of slope is 0 (horizontal) to 90 (vertical). Percent of slope ranges from 0% (horizontal) to approaching infinity (vertical). 45° slope is equal to 100% slope. Most of the model ordinance that specify the use of slope values in determining buffer width express them in percent of slope. Slopes are often referred to as areas of steep slope. In a typical analysis of this nature, slopes are derived from digital elevation models (DEMs) by a raster geoprocessing function in a GIS software environment. The input elevation raster is evaluated on a cell-by-cell basis using an algorithm that is applied to the cell and its immediate 8-cell neighborhood. The result is a raster dataset whose cell values represent the slope at the center of this neighborhood. The slope raster can then be reclassified to

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"bin" values within certain ranges together, creating continuous zones of slope within the specified ranges (i.e. 0-14%, 15-24%, 25% +).*

The use of slope in determining buffer width is based on the idea that the steeply sloped area itself is generally *not* the feature being protected. Areas of steep slope are usually managed in municipal plans by specific steep slope no-build ordinance due to their possible instability and the difficulties that arise from trying to mitigate impacts like erosion and landslides once built upon. Areas of very steep slopes are not useful as areas for infiltration and filtering of sediment, which are primary functions of effective water quality buffers. Steeply sloped areas are areas where overland flow is accelerated and possibly channelized on its way to the stream, contributing to water quality problems. These areas are included in the buffer as impacts that need mitigation with additional setbacks in order to slow the flow in the areas above the steep slopes and to protect the slopes that are proximate to sensitive hydrologic features from being disturbed and contributing to sedimentation.

Slopes under 10-15%, if they are properly vegetated and the soils have high enough infiltration rates, are considered flat enough to function effectively for filtration of sediments and slowing of overland flow and buffers are not typically recommended in the literature. Beyond that range, the model ordinances have varied suggestions for the treatment of these areas. In their simplest application, buffers can be added to steep slopes based on the percentage range within which the area falls. The EPA guidelines use this simple method, whereby slopes within a certain range, say 15-25% are buffered 20 feet and slopes over 25% are buffered 50 feet. There are also more advanced methods

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* For more information on this process, see the ESRI ArcGIS Desktop help documents for the Slope function.

of slope buffering. The Baltimore, Maryland plan calls for the use of a formula that calculates a score for land within 500 feet of a hydrologic feature based on percent of slope, slope length, soil erodibility, land cover, and land use. The score for each reach of the stream network is used to define the buffer width. This type of scoring method is best accomplished through a raster overlay analysis of the various factors, reclassifying each raster based on the plan criteria and then adding them together to derive the score. This type of variable-width buffering, while comprehensive, can be difficult to map and enforce due to the highly variable nature of the input parameters and the possibly awkward spatial implications of the output. Another method for slope integration is to combine aspects of both of the methods just described. By intersecting the slopes with soils and analyzing and buffering the output, the interaction between steepness and erodibility can be assessed and mapped rather easily. This method will be discussed in more detail later on.

Another important set of secondary features that many buffer plans call for consideration are the floodway and/or floodplain. Some of the plans, including the Beaver Creek plan, call for the inclusion of both. The Federal Emergency Management Agency (FEMA), the agency in charge of the National Flood Insurance Program, is responsible for the definition and mapping of these areas. FEMA defines the floodway as "the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height" (FEMA) In other words, during a normal rain event, the river or stream requires a certain area to hold the additional flow without increasing the surface elevation of watercourses upstream to flood stage equal to

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a 100-year event. The floodplain is the area including the floodway and adjacent lands that are inundated during a rain event that loads the network beyond its normal carrying capacity. FEMA maps these areas for flood insurance purposes and defines them in terms of the probability of inundation based on the interval of occurrence. The common definitions are the 100- and 500-year interval weather events that cause flooding, creating what are mapped as the 100- and 500-year floodplains.

The EPA, Baltimore, and Beaver Creek plans all call for the inclusion of the floodplain in the buffered area. In the EPA and Baltimore plans, the 100-year floodplain is the choice for inclusion. In the Beaver Creek plan, the 500-year floodplain was considered due to the fact that as development encroaches on the natural floodplain, the impacts of flooding will increase due to the reduction in capacity. By integrating the 500-year floodplain into the buffer, more of the critical lands needed for flood retention are protected and thus the damaging effects of flooding will be less severe. The Beaver Creek plan also calls for the inclusion of the floodway in Zone 1. In lower reaches of the watershed, the floodway can be a significant portion of the floodplain, especially if the channel becomes narrow or deeply entrenched, and protection of these areas is especially critical.

Other secondary features that can be considered in buffering plans include soils, land use, and land cover. In the slope section, I mentioned the inclusion of soils, but in areas where slope is not a significant issue (in parts of the Midwest, west Tennessee, or the coastal plain, for example) then soil type may be considered as a stand-alone feature for its infiltration or erodibility attributes. For example, sandy soils are less effective at filtering, since water moves through them quickly, and may require a buffer if adjacent to

a sensitive feature. Conversely, clay soils have low infiltration rates and permeability, making them poor at filtration leaving more of the flow to remain overland. These types of soil may need to be buffered or have the vegetation managed in order to improve their functionality in a water buffer.

Land use is typically integrated into the buffer when considering existing residential, commercial, or industrial uses that are hazards to water quality. The Tennessee Department of Environment and Conservation (TDEC) prescribes additional buffers around certain uses if they fall within the minimum buffer of 50 feet on streams with no floodway or 100 feet on streams with a defined floodway. Examples include residential septic drain fields (add 50 feet), hazardous materials storage (add 100 feet), and landfills (add 250 feet). Land cover can also be a factor considered in buffering, and is usually used in combination with one or more other factors. In areas that are heavily agricultural, land cover in combination with soils can be considered so as to reduce the amount of erosion caused by the destruction of the vegetation and disturbance of the soil near a stream or water body by cattle. Impervious surface is also an important issue that is identified in some plans and is treated similarly to slope. Areas of imperviousness within a search distance from the sensitive feature, such as roads, are cause to add additional width to the buffer. This is not always effective, however, since the imperviousness might be very close to the sensitive feature and, in the case of a road, difficult to move out of the buffer zone due to factors such as cost or topography.

Treatment of Sensitive Features in Upland Areas

The presence of karst topography in many areas in the United States brings up an important issue: how should features that are not directly linked to riparian areas on the surface but are part of the total hydrologic network be treated in a buffer plan? Sinkholes are probably the single most important link between the surface and groundwater, due to the nature of the formation of sinkholes in karstic areas. Karst is a generic term which refers to the characteristic terrain produced by erosional processes associated with the chemical weathering and dissolution of limestone or dolomite, two common types of carbonate rocks. Dissolution of these rocks begins when they are exposed to acidic water and it reacts with the calcium and/or magnesium carbonate compounds. Most rainwater is slightly acidic and usually becomes more acidic as it flows over the surface through decaying plant debris. Sinkholes originate beneath the surface when this water percolates through cracks and eventually (over long periods of time) erodes large underground cavities in the rock. When the cavity is full of water, the walls and ceiling are supported, but if the water table drops or fluctuates, the cavity is weakened and exposed to further erosion that eventually results in the collapse of the cavity, causing the area on the surface above the collapse to "sink", creating a sinkhole (Florida Department of Environmental Protection 2003). Once established, the sinkhole becomes a primary site of groundwater recharge, since surface water can enter the aquifer directly, replenishing the subsurface water supply. This, of course, also creates a place where pollutants can enter the groundwater directly, with potentially disastrous effects. Protective measures need to be taken to insure that groundwater resources are protected in addition to surface water.

In East Tennessee, the presence of many known caves, sinkholes, "sinking" creeks, and springs are direct evidence that there is an extensive portion of our hydrologic network under the surface, and that means we need additional protection of these features in order to maintain good water quality. The EPA buffer recommendations are general enough that they make reference simply to "sensitive features", allowing for the inclusion of just about anything that is deemed to be locally important to the overall health of the hydrologic network into the buffer plan. In the Beaver Creek plan, ordinance from Florida, Minnesota, and others was reviewed for recommendations on how to handle the addition of sinkholes in the buffer system. In most cases, simple setbacks (buffers) measured from the sink edge are prescribed for the protection of the area around the sinkhole. This is important because any disturbance on the surface can cause the sinkhole to weaken and collapse, causing significant property damage. Also, unapproved uses or filling of sinkholes can create a potential environmental disaster if a large amount of pollutants are allowed to drain into the sinkhole. In Knox County in 2002, the City of Knoxville and a demolition contractor who dumped 800 truckloads of concrete mixed with contaminated soil from an old inner city industrial site into a large sinkhole in South Knoxville were sued by residents after 17 wells near the site tested positive for contamination with diesel fuel. While the results of dye-testing by TDEC were ruled inconclusive, the City and the contractor were pressured by residents and the State to clean up the site at a cost of $800,000, and the installation of a new municipal water line to provide the area with clean water cost another $1 million. The lawsuit was finally settled in early 2006 before it went to trial, and while the details of the settlement were not disclosed, the initial claim would have put the damages at nearly a half-billion dollars

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(150 plaintiffs at $3 million each plus an additional $20 million for the group = $470 million) (Barker 2002, 2005, 2006). In the aftermath, the State passed legislation to increase the fines for illegal dumping in sinkholes, and TDEC has continued testing in the area to identify the source of the contamination. These kinds of cases are precisely the reason that increased awareness and better management of sinkholes and their surrounding areas are so important. The costs associated with cleanup and property damage far exceed the costs of designing, implementing, and enforcing a plan to protect these areas and to adequately compensate landowners for any loss-of-use.

Summary of Buffer Techniques Used in Beaver Creek

Effective buffering plans are flexible in design. The consideration of different features and their attributes can be leveraged to design buffer plans that are tailored to the area for which they are to be implemented. The features and their uses I have described here are only a sample of the possibilities that exist when designing a buffer plan. The plans I reviewed here were chosen because they were general enough to be widely useful, and contain the major features and appropriate buffer widths for maintaining a wide variety of water quality, flood mitigation, and habitat preservation goals. I will now describe in more detail the specifics of the Beaver Creek buffer model and the methods that were used to execute the plan.

The basic method of the Beaver Creek plan is based on the EPA three-zone buffer system first suggested by Welsch. The TDEC suggested water quality buffer method is also based closely on the EPA method, so the Beaver Creek plan took cues from it as well. The major features included for protection were: 1) the USGS streams and surface

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water (100k); 2) the FEMA-defined floodway and 500-year floodplain; 3) NWI wetlands (100k); 4) USGS springs (24k); 5) USGS sinkholes (24k); and 6) areas of steep slope delineated from USGS 10-meter DEMs. Using the floodway and the streams as the minimum set of features for protection, sensitive features were spatially queried within a distance of 75 feet. This had the effect of selecting all the wetlands, springs, sinkholes, and steeply sloped areas within the minimum buffer requirement for Zone 2 (Z1 + Z2 = search distance; 25 feet + 50 feet = 75 feet) in the interest of creating a contiguous linear stream-side buffer. Once those features had been identified, the buffer rules for Zone 1 were applied to them (25 feet). For the streams and the floodway, the 25 foot buffer is applied to both and the final Zone 1 buffer is the wider of the two, since the floodway is not defined in upper reaches of the watershed. All buffers are applied perpendicularly from the boundary of the feature. Once Zone 1 was identified, the Zone 2 buffer was created. For streams that were designated as first- or second-order, the Zone 2 buffer was 50 feet, and for streams of third-order or higher, 75 feet was added to the Zone 1 buffer. The 500-year floodplain is also included in Zone 2, buffering it 50 feet, and as in Zone 1, the final buffer is the wider of the final stream or floodplain buffer. All other features are given a 50 foot buffer in Zone 2 except springs, which were given a 450 foot buffer in their upland catchment. Zone 3 has no special considerations and the Zone 2 buffer is simply buffered 25 feet. See **FIGURES 4.1-4.3**.

The remaining sensitive features that were not selected as part of the stream-side buffer were considered part of the upland buffer. These features were buffered with the same rules as the stream-side features in each zone: 25 feet in Zone 1, 50 feet in Zone 2, except springs which were buffered 450 feet, and 25 feet in Zone 3. These upland

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features are an important part of the Beaver Creek buffer design. The specific treatment of sensitive hydrologic features in the upland elevates the Beaver Creek method to a higher level of protection than the basic riparian buffer methods outlined by the EPA. It becomes a complete water quality buffer, not just a riparian buffer. See **FIGURES 4.1-4.3**.

Summary of Additional Buffer Techniques for Geoprocessing Model

The Beaver Creek Watershed GIP was developed using as many of the best practices that could be implemented in a practical way with the data and resources that were available at the time. I have since conducted additional research into buffering methods, coupled riparian best practices with methods of protecting upland features, and added new methods for protecting sensitive soils and the implementation of catchment-based rules.

The two major additions to my method for buffering sensitive hydrologic features compared to the Beaver Creek plan are the use of soils and the use of feature catchments. The Beaver Creek plan used soils in the conservation neighborhood suitability analysis and grassland and farmland preservation proposals for the attributes of permeability and suitability for agricultural uses, respectively. We did not, at that time, consider its use in the water quality buffer method. In my research after the completion of the BCWGIP, I found that many authors, including Welsch and Fischer and Fischenich, stated that soils could be a significant factor in determining buffer width. Specifically, the consideration of erodibility of the soil was important.

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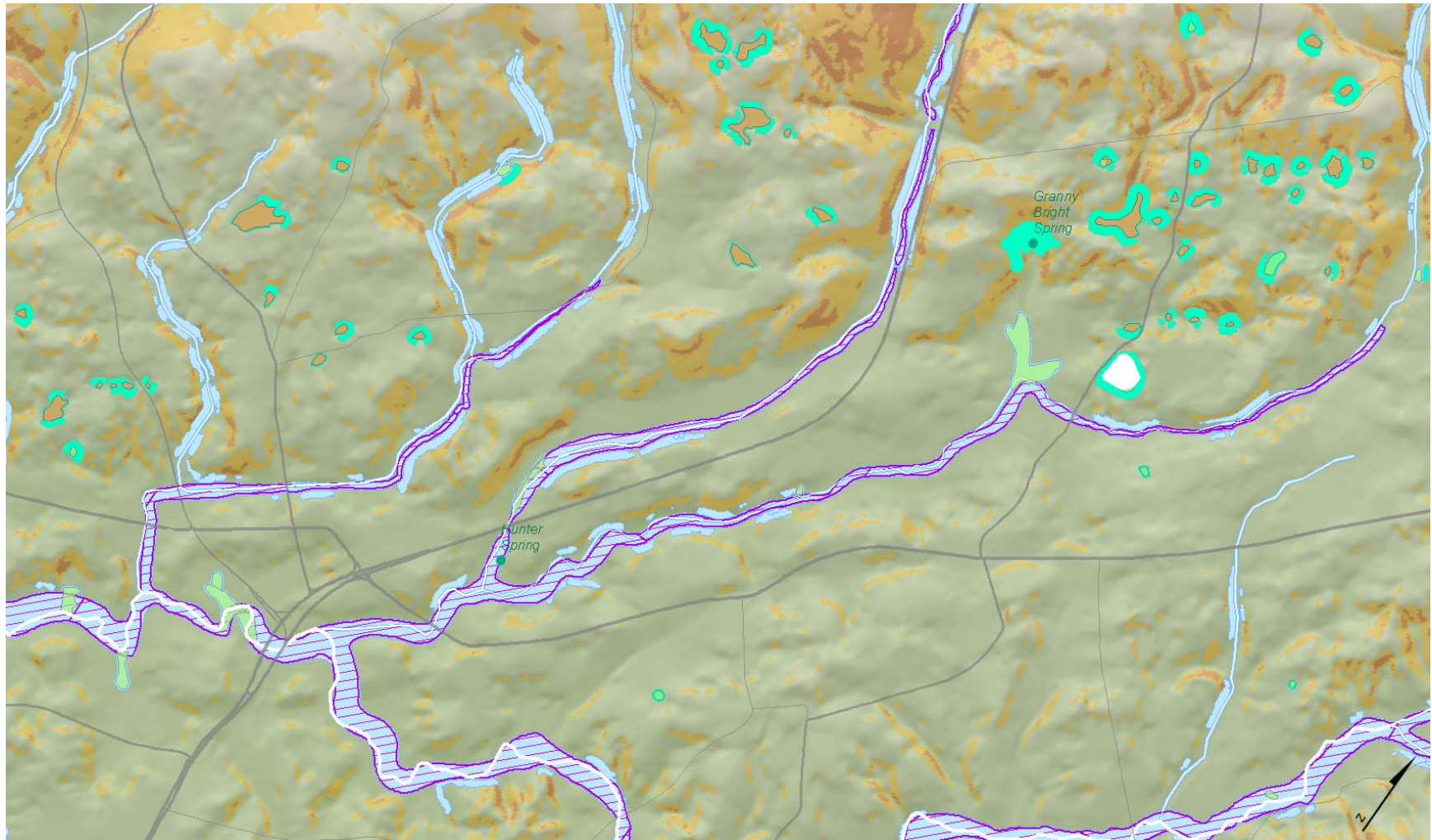
Figure 4.1 BCWGIP buffers in Zone 1. Streams (white lines) and the floodway (purple hatching) are used as the base by which other sensitive lowland features are selected (within 75 feet) and buffered 25 feet. Features not selected in the initial riparian selection become part of the upland feature buffers (light greenish-aqua). They are mostly sinkholes (light brown) and wetlands (pale green) or water bodies (white). Steep slopes in proximity to both lowland and upland features are selected by proximity (within 75 feet) and clipped to that distance and buffered 25 feet. This becomes the Zone 1 Edge Protection buffer, protecting the most critical areas around sensitive features and impacts.

91
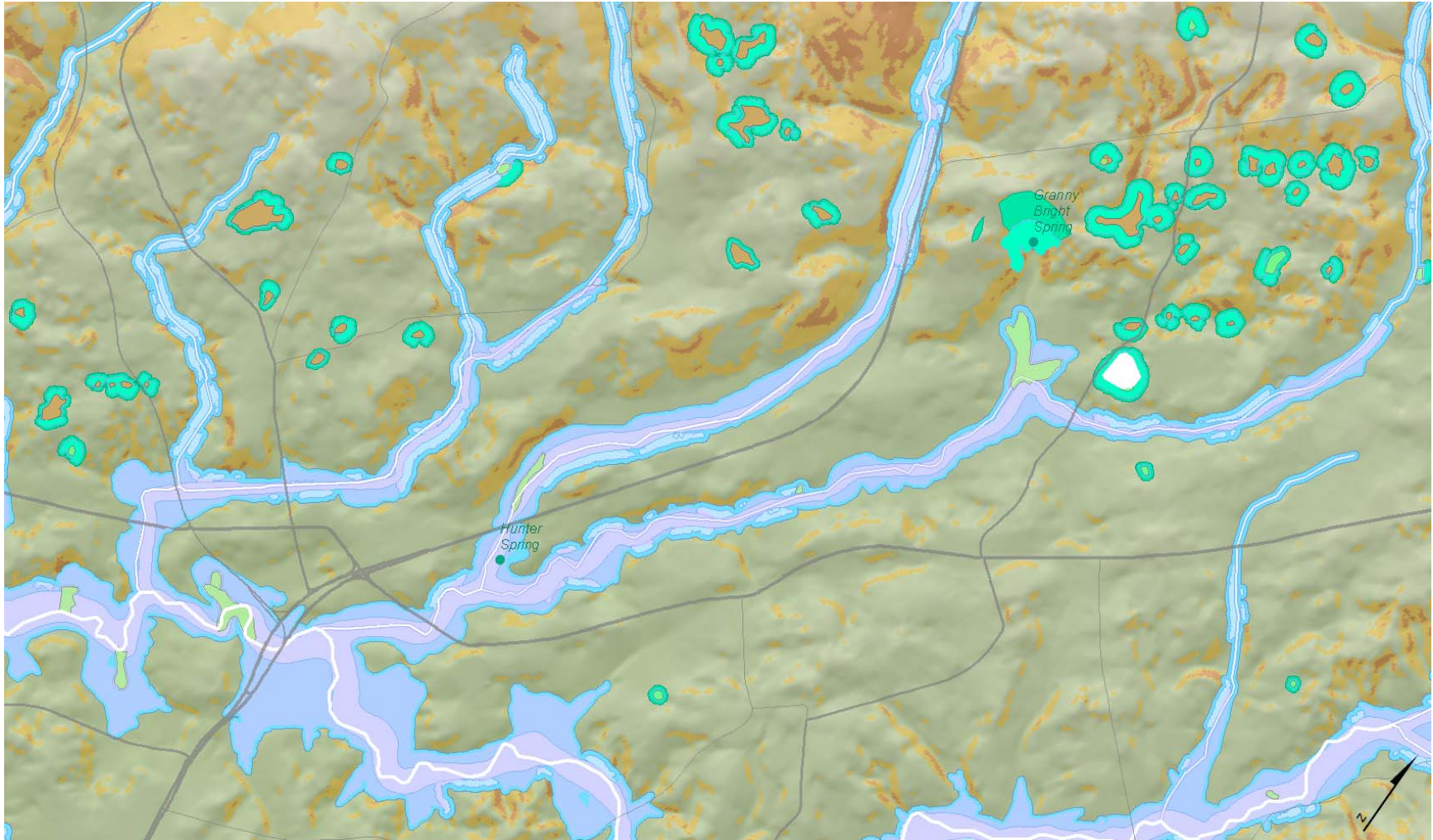
Figure 4.2 BCWGIP buffers in Zone 2. In Zone 2, the FEMA 500-year floodplain (light pinkish-purple) overlays the floodway (pink) and is buffered 50 feet to expand the lowland buffer. First- and second-order streams are buffered 50 feet (thinner white lines) and third- order streams are buffered 75 feet. Additionally, the springs are buffered 450 feet and clipped to their overland catchment (Granny Bright Spring). All other features in the lowland and upland are buffered 50 feet. The Zone 2 buffer's main functions are flood attenuation and the conservation of areas that should be allowed to thrive as riparian habitat.

