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GIS for the Bartlett Hills Association: Increasing Knowledge to Enhance Land Management Practices

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A Major Individual Project submitted in partial satisfaction of the requirements for the degree of Master of Science in Geographic Information Systems

by

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Abstract

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The natural world has many unique areas and when there is no management conducted on these areas, they become lost to time. The 800-acre property owned by the Bartlett Hills Association (BHA) in western Iowa is no different. The loess hills are deposits from glaciers 12,000 to 30,000 years ago, and over the last several decades there has been no management of these unique hills on the property. The BHA has established management objectives that will bring its forest back to a sustainable forest and its members want to use GIS to enhance their knowledge. There are currently trails inside the property, but they are at risk for soil erosion and maintenance is difficult to conduct. By creating a model within Model Builder in ArcGIS Desktop 10.2, suitable areas for new trail construction can be located. In addition, several maps and a 3D terrain model were produced to represent different characteristics of the property and provide new knowledge of the property. With the use of spatial analysis and cartographic skills, the BHA can learn more about its unique property and manage the property for future generations.

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List of Acronyms and Definitions

BHA	Bartlett Hills Association
DEM	Digital Elevation Model
GIS	Geographic information systems
GPS	Global Positioning System
IDNR	Iowa Department of Natural Resources
NRCS	Natural Resources Conservation Service
SQL	Structured Query Language
SSURGO	Soil Survey Geographic Database
TCI	Topographic Convergence Index
USFS	United States Forest Service

Chapter 1 – Introduction

Environmental issues have soared to the attention of people around the world in the last few decades. Due to the complexity of the issues, geographic information systems (GIS) have been one of the most commonly used methods in solving or at least better understanding the issues. The Bartlett Hills Association (BHA), a non-profit organization, wants to implement GIS to better understand the environmental issues that exist on the property. Since the purchase of the 800-acre property in 1975, the property has undergone little to no land management actions to maintain the health of the forests and prairies. By using GIS, the BHA acquired a better understanding of the environmental issues that exist on the property, and with the assistance of the Iowa Department of Natural Resources (IDNR), new land management techniques will improve the sustainability of the property.

The following sections describe the project in more detail, starting with section 1.1, which describes the client, the Bartlett Hills Association (BHA). Section 1.2 states the problem and Section 1.3 discusses using Esri's ArcMap as the proposed. Section 1.3 goes into further detail with Section 1.3.1 which describes the project's goals and objectives, Section 1.3.2 discusses the project scope, and Section 1.3.3 describes the methods the project team used to accomplish solving the project's problem. Section 1.4 discusses the audience and Section 1.5 provides an overview of the remainder of the report.

1.1 Client

The Bartlett Hills Association (BHA) is a nonprofit organization composed of 28 members. The 800-acre property they own is located in the loess hills of western Iowa. Mr. Bill Beeler, a member of the BHA, was the contact for the project. Due to the poor land management since the property purchase in 1975, the ecosystems have become unsustainable and invasive plant species have overtaken the native species. The BHA property is involved in a Woodland Stewardship Plan through the Iowa Department of Natural Resources (IDNR) and the plan will establish techniques to transform the property from an unsustainable ecosystem to a sustainable state. Some of these techniques would include eradicating invasive species, timber management, and minimizing soil erosion. The BHA presented this project because they wanted to use a GIS to learn more about their property in order to make informed decisions on which techniques to use in the Woodland Stewardship Plan. Figure 1-1 shows the BHA property located in the western portion of Iowa and Figure 1-2 shows the boundary of the BHA property.

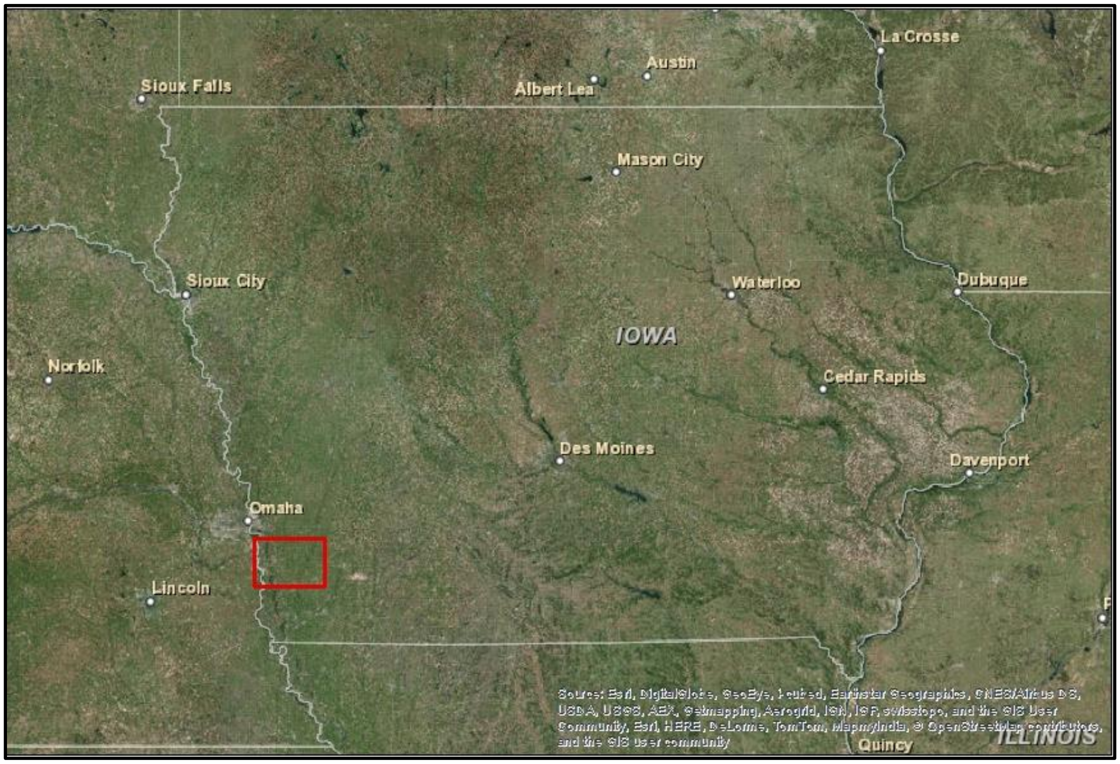

Figure 1-1: BHA property located inside the red box in Iowa.