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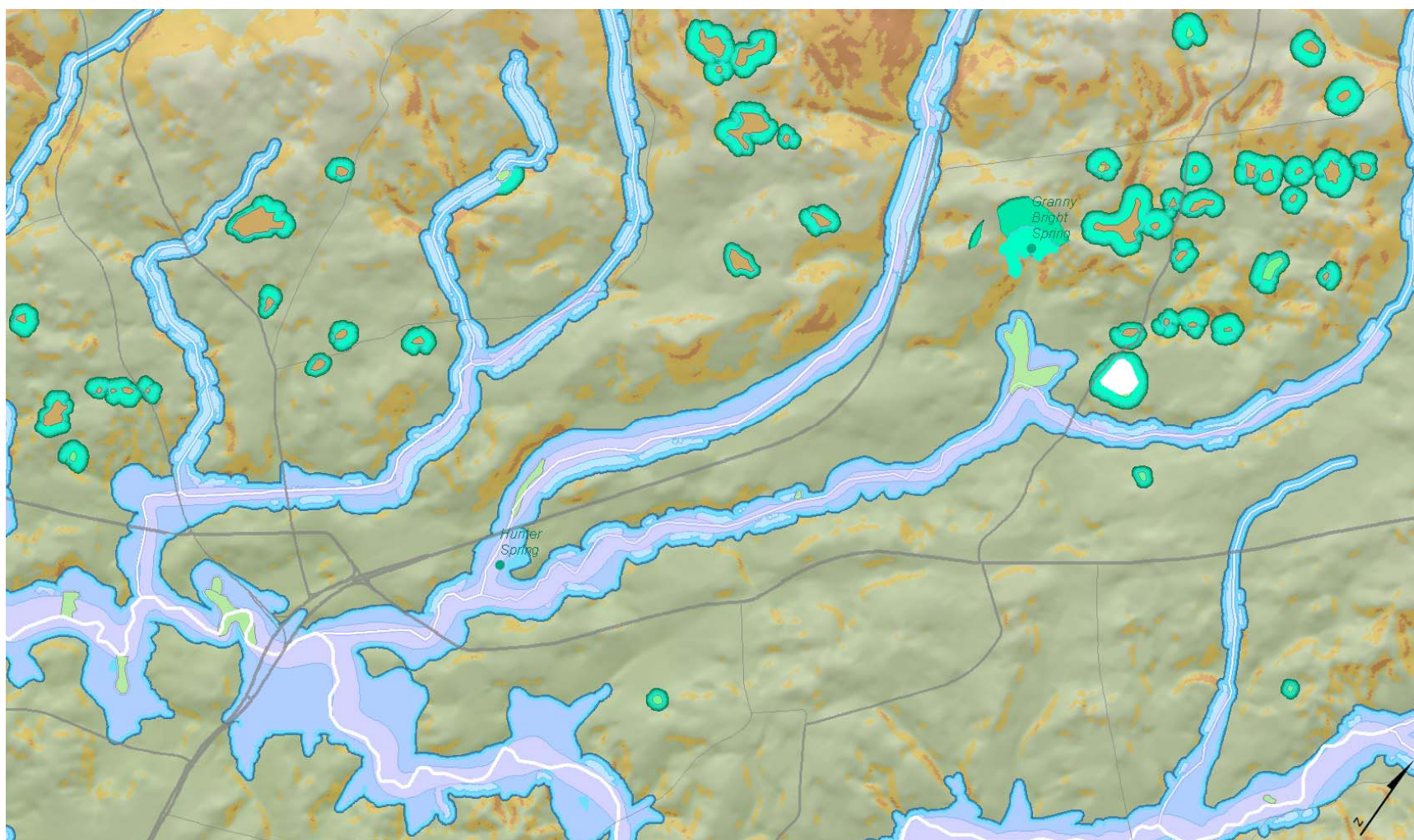
Figure 4.3 BCWGIP buffers in Zone 3. The Zone 3 buffer (dark blue ring) is simply a 25 foot buffer of the Zone 2 buffer, with the spring buffers continuing to be clipped by their overland catchments (Granny Bright Spring). The purpose of the Zone 3 buffer is to define an area of transition between traditional residential yards and landscaped areas and the more natural character of the lands in Zone 2.

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Since the Knox County soil survey has been recently updated (2000) and a digital version of the mapped soils is available, I decided that its addition would be beneficial to my buffer model. Also, since the idea for the buffer model is to be more widely useful, soils may play a more significant role in determining buffer width in an area where agricultural land use or erosion and sedimentation are key issues in a plan for controlling or restoring water quality. The basic method for the use of soils in my model is to use them in conjunction with the slopes, determining the buffer width of sloped areas based on a combination of steepness and soil erodibility.

The second, and more significant addition to my buffer plan is the addition of catchment-based rules for determining the spatial implication of the buffers. A catchment is defined as the surface area that is drained by a specific feature. The feature can be a spring, creek, or a sinkhole or lake. For example, a watershed drained by a creek is a type of catchment. While the use of catchments was identified as an important factor in determining the buffers for springs and sinkholes in the BCWGIP, catchment-based buffering could only be implemented for the springs due to time and personnel constraints. In the Beaver Creek plan, catchments were derived by hand for the springs that were identified for buffering. Not only was this a laborious and time consuming process, but it was difficult to reconcile with other datasets used in the analysis. In my subsequent research and development of improved datasets for my buffer analysis, I discovered two problems: 1) we had identified all of the named springs in the Beaver Creek Watershed and surrounding area, but there were a significant number of unnamed springs that had not been found; and 2) the catchments we delineated for some of the springs had been exaggerated or incorrectly mapped. To combat these two problems, I

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spent a significant amount of time identifying the locations of unnamed springs on the USGS 7.5-minute topographic maps, which coincided with my development of a more detailed stream network and better sinkhole delineation. The spring locations were then analyzed with the Pour Point function within the Hydrology toolset of ArcGIS to delineate the spring feature catchments from DEMs. For sinkholes, the delineation of catchments was similarly facilitated by the use of DEMs and geoprocessing tools. A sinkhole catchment is defined as the area surrounding the feature that drains to the sink. In some cases, the catchments are large enough that a small creek will develop and drain into the sinkhole. These are of particular interest for protection and my buffer plan has specific methods to deal with these "upland" streams. This approach provided a more consistent and faster delineation of the catchments of the springs and sinkholes.

As mentioned previously, watersheds are also types of catchments. Within a watershed, many sub-watersheds can be delineated, down to the catchment of each individual reach of the stream network. One problem in the Beaver Creek plan was that in steeply-sloped areas, the selection of slope zones in proximity to a sensitive feature resulted in large areas being added to the buffer that did not actually contribute directly to the feature being protected. To solve this problem in the BCWGIP, the slope areas were clipped to the search distance of 75 feet measured perpendicularly from the feature edge and buffered. I decided that this was an arbitrary measure and that the buffer would make more sense if the slope areas were divided up by the catchments that drain them, so that the buffer protects the steep slope that drains to a sensitive feature and leaves slopes that have no direct influence on a sensitive feature out of the buffer. See **FIGURE 4.4**.

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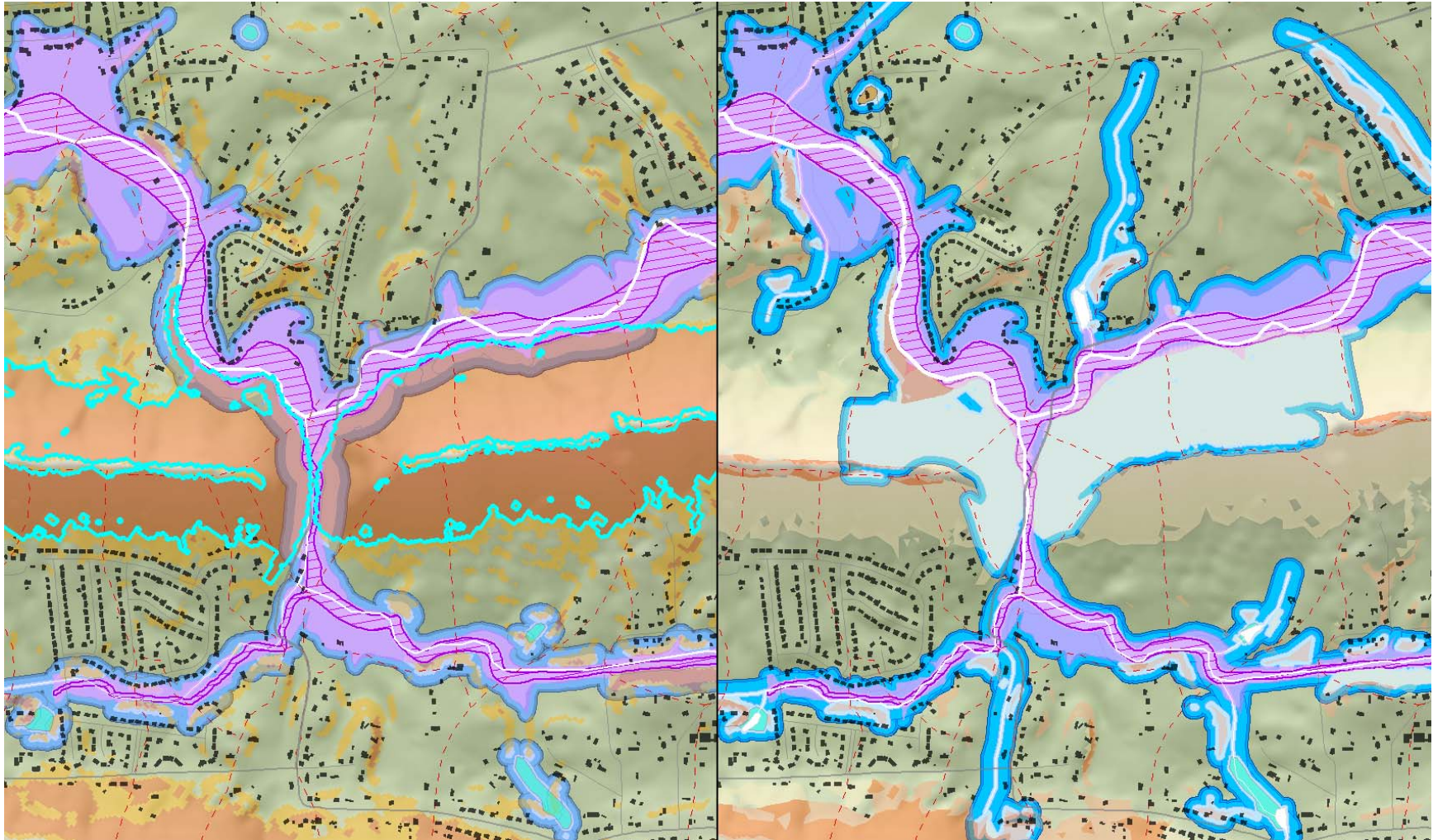
Figure 4.4 Comparison of slope buffering techniques. The map on the left shows the BCWGIP buffers and treatment of slope. Initially, the selection of slopes within the search distance of 75 feet of the stream posed the problem that huge areas (particularly ridges, as shown here outlined in cyan) were being selected and added to the buffer. To deal with the problem, the selected slopes were clipped to the search distance to keep the buffer a reasonable size. The map on the right shows the new slope buffering technique, where the sensitive soil-slope areas are split by the basin features, then selected by proximity to sensitive features. This allows the buffer to include the entire sensitive contributing area, making the buffer delineation less arbitrary and more effective.

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While the Beaver Creek plan water quality buffer methods were solid, well-documented, and rooted in the best practices available at the time, there were definitely areas that still could be improved upon. In the conclusion of the published plan document, Moir-McClean and DeKay note that there were deficiencies in the data available and that some of the methods required more advanced techniques in the use of some of the analysis tools that were utilized (e.g. catchment-based rules). With the improvements to the data and methods, the buffer system that I am proposing should be significantly closer to achieving the technical goals and, in turn, the environmental goals set out in the Beaver Creek Watershed GIP. Also, with the creation of a data model and associated geoprocessing models, I will achieve another goal identified in the BCWGIP: to automate the analysis and facilitate the expansion of the Beaver Creek plan water quality buffer methodology to the rest of Knox County and to other areas. In Chapter 5, I will cover the details of the data model, including the datasets, their development and attribution, and the construction of the geoprocessing models that perform the analysis tasks which create the spatial representations of the hydrologic conservation buffer model.

Chapter 5 Data and Geoprocessing Model Design and Implementation

During the course of the Beaver Creek Watershed GIP, I was responsible for maintaining and organizing the vast number of datasets that our group acquired during our research. We used the electronic file- and folder-based data structure of the Microsoft Windows™ operating system environment to keep our data housed in a way that allowed us to easily access and reference them. Our data relationships were simple and loosely-defined solely by their combined use in different elements of the project components. Our methods for doing analysis and generating the derivative datasets that we used in subsequent analyses were carefully documented and stored separately from the data in word processing documents. So, while we strived to organize, relate, and document the geoprocessing methods and organize our data in a clear and concise way, we did not formally design a data model to describe the datasets and their relationships, nor did we create geoprocess models to formalize our analysis methods within the ArcGIS framework. It is my goal and the basis for the research conducted in this thesis to take the work that was done on the hydrologic network conservation analysis and improve it by proposing a data model and associated geoprocessing models built upon the ESRI ArcGIS platform that better define the nature of the data and analysis methods we developed and expand them by improving the buffer method. I am doing this in the interest of creating a well-documented and repeatable approach to defining the riparian and sensitive hydrologic feature buffers within the context of a Green Infrastructure Plan or similar conservation assessment.

Data Model Design Best Practices

When making a GIS analysis of a complicated problem that involves many attributes and sources of information it is desirable to organize the individual datasets and their relationships with one another more formally. Data models serve this function: they describe the datasets, their organization, and their attributes for a specific analysis or representation purpose, outlined by a data model diagram. They can also describe relationship rules of tabular or spatial attributes, appropriate attribute values, special attribute behaviors, and guidelines for cartographic representation (Arctur and Zeiler 2004). Depending on the complexity of the use and implementation of the database, it may take a considerable amount of time to design, test, and revise a data model. Also, there may be additional design considerations if the database is to house derivative datasets, such as polygons representing areas of steep slopes derived from a digital elevation model (DEM), since these datasets require a set of geoprocessing tasks to create them. Just as a database can be described in detail by a data model diagram, these processing tasks can be documented by a geoprocess model diagram. The geoprocessing model diagram can become part of the overall data model, since the geoprocessing model, or "toolbox", can be housed within the geodatabase.

Database design is much like any other type of design: there are tried and true methods for designing databases and describing their structure. Best practices should be used in selecting the methods and parameters for creating a sensitive hydrologic feature buffer system. Database design methods are also governed to some extent by best practices in their elements and their uses. To be useful to a wide audience and to facilitate collaboration, a database design must contain common elements and familiar

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design characteristics and be described and represented in a way that can be understood by the user community. The most common elements of data models are: 1) thematic layers; 2) spatial representations; 3) a minimum set of attributes; 4) integrity rules and spatial relationships; 5) map layers (graphical representations) and layouts; and 6) metadata and data use and extraction rules (Arctur and Zeiler 2004). Thematic layers refer to the spatial datasets themselves. Spatial representations include points, lines, polygons, rasters, etc. Attributes help define features and their relationships within the database. Integrity rules and spatial relationships (such as topology rules) outline the desired spatial behavior of features within datasets and from one dataset to another (i.e. lines from one class cover the boundaries of polygons in another class). Layouts and layer definitions describe a common set of graphical characteristics to apply to features for cartographic representation. Metadata houses the source, lineage, and description of a dataset. Appropriate data usage and extraction guidelines can also be housed in the metadata. These are the most common and widely accepted elements of a data model and represent the key best practices of their design.

Overview of Data Model Design Phases

A data model design can be broken down into three major design parts: 1) conceptual design; 2) logical design; and 3) physical design (Arctur and Zeiler 2004). The conceptual design is the first and most critical step in the process and involves the selection of the thematic data that will be necessary to fulfill the analytical or information requirements of the model. In Chapter 4, I identified the specific features that are going to be considered for protection with the hydrologic conservation buffers. These features

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will become the thematic layers that form the model's "base" data. In addition to those features that require protection, there will be other datasets needed to complete the various geoprocessing tasks that are necessary to create the data model's derived datasets (the buffers themselves), such as the watershed boundary for use as an analysis mask, and a DEM of the area to derive slope characteristics and help delineate catchments. Another aspect of the conceptual design is scale. Scale is an important control over the use and functionality of a dataset when doing analysis. When defining a data model, it is also necessary to state a nominal scale at which the model was meant to be implemented in order for it not to be misused, or, at the very least, for users to be aware of it in case they need to make modifications. The final major consideration during the conceptual phase of the data model design is the overall database structure and the data types to be used. In this data model, linear buffering makes up most of the geoprocessing tasks for the derived data, so vectors (feature classes) will be the primary data representation type, while the DEM and USGS Digital Raster Graphics (DRGs) of 7.5-minute topographic quadrangles (used for reference) are a raster data type.

In the logical design phase, the datasets that were identified in the conceptual phase are fleshed out with details about the attributes and the structure of the information stored in each dataset. Tabular attributes are the most important part of the database after the spatial data type (point, line, polygon). It is the attribution that helps to define the behavior and limitations of the features in the database and can also be used to create relationships from one class of features to another. In the hydrologic feature protection model, attribution is used to define important characteristics of the features within each

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dataset, such as the stream order of a reach in the streams dataset, or whether a particular soil type is considered highly erodible in the soils dataset.

The physical design of the data model can generally be accomplished by three methods. The first (and easiest) method is to create feature classes within a geodatabase and simply import the structure of the attributes from another database. The second is to build the database from scratch using the tools in ArcCatalog to add classes and build the attribute tables. The third is to use CASE (computer-aided software design) tools such as Microsoft's Visio™ to build a conceptual model of the data structure and then import that design into an empty geodatabase and populate it with features and data. Since the datasets that I am using for this project come from a variety of sources with different table schemas and attributes, I chose not to use CASE tools. Instead, I designed the database around the features and attributes that were already established by the originators of each dataset, or I created my own attributes in the datasets that I developed.

Another consideration for geodatabase design is the type of geodatabase. There are three different types of geodatabases within the ArcGIS environment: personal, file, and ArcSDE geodatabases. Personal geodatabases are meant for smaller, single-user applications that do not require simultaneous access and editing by different users. They utilize the Microsoft Jet database management system (DBMS) and are limited to 2 GB in size on disc, but become slow and inefficient for data access and geoprocessing once they grow beyond about 250 MB. ArcSDE geodatabases are virtually limitless in size and number of users and can utilize a variety of different relational database management systems (RDBMSs), but are more complicated to manage and are generally reserved for enterprise GIS applications. While I do not have a great need for multi-user editing

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capability, the potential for large datasets that will need geoprocessing tasks applied to them with large outputs requires that I use a database that can support larger datasets. The file geodatabase architecture does not require the use of ArcSDE, yet still allows for small workgroups to simultaneously access the data (although only one user can edit any one class at a time) and it has the ability to store and process large datasets (up to 1 TB) efficiently without a DBMS. File geodatabases are also operating system-independent. A more open and flexible database structure can manage large datasets. I chose, therefore, to build my database with file geodatabase architecture, although the data model schema could be applied to either a personal or ArcSDE database.

Database Structure and the Data Model Diagram

With the selection of the file geodatabase architecture to house the data for the hydrologic conservation buffer model, I began to define the basic structure of the database. The datasets for the analysis input and output need to be well-organized to facilitate use and management. For this purpose, I decided to break the data up into several feature datasets. A feature dataset is a container for feature classes from which the classes inherit a common spatial reference. Within the feature dataset, individual feature classes of different data types (point, line, polygon) can be stored each with their own unique attributes stored in a table. See **FIGURE 5.1** for a diagram of a geodatabase and some of the common objects that can be contained within it.[*] The rest of the discussion of geodatabase structure, classes, and attributes will assume the reader has a basic understanding of these concepts.

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[*] For more information about geodatabases, their structure, data types, and design, see the ESRI support website (support.esri.com) and search for the topic "An overview of the geodatabase".

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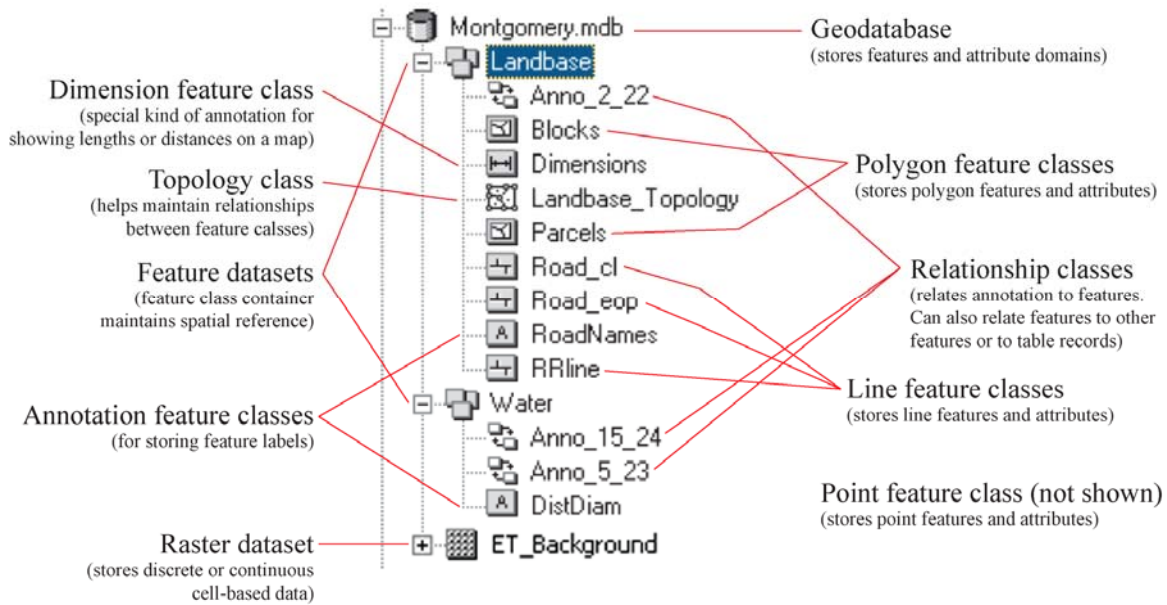
Figure 5.1 Example of a geodatabase and some of its common components.

Once a geodatabase has been created and the feature datasets have been

developed and their spatial references defined, they can be populated with feature classes

and their associated tabular attributes. To better understand the structure and attributes of

a database, an information graphic called a data model diagram can be made. Rather than

try to describe here in the text all the details of the structure, classes, attributes, and

relationships within the geodatabase I developed, I have created a data model diagram for

this purpose. Also, included as an attachment in the Adobe PDF version of this

document is an XML Workspace (ThesisModelSchema.xml). This file, which contains

the schema and metadata of the geodatabase that I created for this research, can be

imported to an empty geodatabase in ArcCatalog for reference. **PLATE 1**[*] displays the

data model diagram for the Hydrologic Feature Conservation data model. It consists of

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[*] In the Adobe PDF version of this document, **PLATES 1–3** are included as attachments in PDF format.
The printed copy includes a CD-ROM with the plates and other attached files mentioned in the text.

four sections: 1) a catalog (or file tree) view of the database; 2) feature class and model component details; 3) feature class attribute table descriptions; and 4) a section describing the relationships of the feature classes within the geoprocessing models. The catalog view is so named because this is the way the geodatabase looks when viewed in ArcCatalog. It has a form similar to the file-folder system view of Windows Explorer and displays the feature datasets and feature classes as if they were folders with files residing within them. The class details section shows the feature datasets and the classes within them, but has more detailed descriptions of them. This section also shows the feature classes as they pertain to the development of the three zones of protection outlined in the buffer model ordinance and discussion in Chapter 4. The feature attribute table descriptions are detailed views of the schemas of each table within the ModelData and FinalOutput feature datasets. The table schemas detail the name, type, and behavior of the field, as well as a short description of the use for the attribute contained in the field. The fourth section is a unique part of the data model diagram that shows the relationships of the feature classes as they pertain to the geoprocessing workflow. As the geoprocessing model runs through its tasks, intermediate feature classes are created to temporarily store features that are needed in subsequent steps on the way to creating the final outputs. These intermediate outputs make up the classes stored in the IntOutput feature dataset, and it is important to understand where each of the intermediate outputs fits into the geoprocessing model. A separate geoprocessing model diagram is included on **PLATE 2**, but its complexity makes it difficult to quickly identify where a class fits into the workflow. I created the Geoprocessing Relationships section of the data model diagram to help bridge the gap between the data and geoprocessing model diagrams and

to help make them more understandable. Also, included as an attachment in the Adobe PDF version of this document is a copy of the ArcGIS toolbox file "Thesis Model.tbx" which contains the geoprocessing models and help documentation developed during my research. It can be viewed and edited in ArcCatalog and the software can be executed as well with appropriate datasets through ArcToolbox.

The next section will discuss the data collected and created for use in populating the ModelData feature dataset in the geodatabase. Following that will be a discussion of the geoprocessing models that create the spatial representations of the sensitive hydrologic feature buffers. Both sections will reference the classes and attributes described on the data model diagram, and the geoprocessing section will reference the simpler schematics of the geoprocessing models in the Geoprocessing Relationships section found on **PLATE 1**.

Data Sources, Derivations, and Creation of New Data

With the list of features for consideration in the hydrologic feature protection buffer model and some of the basic attribution identified, I began collecting data and resources to construct the database and populate it for the Beaver Creek watershed study area. The scale of the published maps for the original Beaver Creek Watershed GIP was 1:36,000, with data source scales ranging from 1:24,000 – 1:100,000. For the data model, I have set a nominal scale of 1:24,000 for all the input datasets. Much of the 1:24,000 scale data that was gathered for the BCWGIP in 2004 and 2005 was reused since newer data has not become available. In the Beaver Creek Water Quality analysis component of the BCWGIP, we only had a 1:100,000 scale water network, and

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incomplete 1:24,000 scale datasets showing the locations of springs and sinkholes. In the cases of the stream, spring, and sinkhole features, it was necessary to create new datasets at the appropriate scale for the data model in order to properly implement it. Using DEMs, ArcGIS Hydrology tools, and DRGs and aerial photos for reference, I was able to generate datasets and attributes for these features at the model scale of 1:24,000. **TABLE 5.1** lists the datasets, their sources, scales and spatial extent, and whether they were derived from another dataset, that I used to construct the model geodatabase.

Most of the data come from public sources. It was my intention that most of the data should be from uniform and widely available sources, or derivatives of those sources, to facilitate the dissemination of the model and its application in as many areas as possible, although it may be necessary to create some datasets from scratch. A discussion of some of the dataset derivations and the methods that I used in the process is definitely warranted since it may be useful to those who are faced with a similar situation as mine: there were not sufficient sources of detailed data available, or there were datasets that needed to be derived from different sources to complete the population of the ModelData feature dataset. Of the datasets listed in **TABLE 5.1** that are denoted as being derived, there are two groups of particular interest: the slope zones and the soil-slope intersection, and the catchments of the springs and sinkholes and the stream network. Each of these were created from stock datasets listed in the table, and each has a particular methodology associated with its creation. The following paragraphs will briefly discuss these methods for each group of features. For a quick reference during the discussion of the processes, please reference the Geoprocessing Relationships section of the data model diagram. For details about the individual functions of the geoprocessing

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models, see **PLATE 2**. For detailed documentation of the geoprocessing model user-input parameters, see **APPENDIX A**.

The first and simplest derived datasets were the slope and soil-slope intersection datasets. The "SlopeZonesFromDEM" model diagram on **PLATE 1** shows the inputs and the basic processes that created this dataset. Using the Slope function within ArcGIS Spatial Analyst for raster data analysis, a percent slope raster for the study area was created from the stock USGS 10-meter DEM. This slope raster was then reclassified so that slopes within certain ranges were assigned a number or "bin" (i.e. 0-14% = 1, 15-24% = 2, etc.) This "binned" raster was then converted to a polygon feature class where adjacent raster cells with the same bin value are aggregated together to form shapes representing the areas of equal value. This polygon feature class is stored in the ModelData feature dataset as "USGS_10m_DEM_SlopeZones". The next step is to intersect these slope zones with the soils feature class, as seen in the "SoilSlopeBasin Intersect" geoprocessing model. The soils feature class is queried for soils that, according to the published soil survey, are classified as being "highly erodible". These erodible soils are intersected with the slope zones, and a new attribute of buffer size is calculated based on the combination of slope zone and erodibility (see **TABLE 5.2**). The final step is to intersect the soil-slope polygons with the basins feature class to split them up by their catchments of influence. Since sensitive features and potential impacts are related by proximity, only soil-slope areas that have a direct influence on a stream reach or sensitive feature should be included in the protective buffer.

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Table 5.1 Model data sources and related information

Feature type	Source/Dataset name	Description	Coverage	Scale*	Derived?
Polygon	FEMA 100yr Flood	Extent of the 100-yr floodplain	Knox County	1:12,000	N
Polygon	FEMA 500yr Flood	Extent of the 500-yr floodplain	Knox County	1:12,000	N
Polygon	FEMA Floodway	Extent of the bank-full floodway	Beaver Creek Watershed	1:12,000	N
Polygon	NRCS 24k Soils	Soil units (queried for erodibility)	Knox County	1:12,000	N
Polygon	NWI 100k Wetlands	Wetland areas from aerial photos and soils	Knox County	1:24,000	N
Polygon	Soil-Slope Basin Intersect	Interaction of steep slopes and erodible soils, split up by basin	Beaver Creek Watershed	1:12,000	Y
Polygon	TVA Basins	Sub-watershed units that define individual reach catchments	Beaver Creek Watershed	1:12,000	N
Polygon	TVA Watershed 4mi Buffer	A 4 mile buffer of the watershed; used as an alternative analysis mask	Beaver Creek Watershed	1:12,000	Y
Polygon	TVA Watershed	The Beaver Creek study area watershed	Beaver Creek Watershed	1:12,000	N
Polygon	USGS 10m DEM Slope Zones	Slope zone polygons created by DEM analysis	Beaver Creek/USGS Quadrangles	1:24,000	Y
Polygon	USGS 24k Sinkhole Catchments	Basins identified as draining to a sinkhole	Beaver Creek Watershed	1:24,000	Y
Polygon	USGS 24k Sinkholes	Sinkholes compiled from USGS DRGs, DEMs, and soil survey	Beaver Creek/USGS Quadrangles	1:24,000	N
Polygon	USGS 24k Spring Catchments	Overland areas that drain to spring location derived from DEM analysis	Beaver Creek Watershed	1:24,000	Y
Point	USGS 24k Springs	Named springs acquired from USGS GNIS; unnamed springs from DRGs	Beaver Creek/USGS Quadrangles	1:24,000	N
Line	USGS 24k Streams	Stream network and stream order from DEM analysis; checked with DRGs	Beaver Creek/USGS Quadrangles	1:24,000	Y
Polygon	USGS 24k Water	Water bodies from DRGs and aerial photos	Beaver Creek/USGS Quadrangles	1:24,000	N
Raster Catalog	USGS DRGs	Digital raster graphics of USGS 7.5-minute quadrangle maps	Beaver Creek/USGS Quadrangles	1:24,000	N
Raster	USGS 10m DEM	Digital elevation model at 10-meter resolution	Beaver Creek/USGS Quadrangles	1:24,000	N
Raster	USGS 10m MDOWHS	Hillshade made by Multi-Directional Oblique-Weighted method	Beaver Creek/USGS Quadrangles	1:24,000	Y

 * Scale value represents the largest scale at which the dataset was intended for use, according to its originator.

Table 5.2 Buffer widths based on slope zone and soil erodibility

Buffer Width (feet)		Slope Zone	
		1	2
Highly Erodible?	0	X	20
	1	40	50

The next set of derived feature classes are the catchments of the springs and sinkholes. These two datasets do not have an associated geoprocessing model because they were delineated using the Hydrology toolset within the ArcGIS toolbox. The Hydrology tools are an advanced set of geoprocessing functions that can be used to create a variety of datasets that model hydrologic functions, including delineation of watersheds and basins, stream networks, and sinks based on DEMs and derivations thereof. The new stream network dataset was also created using the Hydrology toolset. The delineation of the catchments and the stream network, as well as checking the locations of sinkholes, is all part of the process of the hydrologic modeling of a surface. The following is a brief summary of the process.[*] First, a DEM of the study area is needed. This DEM is run through the Flow Direction tool, which identifies the direction of flow from each cell to its steepest down slope neighbor. With the flow direction raster created, all cells that have an undefined flow direction are flagged as sinks using the Sink tool. In many cases the sinks are errors in the DEM, and can be fixed by smoothing them with the Fill tool. This process is repeated: Flow Direction > Sink > Fill until erroneous sinks are filled and

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[*] For more information about the Hydrology tools, see the ArcGIS Desktop help.

legitimate sinks are identified. This is a tricky process that requires a skilled operator to determine the threshold at which the sinks should be considered legitimate. Reference maps are helpful during this process. With a proper flow direction raster, the Flow Accumulation tool can be used to figure out for each cell the number of upslope cells that drain to it. Next, a threshold is specified with a conditional (Con) function to begin to delineate a stream network. In other words, only cells with over a certain number of upstream cells draining to them are going to have enough surface accumulation to be a flowing stream. I used USGS 7.5-minute DRGs and aerial photos to help me identify the threshold at which the accumulation became a blue-line stream or an identifiable channel. With the basic stream network identified, the Stream Order tool is executed to assign stream order to each reach. I chose to use the Strahler stream order, since this is the method most often identified for use in riparian buffering best practices. Finally, I used the Watershed tool to delineate the basins from the flow direction raster. Basins that drain to legitimate sinkholes were identified and those basins were flagged in the Ogden Engineering-derived basins dataset as such and exported to their own dataset (sinkhole catchments). The delineation of the spring catchments uses a slightly different process. Instead of considering all the cells in the flow direction raster, the locations of the springs are identified and made into what are called "pour points". These points become the sole basis for identifying the upslope cells of accumulation, which become their contributing overland catchment. These catchments were converted to polygons and stored in the database as the Spring catchments. This concludes the creation of the derived datasets. The next three sections will discuss the geoprocessing functions used in the hydrologic feature buffer geoprocessing model.

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Geoprocess Modeling in ArcGIS

Before describing the geoprocessing functions for the HydroValueZones model, a few words about the nature of geoprocess modeling in the ModelBuilder environment of ArcGIS. ModelBuilder, which is part of the ArcCatalog application, is the environment in which the geoprocessing elements (tools) are assembled and chained together to create new software for manipulating datasets. This environment is visual and uses flowchart-like graphical representations of the individual geoprocesses and their links to inputs and outputs. It is meant to be simplistic and ease the development of tools needed to accomplish everything from mundane, repetitive tasks, to complicated workflows. With this in mind, look at the geoprocessing model diagrams on **PLATE 2**. The simple tasks related to the creation of the slope zones in the SlopeZonesFromDEM model contrasts sharply with the complexity of those for the HydroValueZones model. The basic logic of the hydrologic feature buffer geoprocessing model is straightforward: select sensitive features based on proximity, buffer those features based on certain criteria, then assemble the individual buffers to form continuous areas of protection for each zone. The actual process for accomplishing this conceptually straightforward plan ends up being considerably more complicated once the geoprocessing model has been developed and all the parameters have been defined. This may seem counterintuitive; after all, isn't the point of geoprocessing to automate a task and provide a documented, easy-to-disseminate representation of a workflow? Despite the answer to this question being 'yes', the nature of the modeling of geoprocessing tasks in ModelBuilder requires that each function, no matter how small, be a separate, non-recyclable task that has to be executed each and every time you want to perform that task. This helps explain some of the redundancy and

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visual complexity of the geoprocessing model diagram, and is the reason why I developed the Geoprocessing Relationships section on the data model diagram. It bridges the gap from data model to geoprocessing model with a diagram of the process parameters and workflow that is easier to understand.

One way to get around this problem is to use a scripting language such as Visual Basic or Python. These programming languages are more flexible in their ability to use Boolean logic and loops to repeat a single process repeatedly without having to explicitly define the parameters for each iteration. Scripting is a more powerful method of geoprocess modeling, but its requirement of programming knowledge and the use of potentially complex syntax deterred me from using it for this project. My goal was to create a model in an object-oriented, visual environment that would be easier for a less-experienced GIS operator to use, thus I chose ModelBuilder as my development platform.

Hydrologic Feature Buffer Model: Zone 1

The hydrologic feature buffer model, shown on the data model diagram as the "HydroValueZones" model in the Geoprocessing Relationships section, identifies land that contributes to increased water quality by delineating buffers around sensitive features and related impacts, implementing the best practices for riparian buffering identified in Chapter 4. It creates these buffers in three concentric zones of protection: preservation of edge, conservation, and stewardship, each with unique attributes and goals for protection and rehabilitation. This model also furthers the initial protection best practices to include sensitive features in not just one, but two categories of land: riparian or lowland areas *and* upland areas of groundwater recharge.

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The first step in the model is to identify the backbone of the hydrologic network: the streams. The streams dataset that I developed is much more comprehensive than the one that was used in the initial BCWGIP. In that analysis, all streams were considered part of the lowland, but in my subsequent analysis of the hydrologic network, I found that there were in fact several streams that drained into sinkholes in the watershed, known as sinking creeks. This prompted me to add an attribute called "DrainsToSink" to the stream feature class that identifies whether the stream is part of the lowland (a value of "0" or false) and sinking creeks which contribute to the upland system of groundwater recharge (a value of "1" or true). The addition of this attribute allows the model to treat lowland and upland streams differently and thus make sensitive feature selections for the upland and lowland more accurate. Using the "DrainsToSink" attribute, the model selects and stores each set of features (upland and lowland streams) to the IntOutput feature dataset.

Next, the lowland sensitive feature selection mask needs to be created. Using the lowland streams and the floodway as the backbone of the lowland, a search distance from the edge needs to be established. To do this, the lowland streams and the floodway are each buffered 75 feet (the search distance established in Chapter 4) and the buffers unioned together to form the raw lowland selection mask. The raw selection mask is then dissolved on the "Buff_Width" attribute to increase its performance while being utilized in the "Select by Location" geoprocessing task.

The term "raw" will be used repeatedly throughout the discussion of the geoprocessing model to refer to unioned or appended feature classes that have not yet been dissolved. It is common that geoprocessing functions will slow down considerably

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due to memory usage if the number of features within a class reaches into the thousands, which can happen easily when doing analysis utilizing many datasets with a lot of overlapping or intersecting features. Dissolving the features increases performance by reducing the number of internal iterations a particular geoprocessing function will have to make to run to completion and thus the amount of memory needed. Also, dissolves improve display performance for the same reasons: fewer objects to draw means faster refresh times. But it is important to note that these dissolves are being done *without* the option to create multi-part features. When used, this option can create complex shapes that are *more* memory intensive and can actually *degrade* performance. The raw feature classes are useful for doing QA/QC work with the buffers that are created by the model, so they are stored in the IntOutput or FinalOutput feature datasets for this purpose.

With the lowland feature selection mask created, a series of "Select by Location" functions are executed on the remaining classes of sensitive features: sinkholes, springs, wetlands, and water bodies. The soil-slope features are handled separately and will be discussed momentarily. The Select by Location function uses the 75-foot selection mask to select all the features in each of the sensitive feature classes that intersect the mask shape. Each set of features is then stored in IntOutput, and another selection function is performed effectively "switching" the selection in each sensitive feature class to include all the features not selected previously. These become the upland sensitive features. There is one caveat to the selection of water bodies and wetlands in the lowland: in a watershed that drains to a large river or lake as Beaver Creek does, there may be large polygons representing the river/lake that extend far beyond the study area. If these polygons have not been split before the model is run, it will result in large buffers being

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created outside the area of interest. For this reason, my model clips the lowland water and wetland features before they are passed to the buffer function.

In order to make selections for the soil-slope features, all the other sensitive features (sinkholes, wetlands, etc.) have to be identified first as lowland and upland so another set of selection masks can be created for the lowland and upland selections of sensitive soil-slope areas. Similar to the creation of the initial selection mask, the lowland sensitive feature (minus springs) and the upland sensitive features (minus springs) are buffered 75 feet and unioned and dissolved to create the lowland and upland soil-slope selection masks. The springs are not used in the creation of the selection masks due to the nature of the spring locations. In the BCWGIP, the stream network was of a much coarser resolution than the springs. This had the effect of creating isolated springs in the upland. When I created a new stream dataset, I realized that all the springs identified on USGS 7.5-minute topographic maps are always connected to a blue line stream as a source point (in other areas, they may also be connected to an intermittent stream, but this was not the case in Beaver Creek or surroundings). So springs identified on the maps and my stream network were correlated to make sure that all springs had a stream connected to them. This has the effect of making buffers of these points exactly coincident with a "full-round" buffer at the vertex of the connecting stream, eliminating the need to buffer the springs separately when all the buffers are being made the same width for the selection masks. With the selection masks made, the soil-slope areas that intersect each selection mask are identified and stored in the IntOutput feature dataset. At this point, all the features needed to create Zone 1 in the lowland and upland have been identified and can be buffered.

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The buffers for Zone 1 features are rather straightforward. All sensitive feature selections are buffered 25 feet, with the exception of the soil-slope areas which are subject to a variable width buffer from 20 to 50 feet based on a combination of slope zone and erodibility, as discussed earlier in this chapter. So each set of features, lowland and upland, are buffered and the buffers appended to form the raw lowland and upland Zone 1 feature classes. The only difference between the two is that the lowland Zone 1 contains a buffer of the floodway, which does not exist in the upland. These raw classes are also appended to form the raw composite lowland-upland Zone 1. Each of the raw classes is then dissolved on an attribute created and calculated for this purpose and the final classes are written to the FinalOutput feature dataset.

Hydrologic Feature Buffer Model: Zone 2

Since the system of buffers is concentric, the buffers for Zone 2 and Zone 3 are based on those of Zone 1. One might conclude then that it is possible to simply send the Zone 1 buffer through another two iterations of the Buffer function, building out the zones that way. In a more simplistic method, that might be possible, but in the best practices identified in Chapter 4, there are some features which need special attention in Zone 2 (and 3) and that requires some additional geoprocessing. The major differences between Zone 1 and Zone 2 (and 3) are the inclusion of the floodplain, the implementation of catchment-based buffers for the springs, and a variable width buffer for streams in Zone 2 based on stream order.

Springs, being a traditional source of drinking water, are of particular interest when protecting sensitive hydrologic features. As discussed in Chapter 4, setbacks for

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springs can be much larger than those for other features in order to make sure that surface runoff is not contaminating these source waters, and upland sinkholes also need protection since in many cases it is through these areas of natural groundwater recharge that a spring is fed. In the Beaver Creek study area in particular, there are many examples of a connection between the system of sinkholes in the upland and springs in the lowland. But blindly buffering spring locations with large setbacks is bound to cause problems with enforcement, since there are potential loss-of-use issues that will be raised. To deal with this problem, the spring catchments derived from the DEM are used to clip the buffers to the area that drains to that location. In some cases, this causes the spring buffer to be much smaller than the 500 feet listed as the total for the three zones, but in many places it simply clips the areas that are not directly influencing the spring, and thus have no direct impact, out of the buffer, making the protection setbacks more defensible. Accomplishing the catchment-based spring buffers is a straightforward process of buffering the springs and then using the Clip function with the catchments as the clip features to remove the parts of the buffer that fall outside the catchments. Once this has been done, the spring buffers can be appended to the other buffers for Zone 2.