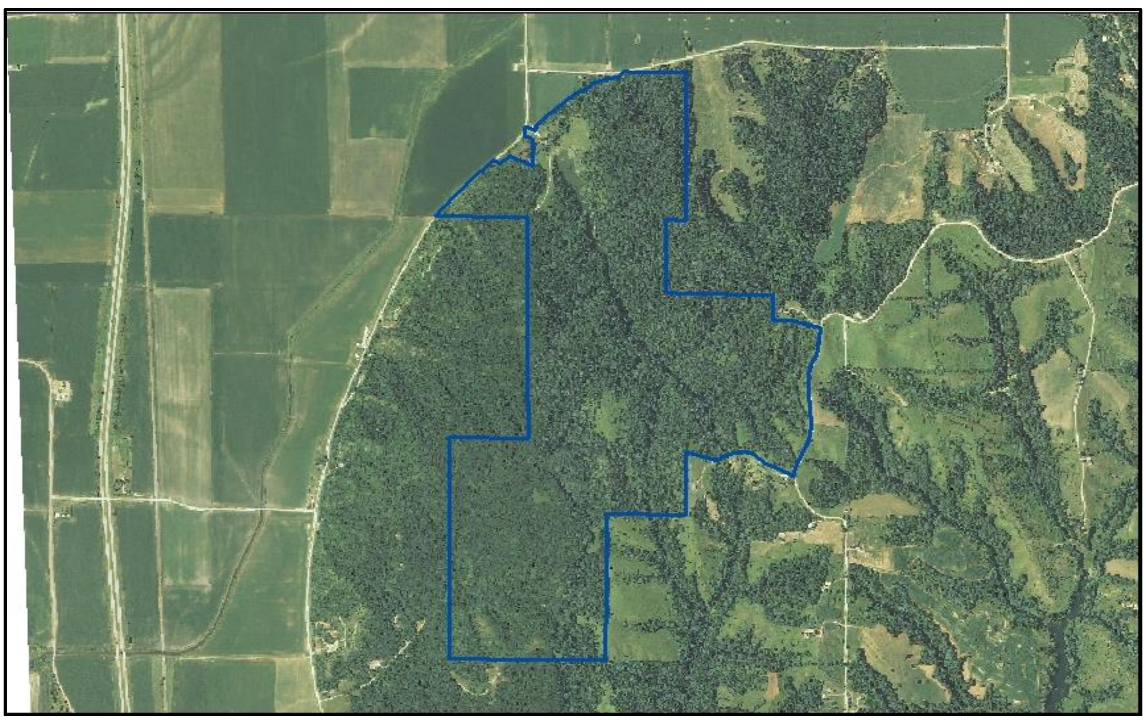

Figure 1-2: BHA property inside the blue polygon.

1.2 Problem Statement

The problem addressed in this project is that the BHA did not have enough information about the property to make informed land management decisions. The BHA did not possess maps of the property, sustainable recreational trails, or information about what types of forests exist on the property.

1.3 Goals and Objectives

The overall goal of this project was to use GIS to increase knowledge of the BHA property to assist in bringing the property back to a sustainable state. To accomplish the overall goal, this project had three objectives. The first objective was to produce nine printed maps of the BHA property. This objective was the client's primary goal and once this objective was completed, the client considered this project a success. The second objective was to create a 3D terrain model of the BHA property. The last objective was to create a suitability model with ModelBuilder using Esri's ArcMap 10.2 to determine areas that are suitable and non-suitable for sustainable trails. Another model identified possible trail locations. All of these objectives provided the information needed to the BHA and IDNR to make informed land management decisions.

1.4 Scope

The scope of this project consisted of presenting four deliverables by December 10, 2014. There were three phases to the project; design, develop, and deploy the deliverables. The project team completed each deliverable individually in order of importance expressed by the client.

1.5 Methods

In order to complete this project, the project team gathered GIS data from credible sources since the BHA did not possess any data. The IDNR provided the data used in this project and the IDNR contact, Lindsey Barney, was readily available for questions and providing resources for learning more about the BHA property. The software used in this project was Esri's ArcMap 10.2 to produce the printed maps, create the 3D file for the 3D terrain model, create the models identifying suitable areas for sustainable trails and possible trail routes. Esri's software was chosen because the project team was already familiar with the software and no extra time would be needed in the project schedule to learn a new GIS software.

To create the printed maps for the BHA cabin, the project team decided to highlight the changes that occurred in the property between 1975 and 2013. In addition to the two maps created highlighting the change over time, one map showed the boundary of the property, another showed the areas of interests of the property, and another map showed the different trails on the property: past trails, current trails, and future trails. The dimensions of the maps were determined by the project team and were verified by the client before printing. ArcScene produced the 3D file format.

When creating the model using ModelBuilder in ArcMap 10.2, the development of the criteria needed to identify areas that are suitable and non-suitable for sustainable trails came from researching several different sources, which are discussed in Chapter 2. The criteria for the model that best represented the BHA property was based on a U.S. Forest Service recommendation. After completing the model, the project team conducted fieldwork at the BHA property, along with two members of the BHA and Lindsey Barney, to assist in determining how accurate the model was at identifying areas correctly.

1.6 Audiences

The audiences for this project are the BHA members, the IDNR, and the parks and recreation industry. The BHA and IDNR needed the information produced from this project to make well-informed decisions on future land management of the property. In addition, professionals in the parks and recreation industry can use this project to learn how to locate areas for sustainable trail construction.

1.7 Overview of the Rest of this Report

Chapter 2 includes the literature review in which there is a discussion of parameters and techniques used to determine area suitability in different projects. Chapter 3 explains the systems analysis and design by looking at the project requirements provided by the BHA. Further detail of the problem statement, the requirements analysis, the system design, and the project plan are also included in Chapter 3. Diagrams and a discussion of the conceptual and logical data models are in Chapter 4. Also in Chapter 4, there are explanations of the data sources, data collection methods, and the data scrubbing. Chapter 5 discusses the steps taken to solve the BHA's problem of needing more information about the property to make informed land management decisions. Chapter 6 provides the results and analysis of the project, including the maps and analyses. Chapter 7 concludes the report with the project conclusions and suggestions for future work.

Chapter 2 – Background and Literature Review

A common application of a geographic information system (GIS) is to operationalize various spatial analysis methods. Some GIS spatial analysis methods are: assess groundwater potential, plan travel routes on trail networks, design monitor programs for landscape management, and identify areas suitable for a specific criterion. When considering which model to locate areas suitable for trail construction on the Bartlett Hills Association (BHA) property, the project team conducted a literature review of techniques that have been used in similar applications of land management. Additionally, the U.S. Forest Service Trail Management Handbook (2008) and journal articles provided guidelines on criteria used to build sustainable trails.

Section 2.1 discusses the different techniques used in past projects. This section includes previous studies that used different spatial analysis techniques to enhance the land management practices in a study area. This research provided insight into which techniques work better in certain applications. Determining the correct or best-represented technique for this project is important to achieve the most accurate model. To create a successful model the project team researched criteria that were best for developing sustainable trails. This research included guidelines for trail construction from the U.S. Forest Service (2008), as well as journal articles. The discussion of these research findings are discussed in Section 2.2.

2.1 Spatial Analysis Methods for Land Management

Spatial analysis techniques used for solving spatial problems are unique in the sense that no problem is the same, but more than one project can use the same technique if the applications are similar. The following paragraphs highlight the different techniques used in past projects to solve similar spatial problems.

One study by Urban (2000) looked into designing a monitoring program and impact assessment for landscape management by using model analysis. Focusing on the southern Sierra Nevada of California, a model was developed to assess the sensitivities of an area due to the change in temperature or precipitation and the uncertainties stemming from the simulation model. Urban used a gap analysis model, FACET, consisting of five submodels that can be turned on and off at the user's discretion. These submodels consisted of "canopy leaf area, the soil water balance, littler decomposition and nutrient (nitrogen) cycling, tree demographics and species-compositional dynamics, and the fire regime" (pg. 1821). These environmental factors interact with each other and determine the sensitivity of an area. The model produced three maps showing the sensitivity to changes in temperature and precipitation, as well as the uncertainty of the topographic convergence. Topographic convergence was indicated by the topographic convergence index (TCI) showing how wet or dry an area is. A high TCI indicates more wetness and a low TCI indicates more dryness. An indication of more wetness suggests that there is a small slope grade and there is greater water flow to this area. Figure 2-1 illustrates the false-color composite image created to locate areas of high sensitivity to change in temperature, sensitivity to change in precipitation, sensitivity to change in both temperature and precipitation, and the uncertainties to topographic convergence. Urban created another map that located cells that were maximally sensitive to change in temperature and precipitation, and maximum variety of topographic convergence indices as well as being between 100 and 500 meters from a road or major trail. Those areas meeting those previous criteria are the best choices for field monitoring.

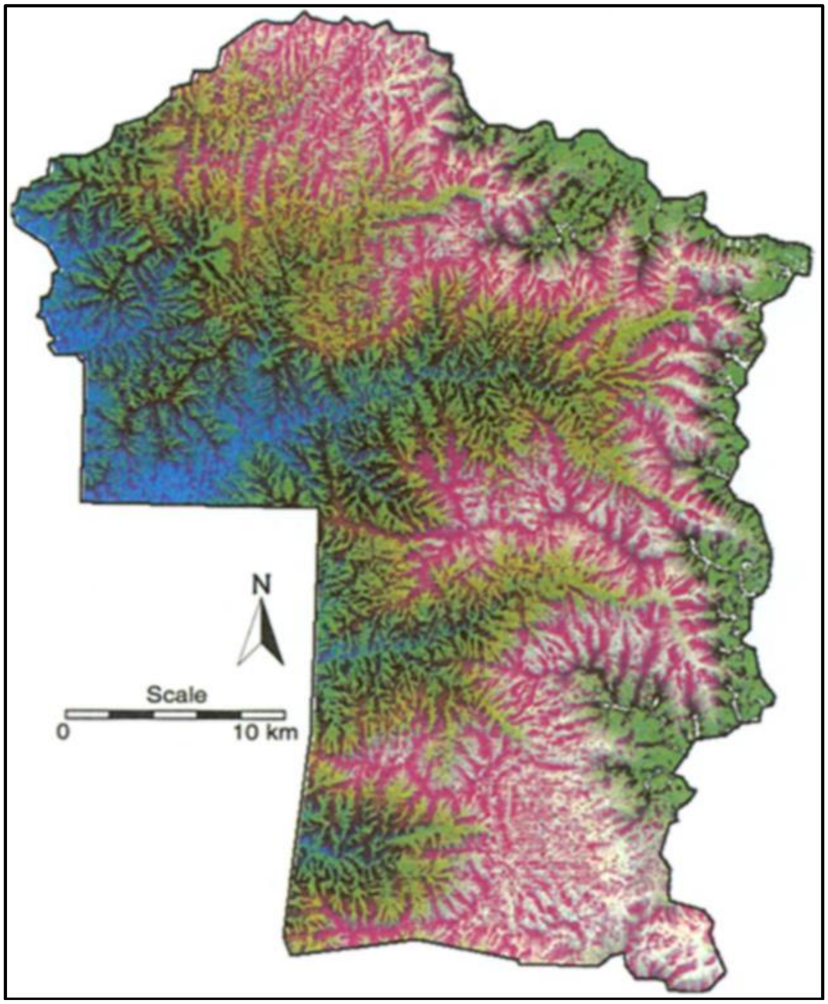

Figure 2-1: False-color composite image. (Image from Urban, 2000).

In Figure 2-1, the magenta areas represent high climate-sensitive zones, white areas represent high convergence, yellow represents areas of moderately high temperature and precipitation sensitivity and high TCI, the green areas represent cool and wet areas, and the blue represents areas sensitive to precipitation but not temperature. The study conducted by Urban showed how a model could be created for a specific local problem, but there was no information provided for others to duplicate the model. The model created for this project incorporated Urban's idea of creating a specific model to solve a local problem, but the model provides information for others to duplicate and manipulate the model for other areas.

Nagarajan and Singh (2009) used a different technique to identify groundwater potential zones in Kattakulathur block, Tamil Nadu, India. They used a weighted overlay analysis between several thematic maps to locate groundwater potential zones. Following the analysis, a field survey selecting wells in different villages within the block validated the output from their analysis. Table 2-1 shows the rank and weights assigned to the different parameters used in this study. The output of the weighted overlay categorized zones into good, moderate, or poor groundwater potential zones. The field study validating the output of the weighted overlay used hand-held GPS instruments and a village was randomly selected to test wells in all three zones. Data collected in the field included the coordinates of the well and the groundwater level depths. The groundwater depths ranging from 10-20 feet were normally found to be in good groundwater potential zones, 20-40 feet in moderate zones, and levels over 50 feet in poor zones. The Nagarajan and Singh study was similar to the Urban (2000) study in that his technique applied to a local problem, but it differed from the Urban model because this technique can be applied to other geographic areas.

Table 2-1: Parameters used by Nagarajan and Singh (2009) for identifying groundwater potential zones. (Table from Nagarajan and Singh, 2009).

Sl. no.	Criteria	Classes	Rank	Weights (%)
1	Geomorphology	flood plain, sedimentary plain	1	25
		buried pediments (shallow, deep)	2	
		Isenberg, pediment complex	3	
2	Land use	agricultural plantation, cropland	1	25
		degraded forest, fallow harvested land, upland with or without scrub	2	
		built up land, hill/barren rock/stone waste/sheet rock, mining/industrial waste/effluents, salt pan, salt affected land	3	
3	Hydrological soil group	A	1	25
		B	2	
		C, D	3	
4	Slope	0-20	1	15
		20-50	2	
		>50	3	
5	Lineament	present	1	5
		not present	3	
6	Drainage	First order	1	5
		Second order	2	
		Third order	3	

Chyi-Rong, Wei-Lun, and Yu-Fai (2010) used dynamic segmentation and network analysis to calculate energy consumption and travel time on routes to identify optimal routes in forests in central Taiwan. This study allowed visitors to the forest to make informed decisions to enhance their recreational experience. Both dynamic segmentation, which gathers data along linear corridors, and network analysis, which locates the shortest path between features or areas of interest, determined optimal routes in the forest. Chyi-Rong, Wei-Lun, and Yu-Fai state that the transportation industry utilizes dynamic segmentation, but the recreation and park discipline under-utilizes this technique. By using dynamic segmentation with the network analysis, the authors identified the least time and highest energy cost of a hiker for a trail. Chyi-Rong, Wei-

Lun, and Yu-Fai discuss how dynamic segmentation can be applied in future studies by expanding the applications for the recreation and park field by linking more attributes to the trail data, “such as landform type, facilities, scenic spots, safety hazards, and resource condition” (pg. 225).

Weighted overlay analysis, a FACET gap model, and dynamic segmentation with network analysis are only three of many techniques used to solve such spatial problems. Examining past studies that have similar spatial problems provided insight into which techniques work well in certain applications. For example, the dynamic segmentation worked well for identifying optimal routes in a forest because dynamic segmentation uses information gathered along linear corridors. That same workflow would not work well for identifying groundwater potential zones because the features are points and areas, not linear features. When considering spatial analysis techniques, one needs to look at the strengths and weaknesses each technique has for that specific study. From there, the most well suited technique can be identified.

2.2 Trail Parameters

An important part of this literature review was identifying parameters for trail construction used in past studies. The most useful information came from the U.S. Forest Service Trails Management Handbook (2008). In Section 23 of the handbook, the U.S. Forest Service discusses the parameters needed for the different types of trails. Since the Bartlett Hills Association (BHA) wanted to build sustainable trails for hiking, horseback riding, and an all-terrain vehicle to conduct trail maintenance, subsections 23.11 (Hiker/Pedestrian Design Parameters) and 23.12 (Pack and Saddle Design Parameters) were used. Table 2-2 contains the guidelines for hiker/pedestrian trail design from Section 23.11. Section 23.12 contained Tables 2-3 and 2-4 for pack and saddle trail design. When determining the parameters for locating suitable areas for trail construction in this project, these three tables were referenced.

Table 2-2: Hiker/pedestrian design (USFS, 2008).