The treatment of streams in Zone 2 is also different from the standard buffer width of 50 feet. In Zone 2, streams are buffered an additional 25 to 50 feet depending on stream order. I chose to use the method of buffering low order streams (1 and 2) by an additional 50 feet and high order streams (3+) an additional 25 feet. Other methods prescribe doing just the opposite (as was done in the BCWGIP), but I chose to use the lower order-bigger buffer method for two reasons. First, it has been shown in the literature that downstream flooding is most influenced by the speed of water entering the

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hydrologic network in the headwaters (Hunter 1990). By slowing down the water entering the lowest-order streams with larger setbacks to increase infiltration, downstream buffers can be narrower where they are less effective and there is less room for them anyway. Second, in the Beaver Creek watershed, FEMA has defined a 100- and 500-year floodplain. In my model, as it is in the BCWGIP, the 500-year floodplain is considered a sensitive feature that needs buffering since it is a critical part of the watershed's ability to deal with flood events. Since the floodplain is typically a lowland feature that has its influence on higher-order streams, these streams don't need as wide a buffer applied to them by the model since the floodplain plus its buffer should be sufficient. Note that the distances listed on the data model diagram are 100 to 125 feet. This is due to the buffers being based on the original features, not the buffers from Zone 1, so the distance reflects the sum of the base Zone 1 buffer, the base Zone 2 buffer, and the additional Zone 2 buffer ($25 + 50 + 25 = 100$ for SO 1 & 2; $25 + 50 + 50 = 125$ for SO 3+).

With the buffers of the streams based on stream order and the floodplain buffer created, the lowland and upland Zone 2 buffers are appended and dissolved to create the raw and final lowland and upland Zone 2 buffers. As it is with Zone 1, the raw Zone 2 buffers are also appended to create a raw composite of Zone 2, which is also dissolved to create the final composite Zone 2 buffer.

Hydrologic Feature Buffer Model: Zone 3

The Zone 3 buffer is the final part of the geoprocessing model. It is the simplest as well, since it is based on the Zone 2 buffer, except for the springs. As with Zone 2, the

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springs are buffered separately and clipped to their catchments. The Zone 2 buffers are

buffered 25 feet, and with the clipped spring buffers, are appended to create the raw

lowland and upland Zone 3 buffers. As it is with Zones 1 and 2, the raw Zone 3 buffers

are appended to create a raw composite of Zone 3, which is dissolved to create the final

composite Zone 3 buffer.

Summary of the HydroValueZones Model Results

Once the three zones of lowland and upland buffers are complete, they are ready

to be inspected on a map and have their spatial implications analyzed. See **PLATE 3** for

a map of the Beaver Creek Watershed with the final results of the HydroValueZones

geoprocessing model displayed on a base map that shows the original input features

overlain on a USGS DEM hillshade topographic base. Also, upon completion of the

model execution, a summary of all the functions, their parameters, and the amount of

time it took to execute each function is displayed a dialog box for the user to review. I

have saved this log and included it in **APPENDIX B**. The log is very helpful in

determining areas of inefficiency (processes taking a long time to execute) or warnings

caused by inconsistencies or non-fatal errors in the geoprocessing functions, such as the

generation of empty outputs which may be a sign of an invalid selection query. Chapter

6 will include a discussion of the results and a comparison of the input datasets and the

output buffers of the geoprocessing model versus the datasets and results of the original

Water Network component of the Beaver Creek Watershed GIP. Also, the conclusions

will discuss some issues encountered during the model design process and execution, and

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a section to outline some possible future implementations and the expansion of
geoprocess modeling to other components of a GIP.

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Chapter 6   Review of Model Results and Conclusions

The main goal of this thesis is to present a data model and associated geoprocessing models for the assessment of land that contributes to increased water quality, in the context of Green Infrastructure planning principles. In Chapter 3, I reviewed the Green Infrastructure plan that was the basis for the research presented in this thesis, the Beaver Creek Watershed Green Infrastructure Plan. My intention was to take the Water Network component of that GI plan and develop the methods presented for hydrologic feature protection into a well-documented and repeatable process. By presenting a buffering methodology, data model, and associated geoprocessing models, and expanding it by implementing some of the suggestions made by Moir-McClean and DeKay in the conclusions of the BCWGIP final report (pp. 82-84), these goals have been accomplished. The methods and tools presented here can be used by planners and environmental analysts to help identify the critical lands needed to maintain and restore good water quality in an area, then pass that information on to help in the process of making more informed decisions regarding development. Chapter 4 identifies the buffering best practices that a solid method for modeling hydrologic feature protection model should implement. Chapter 5 presents a complete data model and geoprocessing methodology to delineate the spatial implications of the buffering best practices. In this chapter, I will discuss the results of my models, and compare my research results with the results obtained during the Water Network analysis in the BCWGIP. Included in this discussion, I will compare the original datasets used for the Beaver Creek analysis and the datasets that I developed, since the spatial implications of the model rely heavily on the nature and level of detail of the inputs. I will also review and discuss some common

data and geoprocess modeling issues, and present some ideas for the future development of more data and geoprocessing models to create a complete Green Infrastructure assessment toolset.

BCWGIP and Hydrologic Conservation Model Comparison

After the development of the Beaver Creek Watershed GIP Water Network methods and datasets, I determined that improvements in the data would make a significant impact on the spatial implications of the results (BCWGIP, pp. 82-84). While I feel that the results of the initial assessment were sound and rooted in a solid methodology, the development of improved datasets that I undertook for this thesis had an even stronger influence on the results than I had originally supposed. The most significant difference between the two assessments was the use of a vastly improved and significantly more detailed stream network for the watershed and surrounding area. The original assessment used a stream network dataset that was developed at a nominal scale of 1:100,000, while the dataset that I developed using the ArcGIS Hydrology toolset and topographic maps and air photos for QA/QC is equivalent to around 1:24,000-scale; about four times more detailed. In a similar fashion, I improved the spring, sinkhole, and water body datasets to correspond to the scale of this improved stream network. **TABLE 6.1** shows a comparison of some of the pertinent characteristics of these datasets. The statistics calculated in **TABLE 6.1** are for the Beaver Creek Watershed area *only* for both the original BCWGIP datasets as well as those developed for this thesis. The statistics do not consider the entire spatial extent of the initial BCWGIP datasets or my datasets, which were developed to cover an area encompassing approximately a 4-mile buffer of

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the watershed, in order to gain some insight from the context of Beaver Creek as a suburban watershed surrounded by more developed areas to the southeast and less developed areas to the northwest.

Comparison of Datasets

The stream network I developed does not only dwarf the original dataset in total miles of stream within the watershed, but perhaps more significantly, is considerably more detailed in its delineation of headwater streams, which accounts for the huge discrepancy in the total number of reaches. This has a significant impact on the spatial implication of the buffers for two reasons. First is the determination of buffer width using stream order, a method used in both the BCWGIP and my model. Scale has a very large impact on the determination of stream order, since a more detailed stream network will have many more headwater segments and junctions, which will have the effect of increasing the final order of the stream that drains a watershed. For example, in the original Beaver Creek analysis, out of 117 stream segments, 54 are 1st order, 22 are 2nd order and 41 are 3rd order. In my stream dataset, out of 715 segments, 299 are 1st order, 183 are 2nd order, 89 are 3rd order, 23 are 4th order, and 121 are 5th order. The final order of Beaver Creek in the original analysis was only a 3, limiting the order-based rules that could be applied in that analysis. In my dataset, the increased detail and subsequent increase in the final order allows for additional flexibility in the treatment of stream order in the buffering methodology. The second important impact is directly related to the first, that is the buffer will be significantly larger in area and thus more influential on existing development, as shown in the two lower sections of **TABLE 6.1**.

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Table 6.1 Comparison of BCWGIP input datasets and buffers with Hydrologic Feature Conservation model datasets and buffers within the Beaver Creek watershed.

Datasets:	BCWGIP			ALW		
Number of Stream Reaches: Length mi (ft)	117	140.9 mi (743,971 ft)		715	245.3 mi (1,295,371 ft)	
Number of Sinkholes: Area sq mi (sq ft)	145	0.361 sq mi (10,068,724 sq ft)		271	0.462 sq mi (12,868,511 sq ft)	
Number of Water Bodies: Area sq mi (sq ft)	2	0.103 sq mi (2,859,537 sq ft)		90	0.446 sq mi (12,424,754 sq ft)	
Number of Springs: (Named, Unnamed)	10	(10, 0)		27	(16, 11)	
Buffers:	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
Number of features	495	230	230	483	242	203
Perimeter mi	436.5 mi	389.4 mi	372.5 mi	833.5 mi	663.9 mi	636.6 mi
Area sq mi (% BCW)[1]	7.47 sq mi (8.3%)	14.6 sq mi (16.2%)	16.4 sq mi (18.2%)	14.6 sq mi (16.2%)	26.7 sq mi (29.7%)	30.1 mi (33.4%)
Affected Property:	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
Number of Parcels (% BCW)[2]	4,716 (13.2%)	7,105 (19.9%)	7,721 (21.6%)	8,570 (24.0%)	12,159 (34.1%)	13,237 (37.1%)
Number of Buildings (% BCW)[2]	1,634 (4.0%)	4,326 (10.7%)	5113 (12.7%)	3,276 (8.1%)	8,220 (20.4 %)	9,589 (23.7 %)

[1] Based on Ogden Engineering flood study (2003):

   Area of Beaver Creek Watershed: 90.0 sq mi

[2] Based on 2003 KGIS data (selected by centroid):

   Total parcels in Beaver Creek Watershed: 35,705 (Knox County: 182,833)

   Total buildings in Beaver Creek Watershed: 40,382 (Knox County: 210,508)

This is probably the more significant impact, since it relates to how the buffer interacts with existing conditions, and how that may effect allowable uses and new development if the buffers are made part of a municipal landuse plan.

The use of ArcGIS Hydrology tools played a significant role in the creation of new datasets and in the improvement of existing ones I used to populate my data model. These powerful geoprocessing tools helped with delineation of the stream network and assisted in the improvement of the sinkhole dataset. They were also leveraged to define the overland catchments of the spring locations, and aided in the identification of basins that drained to sinkholes. One of the first steps in preparing the DEM for use in the Hydrology tools is finding and filling erroneous sinks. This step of the process is particularly useful in finding and fixing anomalies in the DEM, and it also helps identify legitimate sinkholes. Using topographic and soil survey maps as a guide, I was able to relatively quickly and easily bolster the sinkhole dataset, making corrections to the shapes of sinkholes we had already identified in the BCWGIP, and adding many new ones. At the same time, I was able to find and digitize many of the small ponds and lakes that were not part of the original water bodies dataset to bring it up to the standard of the others.

Another big difference between the original BCWGIP datasets and mine are those critical features directly associated with the headwater streams: springs. In the original study, springs from USGS 1:100,000-scale maps were used. My springs were sourced from the USGS Geographic Name Information System (GNIS) database, which contains all the named features on the 7.5-minute topographic maps. I found, however, that there were also a significant number of unnamed springs in the area that are depicted on the

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7.5-minute maps, so these were also added. While the increase in the number of springs definitely changes the spatial implication of the buffer due to catchment-based buffer rules (since there are more of them), the real difference in the BCWGIP and my model treatment of springs is that in my dataset, there are no isolated springs. On the 1:100,000-scale maps, springs of significance are marked, but if the stream fed by the spring is not of a significant size, it may not be shown, leaving some springs disconnected from the stream network, which were treated as "upland" springs in the BCWGIP analysis. On 1:24,000-scale maps, the springs are always connected to a stream, since at that scale they are source points for the headwaters. Whether or not this is purely a cartographic convention of the USGS, I found that this made sense from a hydrologic standpoint as well: that springs should always be coincident with the origin of a stream, and thus be part of the lowland buffers. One exception to this method is if there is a spring that feeds an upland stream (one that drains to a sinkhole) that spring, while not isolated, would be considered part of the upland system in terms of its selection in the geoprocessing model, which is set up to handle this situation.

The additional datasets that I derived, such as the new spring catchments and the sinkhole catchments, were also aided by the Hydrology toolset. The spring catchments were independent of other basin features used in the model, so I accepted the programmatic delineation of these areas with minimal modifications to their shapes, usually only smoothing the edges. To figure out which basins in the Ogden Engineering basin dataset were drained by sinks, I first generated my own basins for the watershed. Through this process, basins that have no outlet are identified by the Watershed tool. I then compared my basins to those delineated by Ogden. They were a bit different, but

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using my basin dataset I was able to identify the basins that were drained by a sinkhole and attribute them accordingly.

The rest of the datasets that I included in my data model were the same as the Beaver Creek assessment, since newer or more detailed data has not become available for the soils, wetlands, floodplains, etc. It is important to note that there are always improvements that can be made in the datasets used for any analysis. While I have pointed out the strengths of the datasets that I developed over the weaknesses of the original data, it was mainly an issue of scale that caused the problems in the initial analysis, not that the data was inaccurate. The same situation arises if the datasets I developed were to be used in the future to do a parcel-level assessment: new datasets would need to be developed for that level of detail in analysis so they are of an appropriate scale. But, since many of the methodologies in the geoprocessing model are relatively scale-independent, the model could be tested with more detailed data, and modifications made to the processes if necessary.

Comparison of Buffers

The two lower sections of **TABLE 6.1** describe some of the spatial characteristics of the completed buffers in each of the three zones. Obviously, since my input datasets are more detailed and cover a larger area, their buffer features will cover a larger area than the original assessment. The fact that the final composite buffers in my analysis have fewer total features than the original BCWGIP is due to the different densities of the features. In my analysis, I used the generalization function "Dissolve" to aggregate overlapping features in order to speed spatial selections and display drawing in ArcMap.

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The old buffers were also unioned and dissolved, but since many of the features, especially upland features, were not as dense, they did not get aggregated, leaving them as isolated buffer features. Although this does not change the meaning of the buffer, it is an interesting effect of the geoprocessing of the lower density features.

Another interesting statistic of the buffers is the perimeter of the buffers. The larger the buffer, the smaller the perimeter. At first this may seem counter intuitive, but it is a common effect when aggregating and buffering features. When a feature is buffered, the outline of the buffer becomes generalized somewhat, and when several individual buffers are aggregated and that feature buffered, any overlap is removed and the outline becomes more generalized and thus shorter. So, in the first zone, where there are a lot of nooks and crannies in the buffers of the detailed edges of the features, and where the buffers do not overlap much, the perimeter of the buffer is longest, and gets shorter with each additional aggregation and buffering. Again, this does not have any great implications for the nature of the buffer, it is just an interesting anomaly of the concentric buffering/aggregation cycle that is used in the geoprocessing model.

The real issue is of course the area that the buffers cover. While the new datasets have more features to add to the buffer, the methods for buffering those features is basically the same. The biggest difference between the two methods is the way that slopes are handled, and how that effects the size of the final buffer. As I described in Chapter 5, the use of slope in the old plan was too simplistic and could not handle the large, continuous zones of steep slopes that are prevalent in the Beaver Creek watershed. At that time, it was decided that the slopes would be clipped parallel to the features being protected in order to keep the buffers a reasonable size. My decision to split the slopes

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up and intersect them with erodible soils (to further enhance the protective methods of the buffer) and allow the model to select the entire contributing area of sensitive soil-slope feature had the effect of significantly increasing the total size of the buffer. See **FIGURES 6.1-6.4** for comparisons of the BCWGIP zones and the Hydrologic Feature Conservation model.

The spatial implications of the buffers are probably the most important issue regarding implementation of any landuse or development restrictions in the buffered areas. This model is meant to identify the land that has the highest value for increasing water quality, and its interaction with existing uses, zoning, and infrastructure will need to be examined before any ordinance can be put in place. The bottom section of **TABLE 6.1** shows a cursory investigation as to the number of buildings and parcels in the watershed are affected by the buffers. It is interesting to note that in all cases: area, buildings, and parcels, the final Zone 3 buffer created by my model affects about one third of each in the watershed. However, the most critical lands protected by Zone 1 only affect about 8% of the structures, 25% of the parcels, and cover about 15% of the land area. Of course, the decisions about the use of this information and whether it is a major factor in the decision to use a buffering system like this one is for planners to decide. These figures are only for the purpose of giving an impression of the size and scope of the buffers and the extent to which the community may be affected by their implementation as regulatory tools. In most cases, the purpose of the buffers (and of GI planning frameworks in general) is to steer future development.

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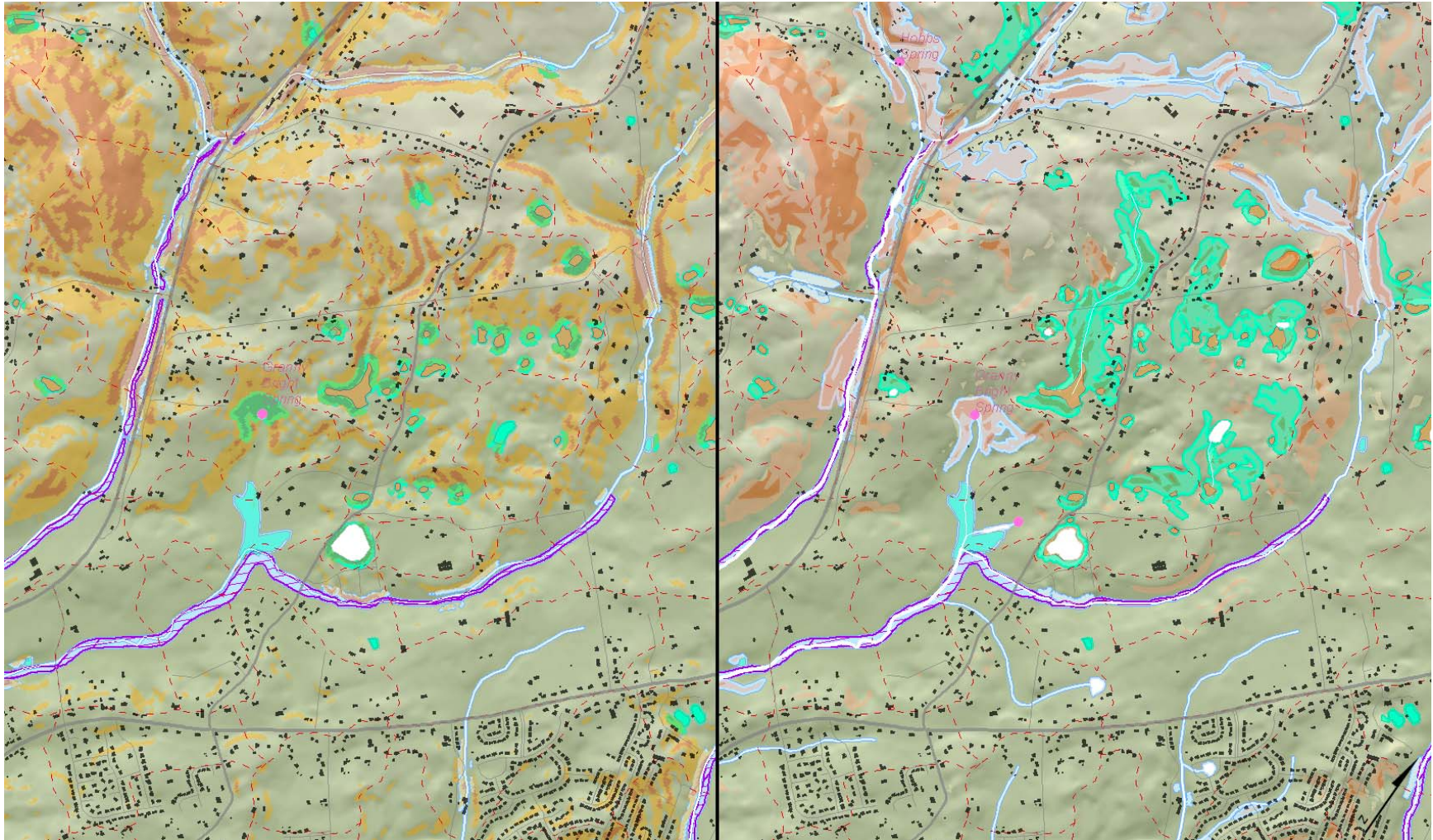
Figure 6.1 Comparison of the BCWGIP buffers (on the left) with the new model results (on the right) in Zone 1. The difference in the treatment of the slopes and soils is the most striking, especially in the upland buffers (light green), where the improvements in the method have the desirable effect of making the buffers more continuous. Also, the detail of the streams, springs, sinkholes, and water bodies is quite apparent. Otherwise, the buffer methods are similar for similar features: for the streams and floodway and any feature within 75 feet the buffer is 25 feet. Features not selected in the lowland are made part of the upland. Note the upland stream that drains to a sink on the new buffers (right map, near center).

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Figure 6.2 Comparison of the BCWGIP buffers (on the left) with the new model results (on the right) in Zone 2. Both buffer methods include the use of the 500-year floodplain in Zone 2, adding 50 feet to its extent. Other features are buffered similarly, with the exception of the use of stream order. In the BCWGIP buffers, 3rd order or higher streams were buffered more than 2nd order or lower streams (75 feet vs. 50 feet). In the new model, these values are reversed in order to add more protected land for infiltration and filtering of pollutants in the headwater streams, improving their ability to handle a surge during a flood event. Also, note the improved spring catchments on the right map, used to clip the spring buffers to their overland catchments.