Designed Use HIKER/PEDESTRIAN		Trail Class 1	Trail Class 2	Trail Class 3 [2]	Trail Class 4 [2]	Trail Class 5 [2]
Design Grade [3]	Target Grade	5% – 25%	5% – 18%	3% – 12%	2% – 10%	2% – 5%
	Short Pitch Maximum	40%	35%	25%	15%	5% FSTAG: 5% – 12% [2]
	Maximum Pitch Density	20% – 40% of trail	20% – 30% of trail	10% – 20% of trail	5% – 20% of trail	0% – 5% of trail
Design Cross Slope	Target Cross Slope	Natural side slope	5% – 20%	5% – 10%	3% – 7%	2% – 3% (or crowned)
	Maximum Cross Slope	Natural side slope	25%	15%	10%	3%
Design Clearing	Height	6'	6' – 7'	7' – 8'	8' – 10'	8' – 10'
	Width	≥ 24" Some vegetation may encroach into clearing area	24" – 48" Some light vegetation may encroach into clearing area	36" – 60"	48" – 72"	60" – 72"
	Shoulder Clearance	3" – 6"	6" – 12"	12" – 18"	12" – 18"	12" – 24"
Design Turn	Radius	No minimum	2' – 3'	3' – 6'	4' – 8'	6' – 8'

Table 2-3: Pack and saddle design (USFS, 2008).

Designed Use PACK AND SADDLE		Trail Class 1	Trail Class 2	Trail Class 3	Trail Class 4	Trail Class 5
Design Tread Width	Wilderness (Single Lane)	Typically not designed or actively managed for equestrians, although use may be allowed	12" – 18" May be up to 48" along steep side slopes 48" – 60" or greater along precipices	18" – 24" May be up to 48" along steep side slopes 48" – 60" or greater along precipices	24" May be up to 48" along steep side slopes 48" – 60" or greater along precipices	Typically not designed or actively managed for equestrians, although use may be allowed
	Non-Wilderness (Single Lane)		12" – 24" May be up to 48" along steep side slopes 48" – 60" or greater along precipices	18" – 48" 48" – 60" or greater along precipices	24" – 96" 48" – 60" or greater along precipices	
	Non-Wilderness (Double Lane)		60"	60" – 84"	84" – 120"	
	Structures (Minimum Width)		Other than bridges: 36" Bridges without handrails: 60" Bridges with handrails: 84" clear width	Other than bridges: 36" Bridges without handrails: 60" Bridges with handrails: 84" clear width	Other than bridges: 36" Bridges without handrails: 60" Bridges with handrails: 84" clear width	
Design Surface[2]	Type		Native, with limited grading May be frequently rough	Native, with some on-site borrow or imported material where needed for stabilization and occasional grading Intermittently rough	Native, with improved sections of borrow or imported material and routine grading Minor roughness	

Table 2-4: Pack and saddle design, continued (USFS, 2008).

Designed Use PACK AND SADDLE		Trail Class 1	Trail Class 2	Trail Class 3	Trail Class 4	Trail Class 5
Design Surface (continued)	Protrusions		≤ 6" May be common and continuous	≤ 3" May be common, not continuous	≤ 3" Uncommon, not continuous	
	Obstacles (Maximum Height)		12"	6"	3"	
Design Grade[2]	Target Grade		5% – 20%	3% – 12%	2% – 10%	
	Short Pitch Maximum		30%	20%	15%	
	Maximum Pitch Density		15% – 20% of trail	5% – 15% of trail	5% – 10% of trail	
Design Cross Slope	Target Cross Slope		5% – 10%	3% – 5%	0% – 5%	
	Maximum Cross Slope		10%	8%	5%	
Design Clearing	Height		8' – 10'	10'	10' – 12'	
	Width		72" Some light vegetation may encroach into clearing area	72" – 96"	96"	
	Shoulder Clearance		6" – 12" Pack clearance: 36" x 36"	12" – 18" Pack clearance: 36" x 36"	12" – 18" Pack clearance: 36" x 36"	
Design Turn	Radius		4' – 5'	5' – 8'	6' – 10'	

Creating effective land management techniques is only part of the solution to bringing ecosystems back to a sustainable state. Umphress (2011) wrote an article for the American Trails magazine in which she discussed what makes a trail sustainable. Umphress defined a trail as sustainable when four factors of sustainability – resource, economic, political and experience – are met. For a trail to be sustainable, the trail cannot harm the environment, and it must protect natural resources. For a trail to remain effective and sustainable in providing a recreational opportunity, a trail is economically sustainable when there is low maintenance cost, and it provides a return on the investment in construction and maintenance over time. The political aspect considers the attitude the community has toward the trail. A trail is sustainable in the last aspect – experience – when it has different difficulties and specific purposes to satisfy all users. Understanding what makes a trail sustainable is important to the design process because if the parameters cannot meet the trail sustainability, then the new trail system will degrade the ecosystem and delay or prevent it from becoming sustainable.

2.3 Summary

There are many techniques to consider when solving a spatial problem. The Chyi-Rong, Wei-Lun, and Yu-Fai study (2010) used dynamic segmentation and spatial analysis to determine the highest energy cost and least time for a hiker on a trail, which is an effective method to use when doing an analysis on linear features. The Nagarajan and Singh study (2009) could not use dynamic segmentation, because their analysis involved polygon and point features instead of linear features. The U.S. Forest Service Trail Management Handbook (2008) provided valuable guidelines on which parameters to use for constructing sustainable trails. A sustainable trail, as explained by Umphress (2011), is a combination of resource, economic, political, and experience sustainability.

Understanding the spatial problem is crucial for choosing the correct analysis method to complete the project. For this project, the project team decided to create a model using weighted overlay analysis to locate areas suitable for trail construction and then apply the least cost path method to provide possible trail locations. The project team felt that this project problem had a similar application to the Nagarajan and Singh (2009) study, and that the weighted overlay analysis would provide the best results. The parameters from the U.S. Forest Service Trail Management Handbook were the guidelines used in the weighted overlay analysis. The U.S. Forest Service Trail Management Handbook was the only document found by the project team that well represented the criteria necessary to determine the model parameters to be used in the analysis.

Chapter 3 – Systems Analysis and Design

Before the project can begin the analysis, the project team needs to understand the system requirements and design. Afterwards, a project plan can be developed. This chapter discusses the system requirements in Section 3.2 and the system design in Section 3.3. Section 3.4 describes the project plan and the schedule followed by a summary in Section 3.5.

3.1 Problem Statement

The problem addressed by this project is that the Bartlett Hills Association (BHA) did not have adequate information about its property to make well informed land management decisions. Since there were no maps of the property and the current trails were unsustainable, this project used GIS to gather information to create property maps and propose locations for sustainable trail construction.

3.2 Requirements Analysis

In order for the project to be successful, the BHA needed to be clear on their requirements. There were two kinds of requirements considered: functional and nonfunctional. A functional requirement states what the system should do while a nonfunctional requirement states how the system should perform. In this project, there were a total of three requirements. Most of the requirements for this project came directly from the client, but the project team added additional requirements to satisfy the client's expectations for the final products.

All requirements for the project were functional (Table 3-1). One of the functional requirements related to the suitability model for identifying areas for trail construction. The other two functional requirements were related to the printed maps. One map needed to show the change over time between 1930 and 2013 while another map needed to show the topography of the property.

Table 3-1: Functional Requirements.

ID	Description
01	The model shall locate all the areas within the property that are suitable for trail construction
02	One map shall show the topography of the property
03	One map shall show the change over time between 1930 and 2013

3.3 System Design

The system design for this project consisted of three components. These components – a geodatabase, a suitability model, and derived outputs – were integrated for a successful project. Section 3.3.1 discusses the design of the geodatabase and Section 3.3.2 provides the structure of the suitability model. The structure presented in Section 3.3.3 is for the printed maps.

3.3.1 Geodatabase Design

This project needed a clear, logical, and understandable structure to hold all of the necessary data. Before the project team could begin implementing the solution to the project, two geodatabases needed to be created: the Source Geodatabase and the Model Output Geodatabase. Creating two geodatabases provided a logical way to separate the original sources from the model outputs and the project team wanted to ensure that the original files were not changed during the model operation. The Source Geodatabase included the original feature classes and the digital elevation model (DEM) provided by the Iowa Department of Natural Resources. The Model Output Geodatabase contained all of the derived rasters from the suitability model. It was important that the project team have all derived outputs in one organized location.

3.3.2 Suitability Model Design

Once the geodatabases were created, the project team began to develop the suitability model. After determining the spatial analysis method to implement, the project team began construction of the model in ArcGIS ModelBuilder. The suitability model included the necessary geoprocessing tools, and the project team configured the model dialog box to facilitate users of various levels of GIS knowledge. In the model properties, the project team stored relative path names which allows users to move the model to different directories. Storing relative path names allows a person to input any feature class into the model parameters to satisfy their application need. In addition, the project team stored the derived products from the completed suitability model to the Model Output Geodatabase.

3.3.3 Printed Maps Design

The printed maps were the most important deliverable to the client, so the project team needed to prioritize map completion, and have a uniform map layout. Since the BHA property is oriented north-south, the uniform map layout had a portrait orientation. One exception to this layout was made at the request of the client.

3.4 Project Plan

Creating and following a project plan provides an organized approach in completing the project successfully. This plan included three phases; planning, initiation, and completion. The first phase consisted of researching the problem statement, understanding the system requirements, identifying possible solutions to the problem, and developing good communication with the client. After completion of the first phase, implementation of the project started. This phase included creating the four deliverables and conducting field work to evaluate the accuracy of the suitability model. The last phase consisted of writing the final report and presenting the deliverables to the client. The schedule for the project plan is shown in Figure 3-1.

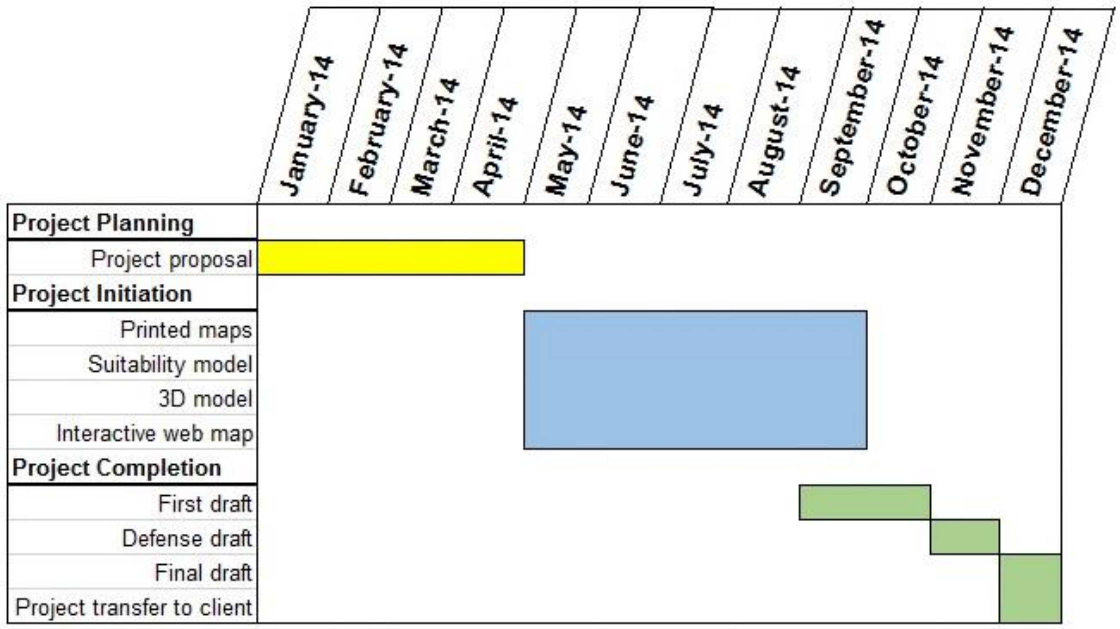

Figure 3-1: Project plan schedule.

3.5 Summary

In order to resolve the BHA's problem, it was necessary for the project team to understand the eight functional and three nonfunctional requirements before beginning project implementation. After understanding the requirements, designs were developed for the geodatabases, the suitability model, and the printed maps. Completion of the system design led to the development of the project plan and schedule. Chapter 4 discusses the geodatabase designs in more depth.

Chapter 4 – Database Design

The previous chapter described the system design and analysis while this chapter describes the database design. Every GIS needs a logical database to ensure the ease and organization of a project. This chapter discusses the database designs and data used for this project. Section 4.1 describes the conceptual model showing the relationships between the entities of the project. The logical model explanation is illustrated in Section 4.2 and Section 4.3 discusses the data sources. Section 4.4 splits into Sections 4.4.1 and 4.4.2, which describe the field survey methods and survey results, respectively. Chapter 4 concludes with a summary of the database design.

4.1 Conceptual Data Model

In order to solve the project problem, the project team needed a thorough understanding of the relationships that exist between the entities in this project. To accomplish this, the project team created a conceptual data model. This data model describes the existing relationships between entities in the project. For this project, it was crucial to understand the environmental factors that make a trail sustainable and the thresholds that make a trail unsustainable. It was also important to understand how the environmental factors interact and influence each other.

For an activity to be environmentally sustainable, its impacts on the natural environment need to be minimized. When planning trail construction and use, the main environmental concern is soil erosion. By understanding how environmental factors interact and how that interaction contributes to soil erosion, the project team defined the conditions an area would need to satisfy to be considered suitable for trail construction. While natural processes such as wind and water cause soil erosion, humans can dramatically accelerate the erosion process.

Figure 4-1 illustrates the conceptual model, showing the relationships between the environmental factors and the points of interest on the property. The primary factors that determine soil erodibility are soil type, vegetation cover, and slope. In general, silt soils are more susceptible to erosion, while clay soils are less susceptible. Since silt soils tend to have low water-holding capacity and compactability, they can be transported more easily than clay soils that have a high water-holding capacity and compactability. Another environmental factor considered was the vegetation cover of an area. In general, soils that have vegetation cover tend to be less susceptible to erosion from water or wind because the roots from the vegetation hold the soil particles together. The last environmental factor considered in this project was the slope of the terrain. The steeper the slope, the more susceptible an area is to soil erosion. In addition, the greater the slope, the harder it is for certain vegetation to establish a root system and hold soil particles together, making it more susceptible to erosion. The points of interest are included to determine which paths would impose the least environmental impact