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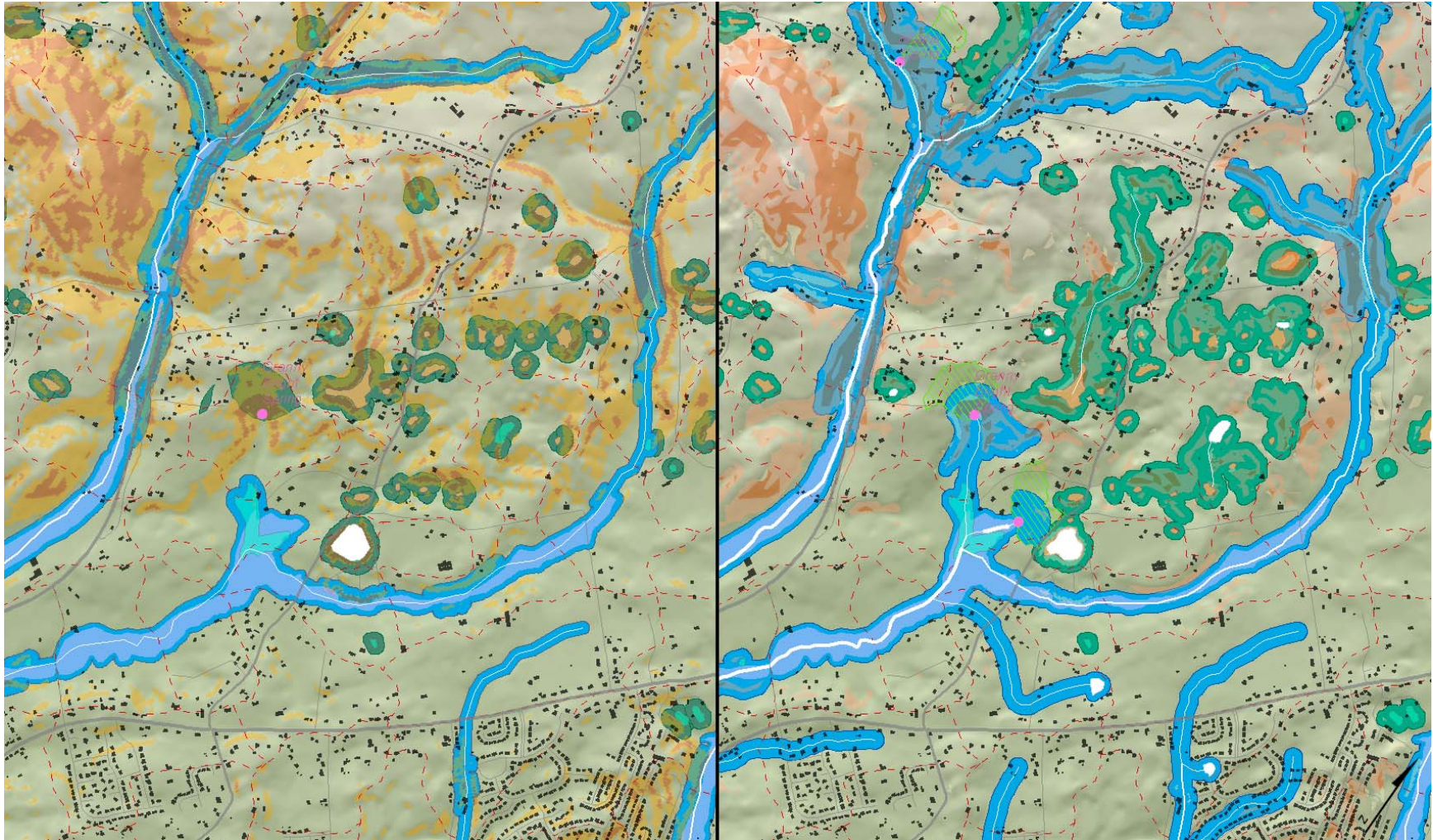
Figure 6.3 Comparison of the BCWGIP buffers (on the left) with the new model results (on the right) in Zone 3. In the third zone, features are buffered an additional 25 feet. At this point, the methods in both maps are basically the same. As the largest zone, Zone 3 also has the most connectivity in the upland areas where the individual feature buffers have merged together, creating more continuous zones of protection for these sensitive areas of groundwater recharge. As the outermost zone of stewardship, the Zone 3 buffer is an area of transition from the more groomed character of residential landscapes to the more natural character of the vegetation that is desirable in Zone 2.

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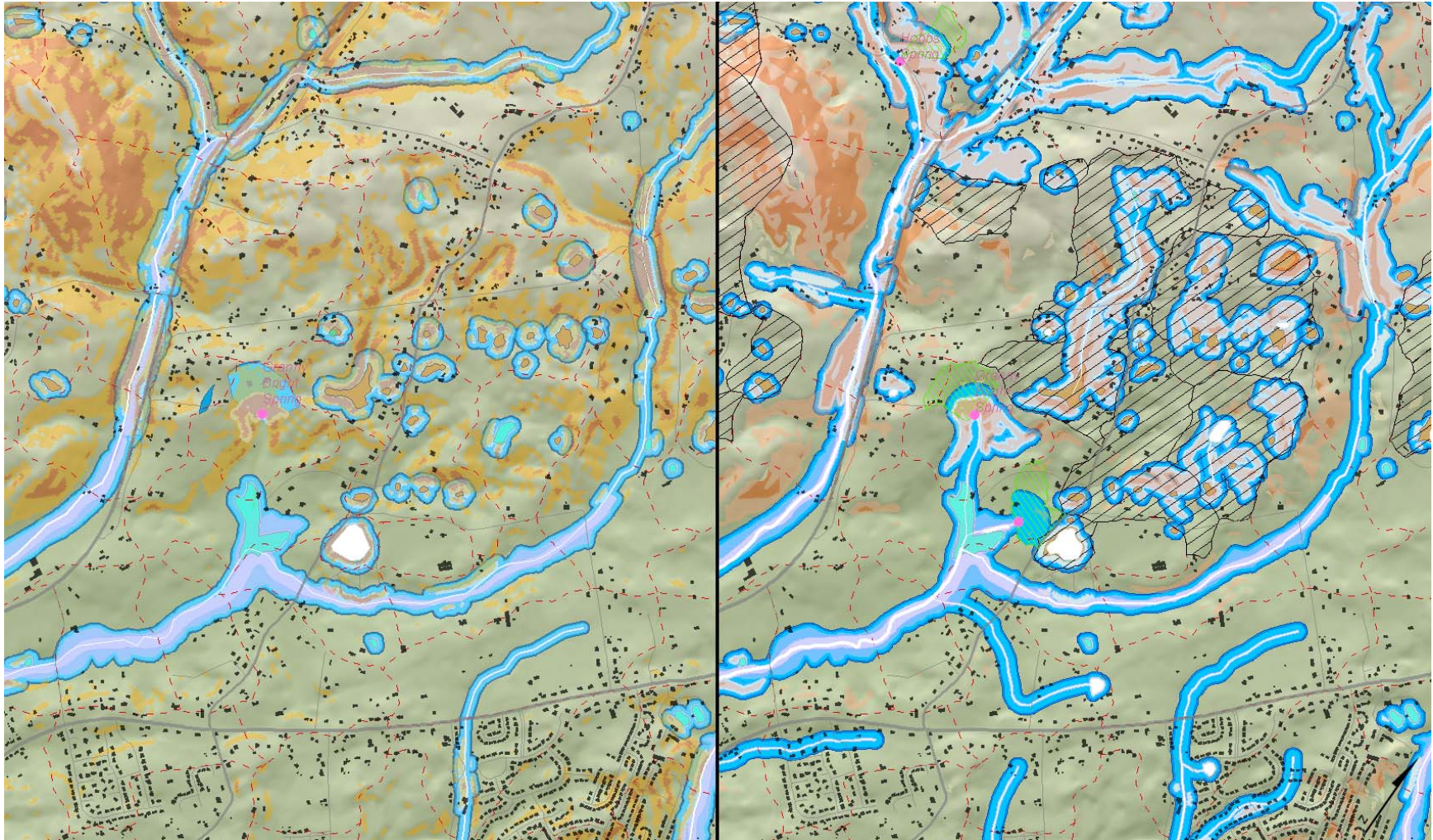
Figure 6.4 Comparison of the BCWGIP composite buffers (on the left) with the new model composite results (on the right). In the BCWGIP, advanced use of catchments was not available. In the new method map, the black hatchings show the areas that drain to sinks. While these areas are not entirely covered by the buffer, these catchments are a vital zone of groundwater recharge and should be protected. Using the catchments as a guide, these areas can be given additional protections, perhaps in the form of land use restrictions, that are separate from the best practices recommendations for acceptable uses in the three zone system.

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Modeling Issues

      The modeling process is complicated. There are a lot of issues to consider when designing a data model and associated geoprocessing models. As with any model, planning is key. Identifying the steps and the correct order of operations is essential to getting the model to run properly. Also, understanding the nature of how the geoprocessing functions work is a big plus. In my experience, I learned through some trial end error, but I also utilized the resources available to me through the ESRI support website and the ArcGIS Desktop help. These are key resources to anyone who is trying to design and test a geoprocessing model. The geoprocess functions and their parameters, which are spelled out in detail in the help, aid in the planning stages and can be of great use in the data modeling aspect since they can give clues as to custom attributes or data relationships you might need in order to complete a sequence of tasks. I will discuss some of the important questions I had to answer while designing the Hydrologic Feature Conservation data model and associated geoprocessing models.

      The first thing I realized was that as the datasets I was trying to process got larger and larger, the personal geodatabase I was using to house the feature classes was having trouble when it was accessed by a complicated geoprocess, such as a dissolve. Sometimes during one of these processes, the software would just hang up and I would have to force ArcCatalog to quit. After some investigation and good advice, I switched to a file geodatabase to store my datasets and that eliminated the problems. The geoprocessing was faster and more reliable and I had no more crashes after that. So, it is important to understand the scope of the project and the size (and potential size) of the datasets that will be used before choosing the storage container. I do not recommend

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using shapefiles, as they can be unreliable during editing. Initially, I had problems with corrupted dBase tables and the common issue of the number of objects in the .shp file and records in the .dbf file not matching up. Geodatabases do not have this problem since the shape is stored in the table, eliminating the mismatching issue.

The datasets that are chosen as inputs in the model need to be thoroughly vetted. Errors in topology, geometry, and unnecessary fields in the attribute tables can slow geoprocessing down and cause errors or undesirable results. Topology issues, such as a point covering the endpoint of a line segment (e.g. springs covering the endpoint of a stream), or geometry issues, such as self intersections or empty geometries, can be repaired with Geodatabase Topology rules and ArcGIS Data Management Feature tools. Topological issues were not significant for this project, since I did not use any datasets that required shared geometry, or the editing raw data that needed cleaning of overlaps, dangles, etc. But, it is good practice to use datasets that have been analyzed by the Repair Geometry tool in the Data Management Tools > Features toolset before running geoprocessing tasks to repair self intersections and empty shapes. These types of errors in a feature class can cause undesired results or errors in the geoprocessing outputs such as buffers and dissolves. Self intersections, especially, give the Buffer tool trouble, creating "inside out" polygons, where a self intersection creates a strange hole in the edge of the buffer at an acute vertex.

Choosing the right kind of field to store an attribute is also important. This has (unfortunately) become a less-noticeable problem as computer hard disk storage has increased, but table size on disk can still be an issue if the database has to be distributed on media, such as a CD-ROM, or served to remote users through an IMS. When adding

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fields in the feature attribute table, use the field definition that best fits the data. For storing buffer widths in whole numbers, use a short or long integer instead of a float or double. Conversely, if high accuracy is needed, as in the case of shape areas or geographic coordinates, a float or double precision field is appropriate. Also, text attributes should be considered carefully. Don't use a text field with a length of 255 characters to store the names of features when 50 to 80 characters is going to be sufficient. With some careful planning, attribute tables can be lean and storage requirements kept to a minimum, improving access times, and keeping the database design clean and concise.

The final issue I want to address is process modeling in the ArcGIS ModelBuilder application. While it is quite powerful, ModelBuilder is hardly a polished development environment, in my opinion. It is rather simplistic, and it does have its issues. I found that the key to using it successfully was to plan the order of geoprocessing operations, then drag and drop the objects in that order from ArcToolbox into the ModelBuilder window and connect them. This seemed to improve the flow of the diagram and make the auto layout work better, without having to use dozens of preconditions to force the order of operations, which also cluttered the diagram. Another important practice is to give the geoprocess and output objects in the model logical and consistent names. When objects are placed on the layout, they are given a generic title consisting of the name of the process ("Buffer") and a generic output name ("Output Feature Class" or "Output Layer"). As a model is built, if more than one process of the same type is added, a number in parenthesis is added to the process and output names ("Buffer (2)" and "Output Feature Class (2)"), since unique object names are required. Once you have

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more than about 10 processes and their outputs on the page (as well as process parameters, etc.), it can be difficult to remember if the object you want to link to the next process is "Output Feature Class (1)" or "Output Feature Class (5)". Also, using a consistent naming convention is of great help when it comes time to test and QA/QC the model, not to mention the fact that if anyone else ever wants to edit or use the model, poorly named objects make it nearly impossible to follow the logic and make changes. I name all the objects what they are and/or what they do (e.g. "Buffer: 25ft Streams" or "FClass: Upland Springs"). This naming convention seems intuitive, but I was surprised to find some models I researched online were not well named or organized, making them hard to understand. Another solution to the problem of complex workflows in the ModelBuilder environment is to use a scripting language such as Visual Basic or Python to help alleviate the visual redundancy of repetitive tasks. Since a script can be added to ArcToolbox as an executable process, they can be integrated into ModelBuilder diagrams as one would a Buffer or Dissolve function. This allows for more modular construction of the model with fewer visual redundancies.

Implications For Further Study

The process of creating the data and geoprocess models for the Hydrologic Feature Conservation Model is one that could be repeated for other components of the Beaver Creek Watershed GIP. The greater implication is that the creation of a set of models for the GIP components could be put together to create a complete Green Infrastructure Network data model package. It could be distributed and used by planners and analysts to create a set of maps that identify the core relationships between the GI

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components and aid in the process of identifying lands for conservation, restoration, and development.

To review some of the accomplishments of this research and to suggest what can be done additionally, I present a brief discussion of some of the concluding thoughts of Moir-McClean and DeKay from the BCWGIP final report that pertain to the water component and the data and geoprocessing models. Some of the key plan recommendations for expansion of the hydrologic analysis done in the Beaver Creek watershed, as well as refinements to the water buffering methods, that were accomplished by this research project include: 1) the automation of the Water Buffer methods; 2) the construction of more detailed hydrology datasets; 3) the addition of catchment-based methods; and 4) identification of previously undocumented sinks and springs from hydrologic analysis and map research. As far as goals for the future, the study could be expanded to all of Knox County relatively easily, especially with support from the Knoxville MPC and data acquisition by KGIS. This goal has now been greatly facilitated by the completion of this research, and the completion of the digital FEMA flood maps for the entire county. With a relatively small amount of additional work to complete the rest of the hydrologic datasets for the county, the models developed here can be executed and results produced in short order. As it stands, anyone with access to datasets that are comparable to those described herewith in could take the supplied geoprocessing model and database schema and conduct a hydrologic buffer analysis and begin the process of identifying the critical lands that support one of the basic tenets of GI planning and help to conserve and restore our most precious natural resource: water.

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APPENDICIES

APPENDIX A

This appendix contains the model-level help available to the user when running the geoprocessing models from the ArcToolbox within ArcMap or ArcCatalog.

ArcToolbox

SlopeZonesFromDEM

This tool creates a polygon feature class which stores user-defined "slope zones" derived from a Digital Elevation Model (DEM)

A slope raster is calculated from the input DEM. The slope raster is then reclassified based on user input. The reclassifed raster is converted to polygons and a field called Slope_Zone is calculated to reflect the reclassification.

Command line syntax
SlopeZonesFromDEM <DEM_Input_raster> {Analysis_Mask} {Z_factor} {PERCENT_RISE | DEGREE} <Reclassification> {NODATA | DATA} {SIMPLIFY | NO_SIMPLIFY} <Output_polygon_feature_class>

Parameters

Expression	Explanation
<DEM_Input_raster>	A raster elevation dataset. The raster should be projected and the Z units should be the same as the X,Y units, otherwise a Z-factor will need to be specified in order to produce valid results.
{Analysis_Mask}	Identifies those cells within the analysis extent that will be considered when performing the slope function. Setting an analysis mask means that processing will only occur on selected locations and that all other locations will be assigned values of NoData. Setting an analysis mask is a three-step process: • An analysis mask must first be created if you do not already have one. It can be a raster or a feature class dataset. • If the analysis mask is a raster, all cells of interest have a value, and all other cells have a value of NoData. Only cells with values will be considered in the analysis. The Reclassify tool can help create a raster analysis mask. • If the analysis mask is a feature dataset, only locations containing features will be considered in the analysis.
{Z_factor}	The Z-factor is the number of ground X,Y units in one surface Z unit. The input surface values are multiplied by the specified Z-factor to adjust the input surface Z units to another measurement unit. For instance, if the X and Y units are in meters and the Z units are in feet, specify a Z-factor of 0.3048, since there are 0.3048 meters in one foot. Conversely, to adjust for X and Y units in feet and Z units in meters, specify a Z-factor of 3.2808399. The default value is 1 (no adjustment).
{PERCENT_RISE	DEGREE}	The output measurement units for slope can be in degrees or percentages. The default is percent slope.
<Reclassification>	Specify the slope values to be included in each zone and specify the zone number. Slope values that are not specified (i.e. 0 - 14) will be made NoData by default (see "Change missing values to NoData" checkbox).
{NODATA	DATA}	Values not specified in the reclassification table are assigned a value of NoData. This is the default.
{SIMPLIFY	NO_SIMPLIFY}	The polygons will be simplified to reduce the "stair-step" effect when the slope zone raster is converted to a polygon feature class. This is the default.
<Output_polygon_feature_class>	Name and location of the final slope zone polygon feature class.

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SoilSlopeBasinIntersect

Selects erodible soils based on a user-defined query and intersects them with slope zones and optionally with basins to create a Soil-Slope-Basin polygon feature class for use with the Sensitive Hydrologic Feature Protection geoprocessing model.

Command line syntax
SoilSlopeBasinIntersect <Slope_Zone_Features> <Soil_Features> {Expression__soil_erodibility_} <Intersect_with_basins_> <Basin_Features> <Output_Soil-Slope-Basin_Intersection_Features>

Parameters

Expression	Explanation
<Slope_Zone_Features>	Input slope zone polygon features created with the SlopeZonesFromDEM tool.
<Soil_Features>	Input soil polygon features from NRCS county-level soil survey. Erodible soils are selected based on a user-defined query (see Expression).
{Expression__soil_erodibility_}	Erodible soil types can be determined from the tables included with the published NRCS county-level soil survey.
<Intersect_with_basins_>	If basins for the study area are available, they can be used to intersect with the soils and slopes in order to break them up into their areas of hydrologic influence. This is important for the Sensitive Hydrologic Feature Protection model, since areas that do not directly influence a sensitive feature should not be considered in the buffer.
<Basin_Features>	Input basin features. Basins are small hydrologic units derived for each section of a reach within a stream network and define the land that directly influences that section.
<Output_Soil-Slope-Basin_Intersection_Features>	Output of the intersection of the Soil-Slope-Basin polygon features.

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HydroValueZones

This data analysis model is for identifying land (surfaces) that contribute to an increase in water quality value. The goal is to identify two categories of land (lowland and upland) that can preserve or improve water quality by buffering sensitive features. Land included in these buffers is zoned to reflect 3 levels of protective action: preservation (of edge), conservation, and stewardship. The lowland buffer identifies features associated with riparian areas and surface hydrology. The upland buffer identifies features associated with groundwater recharge.

Zone 1 (Edge Protection)

The minimum required width for Zone 1 is 25 feet. This is measured perpendicularly from the edge of the FEMA defined floodway and from the stream edge where floodway data is unavailable. Only floodway and stream features within the analysis mask will be considered.

Sensitive features and impacts near the stream are searched for within 75 feet of the floodway + stream network. These include the wetlands, springs, sinkholes and soil-slope areas. These are the lowland feature selections.

Each lowland sensitive feature is buffered based on best practices recommended by EPA, TN MS-4 Working Group Water Quality Buffer Zone Policy, and/or Florida Chapter 62-521 Wellhead Protection ordinance. Springs, wetlands, and sinkholes are buffered 25 feet. Soil-slope areas are selected and buffered 20-50 feet based on the combination of slope zone and soil erodibility attributes. This creates the Zone 1 lowland sensitive feature buffers.

Features not selected in the initial lowland selection are considered part of the upland and are buffered in the same way as the lowland features. Also, streams that attributed as draining to a sinkhole are considered part of the upland and are buffered accordingly.

The lowland and upland buffers are appended and dissolved to create the composite Zone 1 Protection (of edge) buffer.

Zone 2 (Conservation)

The minimum required with for Zone 2 is 50 feet with variations based on feature type. All measurements are made perpendicular to the Zone 1 boundary.

The floodplain (100-500-yr.) is added in Zone 2 and is buffered the minimum 50 feet.

First and second order streams (defined by Strahler method) are buffered an additional 50 feet (total of 100 feet). Third order streams or larger are buffered and additional 25 feet (total of 75 feet). Springs are buffered 450 feet, and clipped to their overland catchments (derived by ESRI Hydrology tools). Sinkholes and sensitive soil-slope areas are buffered 50 feet. These rules are applied to lowland and upland features.

The lowland and upland buffers are appended and dissolved to create the composite Zone 2 Conservation buffer.

Zone 3 (Stewardship)

The minimum required with for Zone 3 is 25 feet. It is measured perpendicular to the Zone 2 boundary. Springs are buffered 25 feet, and clipped to their overland catchments (derived by ESRI Hydrology tools). This rule is applied to lowland and upland features.

The lowland and upland buffers are appended and dissolved to create the composite Zone 3 Stewardship buffer.

Command line syntax

HydroValueZones <Input_Watershed_or_Study_Area_Feature_Class>
<Input_Floodway_Feature_Class> <Input_Floodplain_Features> <Input_Stream_Feature_Class>
<Input_Water_Body_Feature_Class> <Input_Wetlands_Feature_Class>
<Input_Sinkholes_Feature_Class> <Input_Springs_Feature_Class>
<Input_Spring_Catchment_Feature_Class> <Input_Soil-Slope-Basin_Feature_Class>

Parameters

Expression	Explanation
<Input_Watershed_or_Study_Area_Feature_Class>	This feature is used by the model as an analysis mask. Only features that intersect this area will be considered for buffering. Typically, a watershed is the basic analysis unit for this tool. Other shapes can be used as well, including several watersheds merged together or a county boundary.
<Input_Floodway_Feature_Class>	The FEMA-defined floodway, along with streams where the floodway is not defined, is the baseline for the Zone 1 lowland buffer. Features found within the search distance of the floodway are the lowland sensitive features.
<Input_Floodplain_Features>	The FEMA-defined floodplain (100-500yr.) is protected in the Zone 2 lowland buffer as part of the critical lands for mitigating flood effects.
<Input_Stream_Feature_Class>	Stream features form the backbone of the Hydrologic Feature Protection model. To be used with this tool, features should have Strahler stream order assigned to them in a field called "StreamOrder", and be assigned a boolean value to identify if the stream drains into a sinkhole (0 = false; 1 = true).
<Input_Water_Body_Feature_Class>	Water bodies to be considered for protection by the model.
<Input_Wetlands_Feature_Class>	Wetland areas to be considered for protection by the model.
<Input_Sinkholes_Feature_Class>	Sinkholes to be considered for protection by the model.

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<Input_Springs_Feature_Class>	Springs to be considered for protection by the model. Springs should be linked to the hydrologic network as source points of headwater streams.
<Input_Spring_Catchment_Feature_Class>	Spring catchments define the overland area that drains to a spring feature. The tool uses the catchments to limit the buffers in Zones 2 and 3 to the surfaces that drain directly to the springs. These can be delineated using the Hydrology tools available in ArcGIS by defining spring locations as "pour points" and using the flow accumulation tool and a DEM to determine the cells that drain to those points.
<Input_Soil-Slope-Basin_Feature_Class>	These features delineate areas that have a combination of attributes with regard to soil erodibility, slope steepness, and the drainage basin that they are located in. Soils from county soil survey, slope areas delineated from a USGS 10-meter DEM, and basins of the Beaver Creek Watershed delineated by TVA are intersected to form a composite relationship between soil erodibility, steepness and drainage area. The features should have the following attributes: "High_Erode" (0 = false; 1 = true), "Slope_Zone" (1, 2). These attributes can be modified and the tool editied to account for more variables.