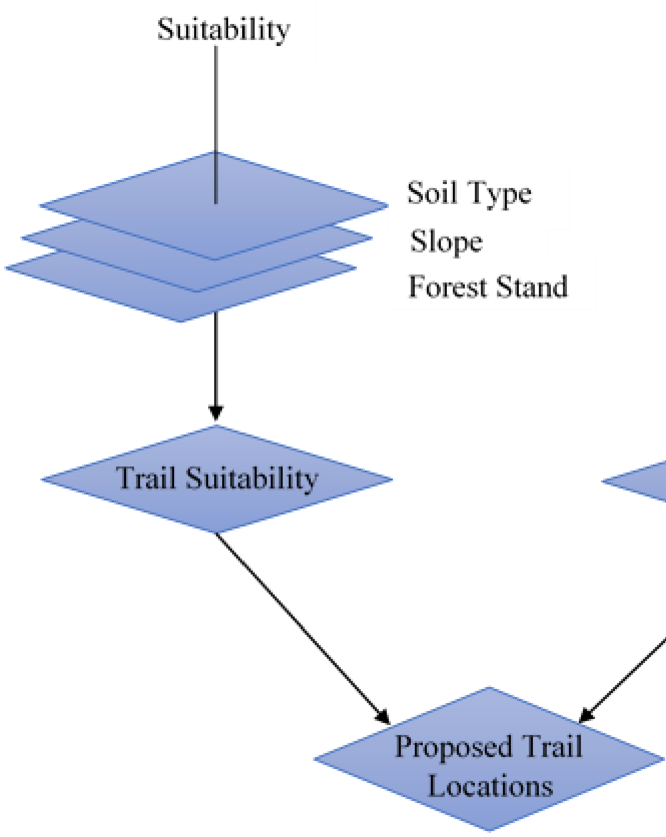

Figure 4-1: Conceptual data model.

When conducting the analysis, the different environmental factors used as the parameters in the suitability model were assigned weights. The weight values represented the influence that specific factors had on trail suitability.

4.2 Logical Data Model

Once an overview of the relationships was recognized in the conceptual data model, the project team determined the logical data model. The logical data model included the datasets needed to implement the solution to the problem. As briefly described in Chapter 3, this project required two geodatabases to logically organize the data: a Model Geodatabase and a Source Geodatabase. Having two databases allowed for the processed data files to be managed in one location – Model Geodatabase – while the Source Geodatabase was used to store the unchanged original data files.

The project team copied the original feature classes from the Source Geodatabase into the Model Geodatabase. Unlike the Source Geodatabase, the data files located there were manipulated during the analysis process (Table 4-3).

Table 4-1: Logical data model of the Model Geodatabase.

Geodatabase	Name	Description	Data Type
Model	BHA_Soil	Shapefile of the soils	Feature Class
	Soil_Raster	Converted soil used in the analysis	Raster Image
	IDNR_ForestStand	Shapefile of the forest stands	Feature Class
	forest_raster	Converted IDNR forest stand used in the analysis	Raster Image
	Slope	Reclassified slope used in the analysis	Raster Image
	Points_of_Interest	Shapefile containing points of interest used in analysis	Feature Class
	Overlay	Weighted overlay output locating area suitable for sustainable trail construction	Raster Image
	absOverlay	Absolute value of the Overlay raster image	Raster Image
	CostDistance	Cost distance output used in the cost path analysis	Raster Image
	costDistBacklink	Cost distance backlink output used in the cost path analysis	Raster Image
	susTrails	Least cost path output proposing suitable trail locations	Raster Image
	SustainableLocations	Feature class converted from the susTrails raster image	Feature Class

The project team added an attribute which contained the weight values for the weighted overlay analysis. The weight attribute was added to the BHA_Soil and IDNR_ForestStand feature classes. Once the feature classes contained the weight value attribute, they were converted to raster images for the weighted overlay analysis. The names of the raster images created from the conversion were forest_raster and Soil_Raster. Since the weighted overlay analysis considered forest stands, soils, and slope, the last required raster image was the slope, which was named Slope. Overlay was the raster image produced from the weighted overlay analysis and absOverlay is the absolute raster of the Overlay image.

In addition to the weighted overlay analysis inputs previously mentioned, the Model Geodatabase also contained the feature classes and raster images needed as inputs to calculate the cost distance, cost distance backlink, and the cost path to identify potential trail locations. The Points_of_Interest feature class contained the locations where the BHA members wanted to hike to and from the cabin. CostDistance and costDistBacklink were the outputs of the cost distance tool and used as the inputs for the least cost path tool to determine sustainable trail locations. The susTrails raster was the output produced from the cost path tool, which proposed the least cost path from the cabin to various points of interest, and the SustainableLocations was the feature class converted from the susTrails image.

The creation of the Source Geodatabase ensured that the original datasets provided by the IDNR would not be altered during the model analysis process. It was important to the project team to have one location for the original datasets because the database provided by the organization needed an easy workflow during project implementation. The Source Geodatabase contained five feature classes and one raster image. All of the features used for the final six printed maps came from the Source Geodatabase (Table 4-2).

Table 4-2: Logical data model of the Source Geodatabase.

Geodatabase	Name	Description	Data Type
Source	BHA_Property	Original shapefile of the BHA property boundary	Feature Class
	BHA_Soil	Original clipped shapefile in the BHA property	Feature Class
	cleared_area	Feature class containing areas that were cleared in 1930	Feature Class
	contour_20extended	Feature class of 20 foot contour intervals	Feature Class
	Contour_index	Feature class of the indexes at 20 foot intervals	Feature Class
	IDNR_ForestStand	Original shapefile of the BHA forest stands	Feature Class
	Lake	Shapefile boundary of the lake	Feature Class
	PinePlantation	Shapefile boundary of the pine plantation	Feature Class
	Points_of_Interest	Shapefile containing points of interest used in analysis	Feature Class
	SurveyPath	Approximate paths of the route taken during the field survey	Feature Class
	Trail	Original shapefile of the BHA trail system	Feature Class
	DEM_3m_expandedProperty	Clipped 3 meter DEM extended outside of the BHA property from the original 3 meter DEM	Raster Image
	dem_extract	3 meter DEM masked to the BHA property boundary	Raster Image
	DEM_ft	Converted the 3 meter to a foot DEM	Raster Image
	forested_80	Reclassified 2013 aerial image	Raster Image
	Hillshade_1m	Hillshade at 1 meter created from the DEM	Raster Image
	slope	Reclassified into the five classes for the analysis	Raster Image
	slope_m	Created from dem_extract raster	Raster Image

4.3 Data Sources

The Iowa Department of Natural Resources (IDNR) provided all of the data used for this project. The project team was in contact with Lindsey Barney, the District Forester for Mills County, throughout the project. Ms. Barney has been working with Mr. Bill Beeler and the BHA on producing the Woodland Stewardship Plan for the property. As part of the Woodland Stewardship Plan, Ms. Barney conducted a field survey to locate and identify forest stands, invasive species, and merchantable timber. This plan describes the current ecosystem condition on the property and recommends forest management prescriptions. The data collected from Ms. Barney's survey, stored in the IDNR_ForestStand feature class, were provided to the project team, along with the DEM, contour line feature class, aerial images, BHA property boundary feature class, Lidar data, and road feature class. The soil data provided by the IDNR came from the Natural Resources Conservation Service (NRCS) that produces and distributes the Soil Survey Geographic Database (SSURGO) soil data. Both the IDNR and the NRCS are authoritative and credible sources for data which are supported by the quality of the metadata they provide, as well as the reputations of the organizations.

All of the data except for two datasets – the BHA_Property feature class and the 2009_CIR_sirphotos_65.sid – were received in the same projection coordinate system: NAD 1983 UTM Zone 15N. The project team re-projected the BHA property feature class from the coordinate system in which it was provided – NAD_1983_StatePlane_Iowa_South_FIPS_1402_Feet – to the same coordinate system as the other data. The aerial photograph taken in 2009 did not have a coordinate system identified, the project team defined the projection to match the other data by projecting it to match the other datasets; when defined as UTM Zone 15N it registered with the other imagery and was assumed to be in this coordinate system. To increase the accuracy of the model, the raster datasets used needed to be high resolution. The IDNR provided aerial photographs that were all at a one meter resolution, except for the 2009 aerial photograph which was at a two foot resolution (Figure 4-2). The time of data acquisition of all datasets was relevant for this project. The oldest dataset used was the soil feature class produced by the NRCS and published in October of 2004. The 2004 publication is the most recent publication for Mills County, Iowa in which the BHA property is located.

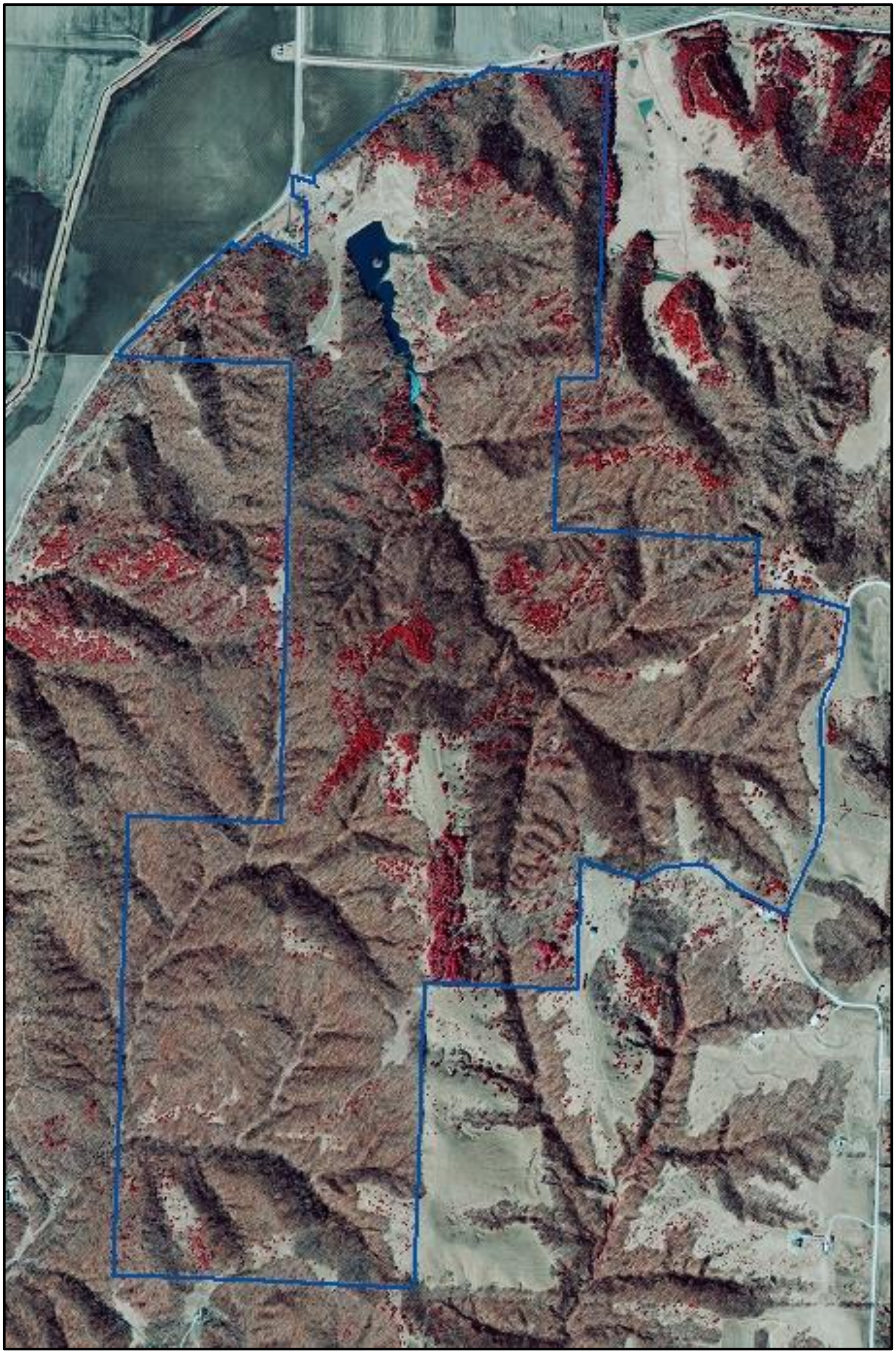

Figure 4-2: 2009 aerial photograph.

4.4 Data Scrubbing

In preparation for conducting the analyses, the feature datasets were scrubbed and placed in the Model Geodatabase. The feature class BHA_Property shows the boundary of the 800-acre property and was the main feature used for the printed maps. To obtain the soil information needed for the project, the project team clipped the county level soil shapefile to the BHA boundary. This feature class was named BHA_soil and is illustrated in Figure 4-3.

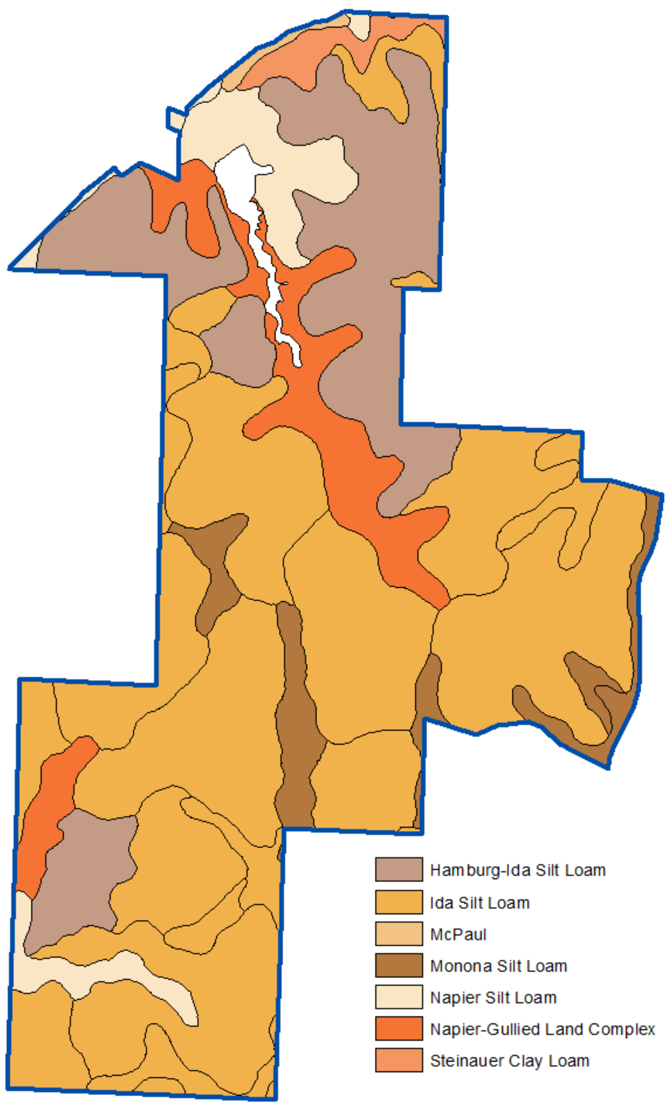

Figure 4-3: The BHA_soil feature dataset illustrating the different soil types.

In order to determine the slope for BHA property, the project team needed a digital elevation model (DEM) which contained elevation information for Mills County, Iowa. To show the topography adjacent to the BHA property, the 3-meter DEM was clipped to the same rectangle used to clip the soil feature dataset and named DEM_3m_expandedProperty. This dataset is illustrated in Figure 4-4 with a hypsographic color scheme superimposed on a 55% hillshade image. The clipping tool was used to clip a raster to an area extent. Clipping the DEM enabled the project team to produce a slope raster for the area of interest to increase performance and reduce data storage.