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The following is a log file that was recorded during the HydroValueZones geoprocessing model execution. It contains the name, parameters, and start and end times for each function carried out during the process. It may be useful to users to see the run times and order of operations during the model execution in order to better understand the process.

```
Executing (HydroValueZones_1): HydroValueZones G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\TVA_Watershed
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\FEMA_Floodway G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\FEMA_500yr_Flood
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Streams G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Water
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\NWI_100k_Wetlands G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Sinkholes
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Springs G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Spring_Catchments
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\Soil_Slope_Basin_Intersect
Start Time: Wed Sep 24 17:22:22 2008
Executing (Make Water Body FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Water Lyr_USGS_24k_Water # # "Name Name VISIBLE; GFID GFID
    VISIBLE; Shape_Length Shape_Length VISIBLE; Shape_Area Shape_Area VISIBLE; IsAgUse IsAgUse VISIBLE"
Start Time: Wed Sep 24 17:22:42 2008
Executed (Make Water Body FLayer) successfully.
End Time: Wed Sep 24 17:22:42 2008 (Elapsed Time: 0.00 seconds)
Executing (Make Floodway FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\FEMA_Floodway Lyr_FEMA_Floodway # # "Shape_Length Shape_Length VISIBLE;
    Shape_Area Shape_Area VISIBLE"
Start Time: Wed Sep 24 17:22:42 2008
Executed (Make Floodway FLayer) successfully.
End Time: Wed Sep 24 17:22:42 2008 (Elapsed Time: 0.00 seconds)
Executing (Make Analysis Mask FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\TVA_Watershed Lyr_AnalysisMask #
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb "HU_10_NAME HU_10_NAME VISIBLE; HU_12_NAME HU_12_NAME VISIBLE; HU_12_TYPE HU_12_TYPE VISIBLE; DRAFTACRE DRAFTACRE VISIBLE;
    HU_8_NAME HU_8_NAME VISIBLE; HUC_6 HUC_6 VISIBLE; HU_6_NAME HU_6_NAME VISIBLE; HUC_4 HUC_4 VISIBLE; HU_4_NAME HU_4_NAME VISIBLE; HUC_2 HUC_2 VISIBLE; HU_2_NAME HU_2_NAME
    VISIBLE; Shape_Length Shape_Length VISIBLE; Shape_Area Shape_Area VISIBLE; GFID GFID VISIBLE"
Start Time: Wed Sep 24 17:22:42 2008
Executed (Make Analysis Mask FLayer) successfully.
End Time: Wed Sep 24 17:22:42 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Floodway w/i Analysis Mask): SelectLayerByLocation Lyr_FEMA_Floodway INTERSECT Lyr_AnalysisMask # NEW_SELECTION Lyr_FEMA_Floodway
Start Time: Wed Sep 24 17:22:42 2008
Executed (Select Floodway w/i Analysis Mask) successfully.
End Time: Wed Sep 24 17:22:42 2008 (Elapsed Time: 0.00 seconds)
Executing (Buffer Floodway w/i Analysis Mask 75ft): Buffer Lyr_FEMA_Floodway G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_FEMA_Floodway "75 Feet" FULL
    ROUND NONE #
Start Time: Wed Sep 24 17:22:42 2008
Executed (Buffer Floodway w/i Analysis Mask 75ft) successfully.
End Time: Wed Sep 24 17:22:44 2008 (Elapsed Time: 2.00 seconds)
Executing (Make Streams FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Streams Lyr_USGS_24k_Streams # # "Shape_Length Shape_Length
    VISIBLE; GFID GFID VISIBLE; StreamOrder StreamOrder VISIBLE; DrainsToSink DrainsToSink VISIBLE; Name Name VISIBLE; IsVisible IsVisible VISIBLE; IsLabeled IsLabeled VISIBLE;
    Z2_BuffDist Z2_BuffDist VISIBLE"
Start Time: Wed Sep 24 17:22:44 2008
Executed (Make Streams FLayer) successfully.
End Time: Wed Sep 24 17:22:44 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Streams w/i Analysis Mask (Lowland)): SelectLayerByLocation Lyr_USGS_24k_Streams INTERSECT Lyr_AnalysisMask # NEW_SELECTION Lyr_USGS_24k_Streams
Start Time: Wed Sep 24 17:22:44 2008
Executed (Select Streams w/i Analysis Mask (Lowland)) successfully.
End Time: Wed Sep 24 17:22:45 2008 (Elapsed Time: 1.00 seconds)
Executing (Select Lowland Streams (DrainsToSink = 0)): SelectLayerByAttribute Lyr_USGS_24k_Streams SUBSET_SELECTION ""DrainsToSink" = 0" Lyr_USGS_24k_Streams
Start Time: Wed Sep 24 17:22:45 2008
Executed (Select Lowland Streams (DrainsToSink = 0)) successfully.
End Time: Wed Sep 24 17:22:45 2008 (Elapsed Time: 0.00 seconds)
Executing (Feature To Line: Lowland Streams): FeatureToLine Lyr_USGS_24k_Streams G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Streams # ATTRIBUTES
Start Time: Wed Sep 24 17:22:45 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Feature To Line: Lowland Streams) successfully.
End Time: Wed Sep 24 17:22:46 2008 (Elapsed Time: 1.00 seconds)
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Executing (Buffer 75ft Lowland Streams): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Streams
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_USGS_24k_Streams "75 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:22:46 2008
Executed (Buffer 75ft Lowland Streams) successfully.
End Time: Wed Sep 24 17:22:48 2008 (Elapsed Time: 2.00 seconds)
Executing (Union: Lowland Selection Mask): Union "G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_FEMA_Floodway #;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_USGS_24k_Streams #"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Mask_75ft_RAW ALL # GAPS
Start Time: Wed Sep 24 17:22:48 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Union: Lowland Selection Mask) successfully.
End Time: Wed Sep 24 17:22:55 2008 (Elapsed Time: 7.00 seconds)
Executing (Calculate Field: Lowland Sel Mask (BUFF_DIST = 75)): CalculateField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Mask_75ft_RAW BUFF_DIST
    75 VB # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Mask_75ft_RAW
Start Time: Wed Sep 24 17:22:56 2008
Executed (Calculate Field: Lowland Sel Mask (BUFF_DIST = 75)) successfully.
End Time: Wed Sep 24 17:22:56 2008 (Elapsed Time: 0.00 seconds)
Executing (Dissolve: Lowland Selection Buffer (BUFF_DIST)): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Mask_75ft_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Buffer_75ft BUFF_DIST # SINGLE_PART
Start Time: Wed Sep 24 17:22:57 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Lowland Selection Buffer (BUFF_DIST)) successfully.
End Time: Wed Sep 24 17:23:02 2008 (Elapsed Time: 5.00 seconds)
Executing (Select Lowland Water Bodies): SelectLayerByLocation Lyr_USGS_24k_Water INTERSECT G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Buffer_75ft
    # NEW_SELECTION Lyr_USGS_24k_Water
Start Time: Wed Sep 24 17:23:03 2008
Executed (Select Lowland Water Bodies) successfully.
End Time: Wed Sep 24 17:23:04 2008 (Elapsed Time: 1.00 seconds)
Executing (Feature To Poly: Lowland Water): FeatureToPolygon Lyr_USGS_24k_Water G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Water # ATTRIBUTES #
Start Time: Wed Sep 24 17:23:04 2008
Reading Features...
Assembling Features...
Executed (Feature To Poly: Lowland Water) successfully.
End Time: Wed Sep 24 17:23:05 2008 (Elapsed Time: 1.00 seconds)
Executing (Lyr: Lowland Water Bodies (SWITCH_SEL)): SelectLayerByAttribute Lyr_USGS_24k_Water SWITCH_SELECTION # Lyr_USGS_24k_Water
Start Time: Wed Sep 24 17:23:05 2008
Executed (Lyr: Lowland Water Bodies (SWITCH_SEL)) successfully.
End Time: Wed Sep 24 17:23:05 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Upland Water w/i Analysis Mask): SelectLayerByLocation Lyr_USGS_24k_Water INTERSECT Lyr_AnalysisMask # SUBSET_SELECTION Lyr_USGS_24k_Water
Start Time: Wed Sep 24 17:23:05 2008
Executed (Select Upland Water w/i Analysis Mask) successfully.
End Time: Wed Sep 24 17:23:05 2008 (Elapsed Time: 0.00 seconds)
Executing (Feature To Poly: Upland Water): FeatureToPolygon Lyr_USGS_24k_Water G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Water # ATTRIBUTES #
Start Time: Wed Sep 24 17:23:05 2008
Reading Features...
Assembling Features...
Executed (Feature To Poly: Upland Water) successfully.
End Time: Wed Sep 24 17:23:06 2008 (Elapsed Time: 1.00 seconds)
Executing (Buffer 25ft Upland Water): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Water
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Water "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:23:06 2008
Executed (Buffer 25ft Upland Water) successfully.
End Time: Wed Sep 24 17:23:08 2008 (Elapsed Time: 2.00 seconds)
Executing (Make Wetlands FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\NWI_100k_Wetlands Lyr_NWI_100k_Wetlands # # "LABEL1 LABEL1 VISIBLE;
    LABEL2 LABEL2 VISIBLE; CODE1 CODE1 VISIBLE; CODE2 CODE2 VISIBLE; Shape_Length Shape_Length VISIBLE; Shape_Area Shape_Area VISIBLE; GFID GFID VISIBLE"
Start Time: Wed Sep 24 17:23:08 2008
Executed (Make Wetlands FLayer) successfully.
End Time: Wed Sep 24 17:23:08 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Lowland Wetlands): SelectLayerByLocation Lyr_NWI_100k_Wetlands INTERSECT G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Buffer_75ft #
    NEW_SELECTION Lyr_NWI_100k_Wetlands
Start Time: Wed Sep 24 17:23:08 2008
Executed (Select Lowland Wetlands) successfully.
End Time: Wed Sep 24 17:23:09 2008 (Elapsed Time: 1.00 seconds)
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Executing (Feature To Poly: Lowland Wetlands): FeatureToPolygon Lyr_NWI_100k_Wetlands G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Wetlands # ATTRIBUTES #
Start Time: Wed Sep 24 17:23:09 2008
Reading Features...
Assembling Features...
Executed (Feature To Poly: Lowland Wetlands) successfully.
End Time: Wed Sep 24 17:23:10 2008 (Elapsed Time: 1.00 seconds)
Executing (Lyr: Lowland Wetlands (SWITCH_SEL)): SelectLayerByAttribute Lyr_NWI_100k_Wetlands SWITCH_SELECTION # Lyr_NWI_100k_Wetlands
Start Time: Wed Sep 24 17:23:10 2008
Executed (Lyr: Lowland Wetlands (SWITCH_SEL)) successfully.
End Time: Wed Sep 24 17:23:10 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Upland Wetlands w/i Analysis Mask): SelectLayerByLocation Lyr_NWI_100k_Wetlands INTERSECT Lyr_AnalysisMask # SUBSET_SELECTION Lyr_NWI_100k_Wetlands
Start Time: Wed Sep 24 17:23:10 2008
Executed (Select Upland Wetlands w/i Analysis Mask) successfully.
End Time: Wed Sep 24 17:23:10 2008 (Elapsed Time: 0.00 seconds)
Executing (Feature To Poly: Upland Wetlands): FeatureToPolygon Lyr_NWI_100k_Wetlands G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Wetlands # ATTRIBUTES #
Start Time: Wed Sep 24 17:23:10 2008
Reading Features...
Assembling Features...
Executed (Feature To Poly: Upland Wetlands) successfully.
End Time: Wed Sep 24 17:23:13 2008 (Elapsed Time: 3.00 seconds)
Executing (Buffer 25ft Upland Wetlands): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Wetlands
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Wetlands "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:23:13 2008
Executed (Buffer 25ft Upland Wetlands) successfully.
End Time: Wed Sep 24 17:23:14 2008 (Elapsed Time: 1.00 seconds)
Executing (Make Soil-Slope-Basin FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\Soil_Slope_Basin_Intersect Lyr_S-S-B_Intersect # # "Slope_Zone
    Slope_Zone VISIBLE; GFID GFID VISIBLE; MUSYM MUSYM VISIBLE; High_Erode High_Erode VISIBLE; BASIN BASIN VISIBLE; CN CN VISIBLE; DrainToSink DrainToSink VISIBLE; Shape_Length
    Shape_Length VISIBLE; Shape_Area Shape_Area VISIBLE; BUFF_SIZE BUFF_SIZE VISIBLE"
Start Time: Wed Sep 24 17:23:14 2008
Executed (Make Soil-Slope-Basin FLayer) successfully.
End Time: Wed Sep 24 17:23:14 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Streams w/i Analysis Mask (Upland)): SelectLayerByLocation Lyr_USGS_24k_Streams INTERSECT Lyr_AnalysisMask # NEW_SELECTION Lyr_USGS_24k_Streams
Start Time: Wed Sep 24 17:23:14 2008
Executed (Select Streams w/i Analysis Mask (Upland)) successfully.
End Time: Wed Sep 24 17:23:14 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Upland Streams (DrainToSink = 1)): SelectLayerByAttribute Lyr_USGS_24k_Streams SUBSET_SELECTION ""DrainsToSink" = 1" Lyr_USGS_24k_Streams
Start Time: Wed Sep 24 17:23:14 2008
Executed (Select Upland Streams (DrainToSink = 1)) successfully.
End Time: Wed Sep 24 17:23:14 2008 (Elapsed Time: 0.00 seconds)
Executing (Feature To Line: Upland Streams): FeatureToLine Lyr_USGS_24k_Streams G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Streams # ATTRIBUTES
Start Time: Wed Sep 24 17:23:14 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Feature To Line: Upland Streams) successfully.
End Time: Wed Sep 24 17:23:16 2008 (Elapsed Time: 2.00 seconds)
Executing (Buffer 75ft Upland Streams): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Streams
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Upland_Streams "75 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:23:16 2008
Executed (Buffer 75ft Upland Streams) successfully.
End Time: Wed Sep 24 17:23:18 2008 (Elapsed Time: 2.00 seconds)
Executing (Buffer 75ft Upland Water): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Water
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Upland_Water "75 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:23:18 2008
Executed (Buffer 75ft Upland Water) successfully.
End Time: Wed Sep 24 17:23:20 2008 (Elapsed Time: 2.00 seconds)
Executing (Make Sinkhole FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Sinkholes Lyr_USGS_24k_Sinkholes # # "Shape_Length
    Shape_Length VISIBLE; Shape_Area Shape_Area VISIBLE; GFID GFID VISIBLE; BUFF_DIST BUFF_DIST VISIBLE"
Start Time: Wed Sep 24 17:23:20 2008
Executed (Make Sinkhole FLayer) successfully.
End Time: Wed Sep 24 17:23:20 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Lowland Sinkholes): SelectLayerByLocation Lyr_USGS_24k_Sinkholes INTERSECT G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Buffer_75ft
    # NEW_SELECTION Lyr_USGS_24k_Sinkholes
Start Time: Wed Sep 24 17:23:20 2008
Executed (Select Lowland Sinkholes) successfully.
End Time: Wed Sep 24 17:23:21 2008 (Elapsed Time: 1.00 seconds)
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Executing (Feature To Poly: Lowland Sinkholes): FeatureToPolygon Lyr_USGS_24k_Sinkholes G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Sinkholes # ATTRIBUTES #
Start Time: Wed Sep 24 17:23:21 2008
Reading Features...
Assembling Features...
Executed (Feature To Poly: Lowland Sinkholes) successfully.
End Time: Wed Sep 24 17:23:22 2008 (Elapsed Time: 1.00 seconds)
Executing (Lyr: Lowland Sinkholes (SWITCH_SEL)): SelectLayerByAttribute Lyr_USGS_24k_Sinkholes SWITCH_SELECTION # Lyr_USGS_24k_Sinkholes
Start Time: Wed Sep 24 17:23:22 2008
Executed (Lyr: Lowland Sinkholes (SWITCH_SEL)) successfully.
End Time: Wed Sep 24 17:23:22 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Upland Sinkholes w/i Analysis Mask): SelectLayerByLocation Lyr_USGS_24k_Sinkholes INTERSECT Lyr_AnalysisMask # SUBSET_SELECTION Lyr_USGS_24k_Sinkholes
Start Time: Wed Sep 24 17:23:22 2008
Executed (Select Upland Sinkholes w/i Analysis Mask) successfully.
End Time: Wed Sep 24 17:23:22 2008 (Elapsed Time: 0.00 seconds)
Executing (Feature To Poly: Upland Sinkholes): FeatureToPolygon Lyr_USGS_24k_Sinkholes G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Sinkholes # ATTRIBUTES #
Start Time: Wed Sep 24 17:23:22 2008
Reading Features...
Assembling Features...
Executed (Feature To Poly: Upland Sinkholes) successfully.
End Time: Wed Sep 24 17:23:25 2008 (Elapsed Time: 3.00 seconds)
Executing (Buffer 75ft Upland Sinkholes): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Sinkholes
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Upland_Sinkholes "75 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:23:25 2008
Executed (Buffer 75ft Upland Sinkholes) successfully.
End Time: Wed Sep 24 17:23:28 2008 (Elapsed Time: 3.00 seconds)
Executing (Buffer 75ft Upland Wetlands): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Wetlands
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Upland_Wetlands "75 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:23:28 2008
Executed (Buffer 75ft Upland Wetlands) successfully.
End Time: Wed Sep 24 17:23:29 2008 (Elapsed Time: 1.00 seconds)
Executing (Union: Upland Sensitive Features (S-S-B Sel Mask)): Union "G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Upland_Streams #;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Upland_Water #; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Upland_Sinkholes #;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Upland_Wetlands #" G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_S_S_B_SelMask_RAW ALL
    # NO_GAPS
Start Time: Wed Sep 24 17:23:29 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Union: Upland Sensitive Features (S-S-B Sel Mask)) successfully.
End Time: Wed Sep 24 17:23:35 2008 (Elapsed Time: 6.00 seconds)
Executing (Calculate Field: Upland S-S-B Sel Mask (BUFF_DIST = 75)): CalculateField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_S_S_B_SelMask_RAW BUFF_DIST 75
    VB # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_S_S_B_SelMask_RAW
Start Time: Wed Sep 24 17:23:35 2008
Executed (Calculate Field: Upland S-S-B Sel Mask (BUFF_DIST = 75)) successfully.
End Time: Wed Sep 24 17:23:35 2008 (Elapsed Time: 0.00 seconds)
Executing (Dissolve: Upland S-S-B Sel Mask): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_S_S_B_SelMask_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_S_S_B_SelMask BUFF_DIST # SINGLE_PART
Start Time: Wed Sep 24 17:23:35 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Upland S-S-B Sel Mask) successfully.
End Time: Wed Sep 24 17:23:39 2008 (Elapsed Time: 4.00 seconds)
Executing (Select S-S-B (High_Erode = 0 AND Slope_Zone = 2)): SelectLayerByAttribute Lyr_S-S-B_Intersect NEW_SELECTION ""High_Erode" = 0 AND "Slope_Zone" = 2" Lyr_S-S-B_Intersect
Start Time: Wed Sep 24 17:23:39 2008
Executed (Select S-S-B (High_Erode = 0 AND Slope_Zone = 2)) successfully.
End Time: Wed Sep 24 17:23:40 2008 (Elapsed Time: 1.00 seconds)
Executing (Calculate Field: S-S-B (BUFF_SIZE = 25)): CalculateField Lyr_S-S-B_Intersect BUFF_SIZE 25 VB # Lyr_S-S-B_Intersect
Start Time: Wed Sep 24 17:23:40 2008
Executed (Calculate Field: S-S-B (BUFF_SIZE = 25)) successfully.
End Time: Wed Sep 24 17:23:41 2008 (Elapsed Time: 1.00 seconds)
Executing (Select S-S-B (High_Erode = 1 AND Slope_Zone = 1)): SelectLayerByAttribute Lyr_S-S-B_Intersect NEW_SELECTION ""High_Erode" = 1 AND "Slope_Zone" = 1" Lyr_S-S-B_Intersect
Start Time: Wed Sep 24 17:23:41 2008
Executed (Select S-S-B (High_Erode = 1 AND Slope_Zone = 1)) successfully.
End Time: Wed Sep 24 17:23:41 2008 (Elapsed Time: 0.00 seconds)
Executing (Calculate Field: S-S-B (BUFF_SIZE = 40)): CalculateField Lyr_S-S-B_Intersect BUFF_SIZE 40 VB # Lyr_S-S-B_Intersect
Start Time: Wed Sep 24 17:23:41 2008
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Executed (Calculate Field: S-S-B (BUFF_SIZE = 40)) successfully.
End Time: Wed Sep 24 17:23:42 2008 (Elapsed Time: 1.00 seconds)
Executing (Select S-S-B (High_Erode = 1 AND Slope_Zone = 2)): SelectLayerByAttribute Lyr_S-S-B_Intersect NEW_SELECTION ""High_Erode" = 1 AND "Slope_Zone" = 2" Lyr_S-S-B_Intersect
Start Time: Wed Sep 24 17:23:42 2008
Executed (Select S-S-B (High_Erode = 1 AND Slope_Zone = 2)) successfully.
End Time: Wed Sep 24 17:23:43 2008 (Elapsed Time: 1.00 seconds)
Executing (Calculate Field: S-S-B (BUFF_SIZE = 50)): CalculateField Lyr_S-S-B_Intersect BUFF_SIZE 50 VB # Lyr_S-S-B_Intersect
Start Time: Wed Sep 24 17:23:43 2008
Executed (Calculate Field: S-S-B (BUFF_SIZE = 50)) successfully.
End Time: Wed Sep 24 17:23:43 2008 (Elapsed Time: 0.00 seconds)
Executing (Buffer 75ft Lowland Sinkholes): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Sinkholes
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Lowland_Sinkholes "75 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:23:43 2008
Executed (Buffer 75ft Lowland Sinkholes) successfully.
End Time: Wed Sep 24 17:23:44 2008 (Elapsed Time: 1.00 seconds)
Executing (Clip Lowland Wetlands (Analysis Mask)): Clip G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Wetlands Lyr_AnalysisMask
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Lowland_Wetlands "1 Feet"
Start Time: Wed Sep 24 17:23:44 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Clip Lowland Wetlands (Analysis Mask)) successfully.
End Time: Wed Sep 24 17:23:48 2008 (Elapsed Time: 4.00 seconds)
Executing (Buffer 75ft Clip_Lowland_Wetlands): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Lowland_Wetlands
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Lowland_Wetlands "75 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:23:48 2008
Executed (Buffer 75ft Clip_Lowland_Wetlands) successfully.
End Time: Wed Sep 24 17:23:49 2008 (Elapsed Time: 1.00 seconds)
Executing (Clip Lowland Water Bodies (Analysis Mask)): Clip G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Water Lyr_AnalysisMask
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Lowland_Water "1 Feet"
Start Time: Wed Sep 24 17:23:50 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Clip Lowland Water Bodies (Analysis Mask)) successfully.
End Time: Wed Sep 24 17:23:52 2008 (Elapsed Time: 2.00 seconds)
Executing (Buffer 75ft Clip_Lowland_Water): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Lowland_Water
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Lowland_Water "75 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:23:52 2008
Executed (Buffer 75ft Clip_Lowland_Water) successfully.
End Time: Wed Sep 24 17:23:56 2008 (Elapsed Time: 4.00 seconds)
Executing (Union: Lowland Sensitive Feature Masks (S-S-B Sel Mask)): Union "G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Buffer_75ft #;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Lowland_Sinkholes #;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Lowland_Wetlands #; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_75ft_Lowland_Water #"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_S_S_B_SelMask_RAW ALL # NO_GAPS
Start Time: Wed Sep 24 17:23:56 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Union: Lowland Sensitive Feature Masks (S-S-B Sel Mask)) successfully.
End Time: Wed Sep 24 17:24:03 2008 (Elapsed Time: 7.00 seconds)
Executing (Calculate Field: Lowland S-S-B Sel Mask (BUFF_DIST = 75)): CalculateField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_S_S_B_SelMask_RAW BUFF_DIST
    75 VB # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_S_S_B_SelMask_RAW
Start Time: Wed Sep 24 17:24:03 2008
Executed (Calculate Field: Lowland S-S-B Sel Mask (BUFF_DIST = 75)) successfully.
End Time: Wed Sep 24 17:24:04 2008 (Elapsed Time: 1.00 seconds)
Executing (Dissolve: Lowland S-S-B Sel Mask): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_S_S_B_SelMask_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_S_S_B_SelMask BUFF_DIST # SINGLE_PART
Start Time: Wed Sep 24 17:24:04 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Lowland S-S-B Sel Mask) successfully.
End Time: Wed Sep 24 17:24:09 2008 (Elapsed Time: 5.00 seconds)
Executing (Select Lowland S-S-B): SelectLayerByLocation Lyr_S-S-B_Intersect INTERSECT G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_S_S_B_SelMask #
    NEW_SELECTION Lyr_S-S-B_Intersect
Start Time: Wed Sep 24 17:24:10 2008
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Executed (Select Lowland S-S-B) successfully.
End Time: Wed Sep 24 17:24:53 2008 (Elapsed Time: 43.00 seconds)
Executing (Feature To Poly: Lowland S-S-B): FeatureToPolygon Lyr_S-S-B_Intersect G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_S_S_B # ATTRIBUTES #
Start Time: Wed Sep 24 17:24:53 2008
Reading Features...
Assembling Features...
Executed (Feature To Poly: Lowland S-S-B) successfully.
End Time: Wed Sep 24 17:25:16 2008 (Elapsed Time: 23.00 seconds)
Executing (Buffer 20-50ft Lowland S-S-B): Buffer Lyr_S-S-B_Intersect G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Lowland_S_S_B BUFF_SIZE FULL ROUND
    NONE #
Start Time: Wed Sep 24 17:25:17 2008
Executed (Buffer 20-50ft Lowland S-S-B) successfully.
End Time: Wed Sep 24 17:25:28 2008 (Elapsed Time: 11.00 seconds)
Executing (Select Upland S-S-B): SelectLayerByLocation Lyr_S-S-B_Intersect INTERSECT G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_S_S_B_SelMask # NEW_SELECTION
    Lyr_S-S-B_Intersect
Start Time: Wed Sep 24 17:25:28 2008
Executed (Select Upland S-S-B) successfully.
End Time: Wed Sep 24 17:25:30 2008 (Elapsed Time: 2.00 seconds)
Executing (Feature To Poly: Upland S-S-B): FeatureToPolygon Lyr_S-S-B_Intersect G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_S_S_B # ATTRIBUTES #
Start Time: Wed Sep 24 17:25:30 2008
Reading Features...
Assembling Features...
Executed (Feature To Poly: Upland S-S-B) successfully.
End Time: Wed Sep 24 17:25:35 2008 (Elapsed Time: 5.00 seconds)
Executing (Buffer 20-50ft Upland S-S-B): Buffer Lyr_S-S-B_Intersect G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Upland_S_S_B BUFF_SIZE FULL ROUND NONE
    #
Start Time: Wed Sep 24 17:25:35 2008
Executed (Buffer 20-50ft Upland S-S-B) successfully.
End Time: Wed Sep 24 17:25:39 2008 (Elapsed Time: 4.00 seconds)
Executing (Buffer 25ft Upland Sinkholes): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Sinkholes
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Sinkholes "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:25:39 2008
Executed (Buffer 25ft Upland Sinkholes) successfully.
End Time: Wed Sep 24 17:25:41 2008 (Elapsed Time: 2.00 seconds)
Executing (Create Zone 1 Upland Composite Feature Class (No Streams, Springs)): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput
    Zone1_Upland_Composite_NoStreamsSprings POLYGON Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone1_Upland_Composite_NoStreamsSprings
Start Time: Wed Sep 24 17:25:41 2008
Executed (Create Zone 1 Upland Composite Feature Class (No Streams, Springs)) successfully.
End Time: Wed Sep 24 17:25:42 2008 (Elapsed Time: 1.00 seconds)
Executing (Append: All Zone 1 Upland Buffers (No Streams, Springs)): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Water;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Wetlands; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Upland_S_S_B;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Sinkholes
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone1_Upland_Composite_NoStreamsSprings NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #;
    Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Water, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Wetlands, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Upland_S_S_B, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone1_Upland_Composite_NoStreamsSprings
Start Time: Wed Sep 24 17:25:42 2008
Executed (Append: All Zone 1 Upland Buffers (No Streams, Springs)) successfully.
End Time: Wed Sep 24 17:25:45 2008 (Elapsed Time: 3.00 seconds)
Executing (Buffer: 50ft Z1 Upland Composite (No Streams, Springs)): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone1_Upland_Composite_NoStreamsSprings
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Z1_Upland_Composite_NoStreamsSprings "50 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:25:45 2008
Executed (Buffer: 50ft Z1 Upland Composite (No Streams, Springs)) successfully.
End Time: Wed Sep 24 17:25:51 2008 (Elapsed Time: 6.00 seconds)
Executing (Buffer Upland Streams 100-125ft (Z2_BuffDist)): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Streams
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Upland_Streams Z2_BuffDist FULL ROUND NONE #
Start Time: Wed Sep 24 17:25:51 2008
Executed (Buffer Upland Streams 100-125ft (Z2_BuffDist)) successfully.
End Time: Wed Sep 24 17:25:54 2008 (Elapsed Time: 3.00 seconds)
Executing (Create Zone 2 Upland Composite Feature Class (No Springs)): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput Zone2_Upland_Composite_NoSprings
    POLYGON Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0 G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone2_Upland_Composite_NoSprings
Start Time: Wed Sep 24 17:25:54 2008
Executed (Create Zone 2 Upland Composite Feature Class (No Springs)) successfully.
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End Time: Wed Sep 24 17:25:55 2008 (Elapsed Time: 1.00 seconds)
Executing (Append: All Zone 2 Upland Buffers (No Springs)): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Z1_Upland_Composite_NoStreamsSprings;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Upland_Streams
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone2_Upland_Composite_NoSprings NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #;
    Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Upland_Streams, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone2_Upland_Composite_NoSprings
Start Time: Wed Sep 24 17:25:55 2008
Executed (Append: All Zone 2 Upland Buffers (No Springs)) successfully.
End Time: Wed Sep 24 17:25:58 2008 (Elapsed Time: 3.00 seconds)
Executing (Buffer: 25ft Z2 Upland Composite (No Springs)): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone2_Upland_Composite_NoSprings
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Z2_Upland_Composite_NoSprings "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:25:58 2008
Executed (Buffer: 25ft Z2 Upland Composite (No Springs)) successfully.
End Time: Wed Sep 24 17:26:13 2008 (Elapsed Time: 15.00 seconds)
Executing (Make Springs FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Springs Lyr_USGS_24k_Springs # # "ID ID VISIBLE; NAME NAME
    VISIBLE; CLASS CLASS VISIBLE; COUNTY COUNTY VISIBLE; STATE STATE VISIBLE; LAT_Y LAT_Y VISIBLE; LON_X LON_X VISIBLE; TOPO24K TOPO24K VISIBLE; ELEV_FT ELEV_FT VISIBLE; ENT_DATE
    ENT_DATE VISIBLE; GFID GFID VISIBLE"
Start Time: Wed Sep 24 17:26:13 2008
Executed (Make Springs FLayer) successfully.
End Time: Wed Sep 24 17:26:14 2008 (Elapsed Time: 1.00 seconds)
Executing (Select Lowland Springs): SelectLayerByLocation Lyr_USGS_24k_Springs INTERSECT G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Selection_Buffer_75ft #
    NEW_SELECTION Lyr_USGS_24k_Springs
Start Time: Wed Sep 24 17:26:14 2008
Executed (Select Lowland Springs) successfully.
End Time: Wed Sep 24 17:26:14 2008 (Elapsed Time: 0.00 seconds)
Executing (Feature To Point: Lowland Springs): FeatureToPoint Lyr_USGS_24k_Springs G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Springs CENTROID
Start Time: Wed Sep 24 17:26:14 2008
Executed (Feature To Point: Lowland Springs) successfully.
End Time: Wed Sep 24 17:26:16 2008 (Elapsed Time: 2.00 seconds)
Executing (Lyr: Lowland Springs (SWITCH_SEL)): SelectLayerByAttribute Lyr_USGS_24k_Springs SWITCH_SELECTION # Lyr_USGS_24k_Springs
Start Time: Wed Sep 24 17:26:16 2008
Executed (Lyr: Lowland Springs (SWITCH_SEL)) successfully.
End Time: Wed Sep 24 17:26:16 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Upland Springs w/i Analysis Mask): SelectLayerByLocation Lyr_USGS_24k_Springs INTERSECT Lyr_AnalysisMask # SUBSET_SELECTION Lyr_USGS_24k_Springs
Start Time: Wed Sep 24 17:26:16 2008
Executed (Select Upland Springs w/i Analysis Mask) successfully.
End Time: Wed Sep 24 17:26:16 2008 (Elapsed Time: 0.00 seconds)
Executing (Feature To Point: Upland Springs): FeatureToPoint Lyr_USGS_24k_Springs G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Springs CENTROID
Start Time: Wed Sep 24 17:26:16 2008
Executed (Feature To Point: Upland Springs) successfully.
End Time: Wed Sep 24 17:26:19 2008 (Elapsed Time: 3.00 seconds)
Executing (Buffer 500ft Upland Springs (Z3)): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Springs
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_500ft_Upland_Springs "500 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:26:19 2008
Executed (Buffer 500ft Upland Springs (Z3)) successfully.
End Time: Wed Sep 24 17:26:20 2008 (Elapsed Time: 1.00 seconds)
Executing (Make Spring Catchment FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\USGS_24k_Spring_Catchments USGS_24k_Spring_Catchments_L # # "ID
    ID VISIBLE; GRIDCODE GRIDCODE VISIBLE; Shape_Length Shape_Length VISIBLE; Shape_Area Shape_Area VISIBLE"
Start Time: Wed Sep 24 17:26:20 2008
Executed (Make Spring Catchment FLayer) successfully.
End Time: Wed Sep 24 17:26:20 2008 (Elapsed Time: 0.00 seconds)
Executing (Clip Buffer 500ft Upland Springs w/ Spring Catchments (Z3)): Clip G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_500ft_Upland_Springs
    USGS_24k_Spring_Catchments_L G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_500ft_Upland_Springs #
Start Time: Wed Sep 24 17:26:20 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Clip Buffer 500ft Upland Springs w/ Spring Catchments (Z3)) successfully.
End Time: Wed Sep 24 17:26:23 2008 (Elapsed Time: 3.00 seconds)
Executing (Create Zone 3 Stewardship Upland Feature Class): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput Zone3_Stewardship_Upland_RAW POLYGON
    Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0 G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland_RAW
Start Time: Wed Sep 24 17:26:23 2008
Executed (Create Zone 3 Stewardship Upland Feature Class) successfully.
End Time: Wed Sep 24 17:26:25 2008 (Elapsed Time: 2.00 seconds)
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Executing (Append: All Zone 3 Upland Buffers): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Z2_Upland_Composite_NoSprings;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_500ft_Upland_Springs
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland_RAW NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #; Shape_Area
    Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_500ft_Upland_Springs, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland_RAW
Start Time: Wed Sep 24 17:26:26 2008
Executed (Append: All Zone 3 Upland Buffers) successfully.
End Time: Wed Sep 24 17:26:30 2008 (Elapsed Time: 4.00 seconds)
Executing (Add Field: Zone 3 Upland (DISSOLVE)): AddField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland_RAW DISSOLVE SHORT # # # # NULLABLE
    NON_REQUIRED # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland_RAW
Start Time: Wed Sep 24 17:26:30 2008
Adding DISSOLVE to G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland_RAW...
Executed (Add Field: Zone 3 Upland (DISSOLVE)) successfully.
End Time: Wed Sep 24 17:26:30 2008 (Elapsed Time: 0.00 seconds)
Executing (Calculate Field: Zone 3 Upland (DISSOLVE = 256)): CalculateField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland_RAW DISSOLVE 256 VB
    # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland_RAW
Start Time: Wed Sep 24 17:26:30 2008
Executed (Calculate Field: Zone 3 Upland (DISSOLVE = 256)) successfully.
End Time: Wed Sep 24 17:26:31 2008 (Elapsed Time: 1.00 seconds)
Executing (Dissolve: Zone3_Stewardship_Upland_RAW): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland BUFF_DIST # SINGLE_PART
Start Time: Wed Sep 24 17:26:31 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Zone3_Stewardship_Upland_RAW) successfully.
End Time: Wed Sep 24 17:27:08 2008 (Elapsed Time: 37.00 seconds)
Executing (Buffer 25ft Clip_Lowland_Water): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Lowland_Water
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Water "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:27:08 2008
Executed (Buffer 25ft Clip_Lowland_Water) successfully.
End Time: Wed Sep 24 17:27:11 2008 (Elapsed Time: 3.00 seconds)
Executing (Buffer 25ft Clip_Lowland_Wetlands): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Lowland_Wetlands
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Wetlands "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:27:11 2008
Executed (Buffer 25ft Clip_Lowland_Wetlands) successfully.
End Time: Wed Sep 24 17:27:13 2008 (Elapsed Time: 2.00 seconds)
Executing (Buffer 25ft Lowland Sinkholes): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Sinkholes
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Lowland_Sinkholes "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:27:13 2008
Executed (Buffer 25ft Lowland Sinkholes) successfully.
End Time: Wed Sep 24 17:27:16 2008 (Elapsed Time: 3.00 seconds)
Executing (Buffer Floodway w/i Analysis Mask 25ft): Buffer Lyr_FEMA_Floodway G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_FEMA_Floodway "25 Feet" FULL
    ROUND NONE #
Start Time: Wed Sep 24 17:27:16 2008
Executed (Buffer Floodway w/i Analysis Mask 25ft) successfully.
End Time: Wed Sep 24 17:27:18 2008 (Elapsed Time: 2.00 seconds)
Executing (Create Zone 1 Lowland Composite Feature Class (No Streams, Springs)): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput
    Zone1_Lowland_Composite_NoStreamsSprings POLYGON Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone1_Lowland_Composite_NoStreamsSprings
Start Time: Wed Sep 24 17:27:18 2008
Executed (Create Zone 1 Lowland Composite Feature Class (No Streams, Springs)) successfully.
End Time: Wed Sep 24 17:27:19 2008 (Elapsed Time: 1.00 seconds)
Executing (Append: All Zone 1 Lowland Buffers (No Streams, Springs)): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Water;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Wetlands;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Lowland_S_S_B; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Lowland_Sinkholes;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_FEMA_Floodway
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone1_Lowland_Composite_NoStreamsSprings NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #;
    Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Water, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Wetlands, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Lowland_S_S_B, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_FEMA_Floodway, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone1_Lowland_Composite_NoStreamsSprings
Start Time: Wed Sep 24 17:27:19 2008
Executed (Append: All Zone 1 Lowland Buffers (No Streams, Springs)) successfully.
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End Time: Wed Sep 24 17:27:24 2008 (Elapsed Time: 5.00 seconds)
Executing (Buffer 50ft Z1 Lowland Composite (No Streams, Springs)): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone1_Lowland_Composite_NoStreamsSprings
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Z1_Lowland_Composite_NoStreamsSprings "50 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:27:24 2008
Executed (Buffer 50ft Z1 Lowland Composite (No Streams, Springs)) successfully.
End Time: Wed Sep 24 17:27:49 2008 (Elapsed Time: 25.00 seconds)
Executing (Make Floodplain FLayer): MakeFeatureLayer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\ModelData\FEMA_500yr_Flood FEMA_500yr_Flood_Layer # # "Shape_Length
    Shape_Length VISIBLE; Shape_Area Shape_Area VISIBLE"
Start Time: Wed Sep 24 17:27:49 2008
Executed (Make Floodplain FLayer) successfully.
End Time: Wed Sep 24 17:27:49 2008 (Elapsed Time: 0.00 seconds)
Executing (Select Floodplain w/i Analysis Mask): SelectLayerByLocation FEMA_500yr_Flood_Layer INTERSECT Lyr_AnalysisMask # NEW_SELECTION FEMA_500yr_Flood_Layer
Start Time: Wed Sep 24 17:27:49 2008
Executed (Select Floodplain w/i Analysis Mask) successfully.
End Time: Wed Sep 24 17:27:49 2008 (Elapsed Time: 0.00 seconds)
Executing (Buffer 25ft Lowland Streams): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Streams
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Lowland_Streams "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:27:49 2008
Executed (Buffer 25ft Lowland Streams) successfully.
End Time: Wed Sep 24 17:27:53 2008 (Elapsed Time: 4.00 seconds)
Executing (Buffer 25ft Lowland Springs): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Springs
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Lowland_Springs "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:27:53 2008
Executed (Buffer 25ft Lowland Springs) successfully.
End Time: Wed Sep 24 17:27:56 2008 (Elapsed Time: 3.00 seconds)
Executing (Create Zone 1 Edge Protect Lowland Feature Class): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput Zone1_EdgeProtect_Lowland_RAW POLYGON
    Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0 0 G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW
Start Time: Wed Sep 24 17:27:56 2008
Executed (Create Zone 1 Edge Protect Lowland Feature Class) successfully.
End Time: Wed Sep 24 17:27:58 2008 (Elapsed Time: 2.00 seconds)
Executing (Append: All Zone 1 Lowland Buffers): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Water;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Wetlands;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Lowland_S_S_B; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Lowland_Sinkholes;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Lowland_Streams; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Lowland_Springs;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_FEMA_Floodway G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW
    NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #; Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0
    0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #, G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Water, BUFF_DIST,
    -1, -1, G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Clip_Lowland_Wetlands, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Lowland_S_S_B, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Lowland_Streams, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Lowland_Springs, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_FEMA_Floodway, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW
Start Time: Wed Sep 24 17:27:59 2008
Executed (Append: All Zone 1 Lowland Buffers) successfully.
End Time: Wed Sep 24 17:28:05 2008 (Elapsed Time: 6.00 seconds)
Executing (Add Field: Zone 1 Lowland (DISSOLVE)): AddField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW DISSOLVE SHORT # # # # NULLABLE
    NON_REQUIRED # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW
Start Time: Wed Sep 24 17:28:05 2008
Adding DISSOLVE to G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW...
Executed (Add Field: Zone 1 Lowland (DISSOLVE)) successfully.
End Time: Wed Sep 24 17:28:05 2008 (Elapsed Time: 0.00 seconds)
Executing (Calculate Field: Zone 1 Lowland (DISSOLVE = 256)): CalculateField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW DISSOLVE 256
    VB # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW
Start Time: Wed Sep 24 17:28:05 2008
Executed (Calculate Field: Zone 1 Lowland (DISSOLVE = 256)) successfully.
End Time: Wed Sep 24 17:28:06 2008 (Elapsed Time: 1.00 seconds)
Executing (Buffer 25ft Upland Streams): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Streams
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Streams "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:28:06 2008
Executed (Buffer 25ft Upland Streams) successfully.
End Time: Wed Sep 24 17:28:07 2008 (Elapsed Time: 1.00 seconds)
Executing (Buffer 25ft Upland Springs): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Springs
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Springs "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:28:08 2008
Executed (Buffer 25ft Upland Springs) successfully.
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End Time: Wed Sep 24 17:28:10 2008 (Elapsed Time: 2.00 seconds)
Executing (Create Zone 1 Edge Protect Upland Feature Class): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput Zone1_EdgeProtect_Upland_RAW POLYGON
    Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0 G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW
Start Time: Wed Sep 24 17:28:10 2008
Executed (Create Zone 1 Edge Protect Upland Feature Class) successfully.
End Time: Wed Sep 24 17:28:11 2008 (Elapsed Time: 1.00 seconds)
Executing (Append: All Zone 1 Upland Buffers): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Upland_S_S_B;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Streams; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Water;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Sinkholes; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Wetlands;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Springs G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW
    NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #; Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0
    0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #, G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_20_50ft_Upland_S_S_B, BUFF_DIST, -1,
    -1, G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Streams, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Water, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Wetlands, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Upland_Springs, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW
Start Time: Wed Sep 24 17:28:11 2008
Executed (Append: All Zone 1 Upland Buffers) successfully.
End Time: Wed Sep 24 17:28:14 2008 (Elapsed Time: 3.00 seconds)
Executing (Add Field: Zone 1 Upland (DISSOLVE)): AddField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW DISSOLVE SHORT # # # # NULLABLE
    NON_REQUIRED # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW
Start Time: Wed Sep 24 17:28:14 2008
Adding DISSOLVE to G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW...
Executed (Add Field: Zone 1 Upland (DISSOLVE)) successfully.
End Time: Wed Sep 24 17:28:14 2008 (Elapsed Time: 0.00 seconds)
Executing (Calculate Field: Zone 1 Upland (DISSOLVE = 256)): CalculateField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW DISSOLVE 256 VB
    # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW
Start Time: Wed Sep 24 17:28:15 2008
Executed (Calculate Field: Zone 1 Upland (DISSOLVE = 256)) successfully.
End Time: Wed Sep 24 17:28:15 2008 (Elapsed Time: 0.00 seconds)
Executing (Dissolve: Zone1_EdgeProtect_Lowland_RAW): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland DISSOLVE # SINGLE_PART
Start Time: Wed Sep 24 17:28:15 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Zone1_EdgeProtect_Lowland_RAW) successfully.
End Time: Wed Sep 24 17:28:41 2008 (Elapsed Time: 26.00 seconds)
Executing (Dissolve: Zone1_EdgeProtect_Upland_RAW): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland DISSOLVE # SINGLE_PART

Start Time: Wed Sep 24 17:28:41 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Zone1_EdgeProtect_Upland_RAW) successfully.
End Time: Wed Sep 24 17:28:47 2008 (Elapsed Time: 6.00 seconds)
Executing (Create Zone 1 Edge Protect Composite Feature Class): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput Zone1_EdgeProtect_Composite_RAW
    POLYGON G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW DISABLED DISABLED # # 0 0 0
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Composite_RAW
Start Time: Wed Sep 24 17:28:47 2008
Executed (Create Zone 1 Edge Protect Composite Feature Class) successfully.
End Time: Wed Sep 24 17:28:48 2008 (Elapsed Time: 1.00 seconds)
Executing (Append: Zone 1 Edge Protect Composite): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Composite_RAW NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW, Shape_Length, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW, Shape_Length, -1, -1; Shape_Area Shape_Area false true true 8 Double 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW, Shape_Area, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW, Shape_Area, -1, -1; GFID GFID true true false 38 Text 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW, GFID, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW, GFID, -1, -1; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Lowland_RAW, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Upland_RAW, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Composite_RAW
Start Time: Wed Sep 24 17:28:48 2008
Executed (Append: Zone 1 Edge Protect Composite) successfully.
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End Time: Wed Sep 24 17:28:53 2008 (Elapsed Time: 5.00 seconds)
Executing (Dissolve: Zone 1 Edge Protect Composite): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Composite_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Composite DISSOLVE # SINGLE_PART
Start Time: Wed Sep 24 17:28:53 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Zone 1 Edge Protect Composite) successfully.
End Time: Wed Sep 24 17:29:26 2008 (Elapsed Time: 33.00 seconds)
Executing (Buffer 50ft Floodplain w/i Analysis Mask): Buffer FEMA_500yr_Flood_Layer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Floodplain "50 Feet" FULL
    ROUND NONE #
Start Time: Wed Sep 24 17:29:26 2008
Buffering complex feature 28 ...
Executed (Buffer 50ft Floodplain w/i Analysis Mask) successfully.
End Time: Wed Sep 24 17:32:27 2008 (Elapsed Time: 3 minutes 1 seconds)
Executing (Buffer Lowland Streams 100-125ft (Z2_BuffDist)): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Streams
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Lowland_Streams Z2_BuffDist FULL ROUND NONE #
Start Time: Wed Sep 24 17:32:27 2008
Executed (Buffer Lowland Streams 100-125ft (Z2_BuffDist)) successfully.
End Time: Wed Sep 24 17:32:29 2008 (Elapsed Time: 2.00 seconds)
Executing (Buffer 475ft Upland Springs): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Upland_Springs
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_475ft_Upland_Springs "475 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:32:29 2008
Executed (Buffer 475ft Upland Springs) successfully.
End Time: Wed Sep 24 17:32:31 2008 (Elapsed Time: 2.00 seconds)
Executing (Clip Buffer 475ft Upland Springs w/ Spring Catchments): Clip G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_475ft_Upland_Springs
    USGS_24k_Spring_Catchments_L G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_475ft_Upland_Springs #
Start Time: Wed Sep 24 17:32:32 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Clip Buffer 475ft Upland Springs w/ Spring Catchments) successfully.
End Time: Wed Sep 24 17:32:33 2008 (Elapsed Time: 1.00 seconds)
Executing (Create Zone 2 Conservation Upland Feature Class): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput Zone2_Conservation_Upland_RAW POLYGON
    Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0 G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland_RAW
Start Time: Wed Sep 24 17:32:33 2008
Executed (Create Zone 2 Conservation Upland Feature Class) successfully.
End Time: Wed Sep 24 17:32:36 2008 (Elapsed Time: 3.00 seconds)
Executing (Append: All Zone 2 Upland Buffers): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Z1_Upland_Composite_NoStreamsSprings;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_475ft_Upland_Springs;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Upland_Streams
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland_RAW NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #;
    Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_475ft_Upland_Springs, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Upland_Streams, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland_RAW
Start Time: Wed Sep 24 17:32:36 2008
Executed (Append: All Zone 2 Upland Buffers) successfully.
End Time: Wed Sep 24 17:32:39 2008 (Elapsed Time: 3.00 seconds)
Executing (Add Field: Zone 2 Upland (DISSOLVE)): AddField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland_RAW DISSOLVE SHORT # # # # NULLABLE
    NON_REQUIRED # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland_RAW
Start Time: Wed Sep 24 17:32:39 2008
Adding DISSOLVE to G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland_RAW...
Executed (Add Field: Zone 2 Upland (DISSOLVE)) successfully.
End Time: Wed Sep 24 17:32:39 2008 (Elapsed Time: 0.00 seconds)
Executing (Calculate Field: Zone 2 Upland (DISSOLVE = 256)): CalculateField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland_RAW DISSOLVE 256
    VB # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland_RAW
Start Time: Wed Sep 24 17:32:40 2008
Executed (Calculate Field: Zone 2 Upland (DISSOLVE = 256)) successfully.
End Time: Wed Sep 24 17:32:40 2008 (Elapsed Time: 0.00 seconds)
Executing (Dissolve: Zone2_Conservation_Upland_RAW): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland BUFF_DIST # SINGLE_PART
Start Time: Wed Sep 24 17:32:40 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Zone2_Conservation_Upland_RAW) successfully.
End Time: Wed Sep 24 17:32:56 2008 (Elapsed Time: 16.00 seconds)
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Executing (Buffer 475ft Lowland Springs (Z2)): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Springs
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_475ft_Lowland_Springs "475 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:32:56 2008
Executed (Buffer 475ft Lowland Springs (Z2)) successfully.
End Time: Wed Sep 24 17:32:59 2008 (Elapsed Time: 3.00 seconds)
Executing (Clip Buffer 475ft Lowland Springs w/ Spring Catchments (Z2)): Clip G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_475ft_Lowland_Springs
    USGS_24k_Spring_Catchments_L G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_475ft_Lowland_Springs #
Start Time: Wed Sep 24 17:32:59 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Clip Buffer 475ft Lowland Springs w/ Spring Catchments (Z2)) successfully.
End Time: Wed Sep 24 17:33:01 2008 (Elapsed Time: 2.00 seconds)
Executing (Create Zone 2 Conservation Lowland Feature Class): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput Zone2_Conservation_Lowland_RAW POLYGON
    Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0 G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland_RAW
Start Time: Wed Sep 24 17:33:01 2008
Executed (Create Zone 2 Conservation Lowland Feature Class) successfully.
End Time: Wed Sep 24 17:33:03 2008 (Elapsed Time: 2.00 seconds)
Executing (Append: All Zone 2 Lowland Buffers): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Z1_Lowland_Composite_NoStreamsSprings;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_475ft_Lowland_Springs; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Floodplain;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Lowland_Streams
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland_RAW NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #;
    Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_475ft_Lowland_Springs, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Floodplain, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Lowland_Streams, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland_RAW
Start Time: Wed Sep 24 17:33:04 2008
Executed (Append: All Zone 2 Lowland Buffers) successfully.
End Time: Wed Sep 24 17:33:12 2008 (Elapsed Time: 8.00 seconds)
Executing (Add Field: Zone 2 Lowland (DISSOLVE)): AddField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland_RAW DISSOLVE SHORT # # # #
    NULLABLE NON_REQUIRED # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland_RAW
Start Time: Wed Sep 24 17:33:12 2008
Adding DISSOLVE to G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland_RAW...
Executed (Add Field: Zone 2 Lowland (DISSOLVE)) successfully.
End Time: Wed Sep 24 17:33:12 2008 (Elapsed Time: 0.00 seconds)
Executing (Calculate Field: Zone 2 Lowland (DISSOLVE = 256)): CalculateField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland_RAW DISSOLVE 256
    VB # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland_RAW
Start Time: Wed Sep 24 17:33:12 2008
Executed (Calculate Field: Zone 2 Lowland (DISSOLVE = 256)) successfully.
End Time: Wed Sep 24 17:33:13 2008 (Elapsed Time: 1.00 seconds)
Executing (Dissolve: Zone2_Conservation_Lowland_RAW): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland BUFF_DIST # SINGLE_PART
Start Time: Wed Sep 24 17:33:14 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Zone2_Conservation_Lowland_RAW) successfully.
End Time: Wed Sep 24 17:34:04 2008 (Elapsed Time: 50.00 seconds)
Executing (Create Zone 2 Conservation Composite Feature Class): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput Zone2_Conservation_Composite_RAW
    POLYGON G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Composite_RAW DISABLED DISABLED # # 0 0 0
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Composite_RAW
Start Time: Wed Sep 24 17:34:04 2008
Executed (Create Zone 2 Conservation Composite Feature Class) successfully.
End Time: Wed Sep 24 17:34:05 2008 (Elapsed Time: 1.00 seconds)
Executing (Append: Zone 2 Conservation Composite): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland;
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Composite_RAW NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #;
    Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Upland, BUFF_DIST, -1, -1,
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Lowland, BUFF_DIST, -1, -1"
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Composite_RAW
Start Time: Wed Sep 24 17:34:05 2008
Executed (Append: Zone 2 Conservation Composite) successfully.
End Time: Wed Sep 24 17:34:10 2008 (Elapsed Time: 5.00 seconds)
Executing (Dissolve: Zone 2 Conservation Composite): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Composite_RAW
    G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone2_Conservation_Composite DISSOLVE # SINGLE_PART
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Start Time: Wed Sep 24 17:34:10 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Zone 2 Conservation Composite) successfully.
End Time: Wed Sep 24 17:34:37 2008 (Elapsed Time: 27.00 seconds)
Executing (Create Zone 2 Lowland Composite Feature Class (No Springs)): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput
        Zone2_Lowland_Composite_NoSprings POLYGON Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone2_Lowland_Composite_NoSprings
Start Time: Wed Sep 24 17:34:38 2008
Executed (Create Zone 2 Lowland Composite Feature Class (No Springs)) successfully.
End Time: Wed Sep 24 17:34:38 2008 (Elapsed Time: 0.00 seconds)
Executing (Append: All Zone 2 Lowland Buffers (No Springs)): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Z1_Lowland_Composite_NoStreamsSprings;
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Floodplain; G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Lowland_Streams
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone2_Lowland_Composite_NoSprings NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #;
        Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_50ft_Floodplain, BUFF_DIST, -1, -1,
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_100_125ft_Lowland_Streams, BUFF_DIST, -1, -1"
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone2_Lowland_Composite_NoSprings
Start Time: Wed Sep 24 17:34:39 2008
Executed (Append: All Zone 2 Lowland Buffers (No Springs)) successfully.
End Time: Wed Sep 24 17:34:46 2008 (Elapsed Time: 7.00 seconds)
Executing (Buffer: 25ft Z2 Lowland Composite (No Springs)): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Zone2_Lowland_Composite_NoSprings
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Z2_Lowland_Composite_NoSprings "25 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:34:47 2008
Buffering complex feature 65 ...
Buffering complex feature 3572 ...
Executed (Buffer: 25ft Z2 Lowland Composite (No Springs)) successfully.
End Time: Wed Sep 24 17:36:36 2008 (Elapsed Time: 1 minutes 49 seconds)
Executing (Buffer 500ft Lowland Springs (Z2)): Buffer G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Lowland_Springs
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_500ft_Lowland_Springs "500 Feet" FULL ROUND NONE #
Start Time: Wed Sep 24 17:36:36 2008
Executed (Buffer 500ft Lowland Springs (Z2)) successfully.
End Time: Wed Sep 24 17:36:38 2008 (Elapsed Time: 2.00 seconds)
Executing (Clip Buffer 500ft Lowland Springs w/ Spring Catchments (Z3)): Clip G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_500ft_Lowland_Springs
        USGS_24k_Spring_Catchments_L G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_500ft_Lowland_Springs #
Start Time: Wed Sep 24 17:36:38 2008
Reading Features...
Cracking Features...
Assembling Features...
Executed (Clip Buffer 500ft Lowland Springs w/ Spring Catchments (Z3)) successfully.
End Time: Wed Sep 24 17:36:42 2008 (Elapsed Time: 4.00 seconds)
Executing (Create Zone 3 Stewardship Lowland Feature Class): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput Zone3_Stewardship_Lowland_RAW POLYGON
        Lyr_USGS_24k_Sinkholes DISABLED DISABLED # # 0 0 0 G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland_RAW
Start Time: Wed Sep 24 17:36:42 2008
Executed (Create Zone 3 Stewardship Lowland Feature Class) successfully.
End Time: Wed Sep 24 17:36:44 2008 (Elapsed Time: 2.00 seconds)
Executing (Append: All Zone 3 Lowland Buffers): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Buffer_25ft_Z2_Lowland_Composite_NoSprings;
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_500ft_Lowland_Springs
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland_RAW NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #;
        Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\IntOutput\Clip_Buffer_500ft_Lowland_Springs, BUFF_DIST, -1, -1"
        G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland_RAW
Start Time: Wed Sep 24 17:36:44 2008
Executed (Append: All Zone 3 Lowland Buffers) successfully.
End Time: Wed Sep 24 17:36:59 2008 (Elapsed Time: 15.00 seconds)
Executing (Add Field: Zone 3 Lowland (DISSOLVE)): AddField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland_RAW DISSOLVE SHORT # # # # NULLABLE
        NON_REQUIRED # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland_RAW
Start Time: Wed Sep 24 17:36:59 2008
Adding DISSOLVE to G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland_RAW...
Executed (Add Field: Zone 3 Lowland (DISSOLVE)) successfully.
End Time: Wed Sep 24 17:36:59 2008 (Elapsed Time: 0.00 seconds)
Executing (Calculate Field: Zone 3 Lowland (DISSOLVE = 256)): CalculateField G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland_RAW DISSOLVE 256
        VB # G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland_RAW
Start Time: Wed Sep 24 17:36:59 2008
Executed (Calculate Field: Zone 3 Lowland (DISSOLVE = 256)) successfully.
End Time: Wed Sep 24 17:37:01 2008 (Elapsed Time: 2.00 seconds)
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Executing (Dissolve: Zone3_Stewardship_Lowland_RAW): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland_RAW
     G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland BUFF_DIST # SINGLE_PART
Start Time: Wed Sep 24 17:37:01 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Zone3_Stewardship_Lowland_RAW) successfully.
End Time: Wed Sep 24 17:40:18 2008 (Elapsed Time: 3 minutes 17 seconds)
Executing (Create Zone 3 Stewardship Composite Feature Class): CreateFeatureclass G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput Zone3_Stewardship_Composite_RAW
     POLYGON G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone1_EdgeProtect_Composite_RAW DISABLED DISABLED # # 0 0 0
     G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Composite_RAW
Start Time: Wed Sep 24 17:40:18 2008
Executed (Create Zone 3 Stewardship Composite Feature Class) successfully.
End Time: Wed Sep 24 17:40:19 2008 (Elapsed Time: 1.00 seconds)
Executing (Append: Zone 3 Stewardship Composite): Append G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland;
     G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland
     G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Composite_RAW NO_TEST "Shape_Length Shape_Length false true true 8 Double 0 0 , First, #;
     Shape_Area Shape_Area false true true 8 Double 0 0 , First, #; GFID GFID true true false 38 Text 0 0 , First, #; BUFF_DIST BUFF_DIST true true false 4 Float 0 0 , First, #,
     G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Upland, BUFF_DIST, -1, -1,
     G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Lowland, BUFF_DIST, -1, -1"
     G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Composite_RAW
Start Time: Wed Sep 24 17:40:19 2008
Executed (Append: Zone 3 Stewardship Composite) successfully.
End Time: Wed Sep 24 17:40:31 2008 (Elapsed Time: 12.00 seconds)
Executing (Dissolve: Zone 3 Stewardship Composite): Dissolve G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Composite_RAW
     G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb\FinalOutput\Zone3_Stewardship_Composite DISSOLVE # SINGLE_PART
Start Time: Wed Sep 24 17:40:31 2008
Sorting Attributes...
Dissolving...
Executed (Dissolve: Zone 3 Stewardship Composite) successfully.
End Time: Wed Sep 24 17:41:14 2008 (Elapsed Time: 43.00 seconds)
Executing (Compact Geodatabase; Z1, Z2, Z3 complete): Compact G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb G:\Andrew\Thesis\Thesis_Models\ThesisModel.gdb
Start Time: Wed Sep 24 17:41:14 2008
Executed (Compact Geodatabase; Z1, Z2, Z3 complete) successfully.
End Time: Wed Sep 24 17:42:05 2008 (Elapsed Time: 51.00 seconds)
Executed (HydroValueZones_1) successfully.
End Time: Wed Sep 24 17:42:06 2008 (Elapsed Time: 19 minutes 44 seconds)
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VITA

Andrew Lorenz Wunderlich was born in Knoxville, Tennessee. He was raised in Fountain City (North Knoxville) and attended Central High School, from which he graduated with honors in 1997. He was admitted to the University of Tennessee, Knoxville and following a short tenure in the Material Science Engineering department, switched his major to Geography in late 1999. After completing his undergraduate degree in May, 2002 he was accepted to the graduate program in Geography at UTK and began his studies in August of the same year. In Fall 2003, he was awarded an internship with the National Geographic Society, Maps division in Washington D.C., which turned into a full-time contracted position in 2004. Upon expiration of the contract, Andrew returned to Knoxville in the summer of 2004 and began working in the Green Vision Studio of the College of Architecture and Design at UTK on the Beaver Creek Watershed Green Infrastructure Plan. In late 2005, National Geographic once again called upon Andrew's services, and by January, 2006 he was back in Washington D.C. working as a GIS analyst and cartographer. By April of 2007, the pressure to complete his graduate studies brought Andrew back to Knoxville, where he now resides.

Andrew is currently a full-time GIS research analyst and cartographer in the University of Tennessee Geology Department's Tectonics and Structural Geology Research Group and Science Alliance Center of Excellence under the direction of Dr. Robert D. Hatcher, Jr.