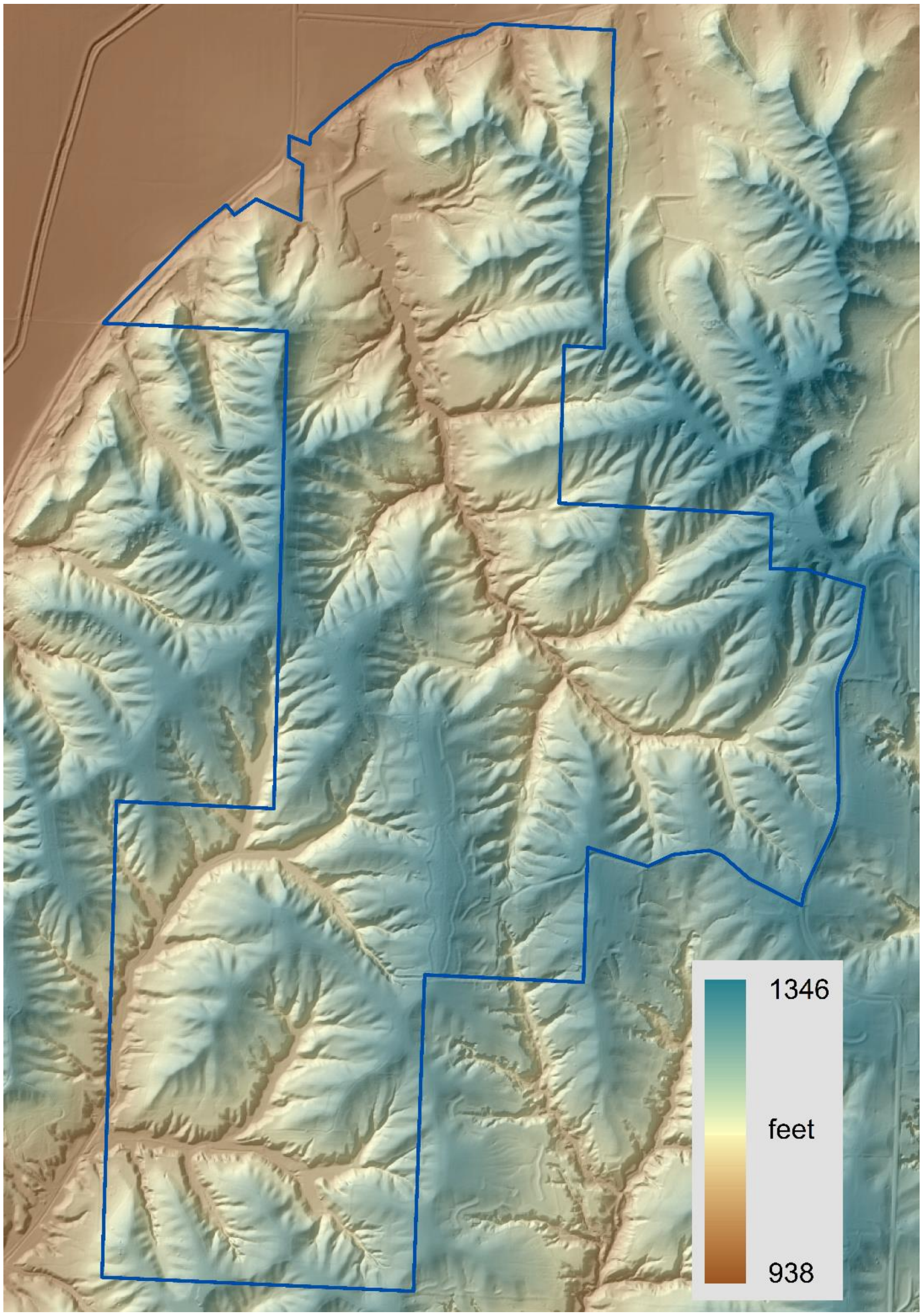

Figure 4-4: Hypsographic color scheme DEM with shaded relief.

In addition to the 3 meter DEM provided by the IDNR, a dem_extract dataset was created by clipping the DEM to the property boundary. Also, in order to create the contour lines in feet, a DEM was converted into feet and named DEM_ft. A dataset named Hillshade_1m was created from a 1 meter DEM that was created from the original DEM provided by the IDNR.

The slope dataset used in the analysis was created from the 3 meter DEM. The dataset named slope_m contains all of the slope values, while the slope dataset reclassified the slope values into five class values in preparation for the analysis.

The feature class named IDNR_ForestStand contained the information needed to identify the different forests types on the BHA property. This feature class was not clipped to the rectangle similar to the previous two datasets, because the original data were all within the property boundary. The dataset is illustrated in Figure 4-5.

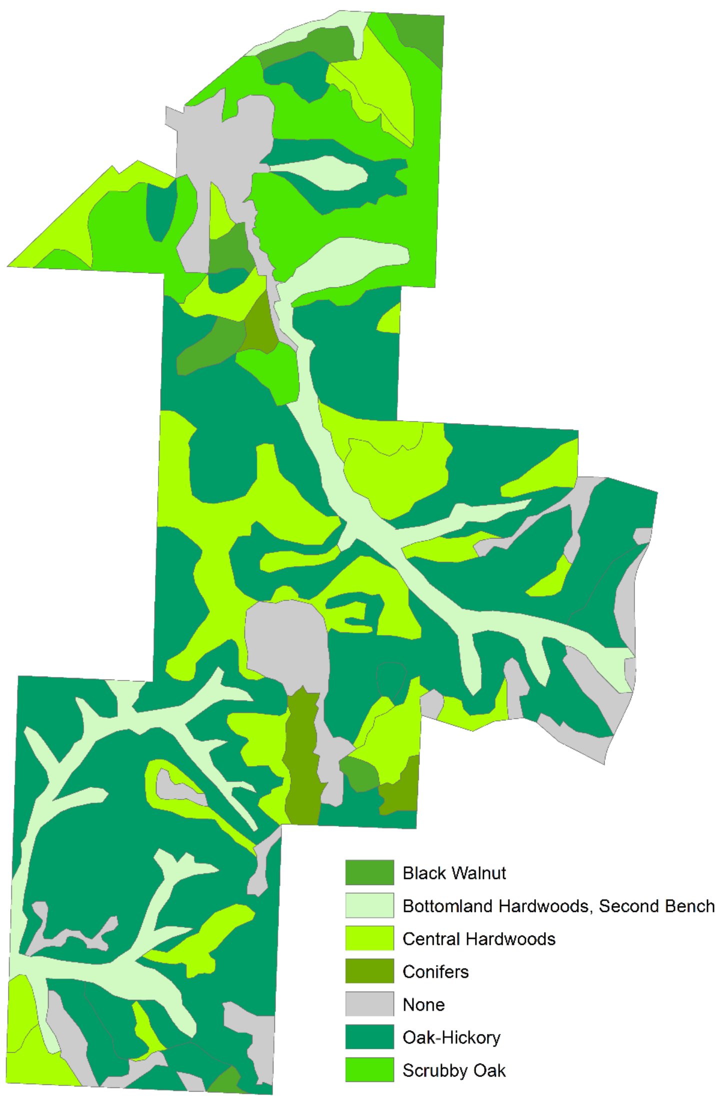

Figure 4-5: The IDNR_ForstStand illustrating the different forest types.

The feature class named contour_20extended and Contour_index were the contour lines in feet used in this project and is illustrated in Figure 4-6.

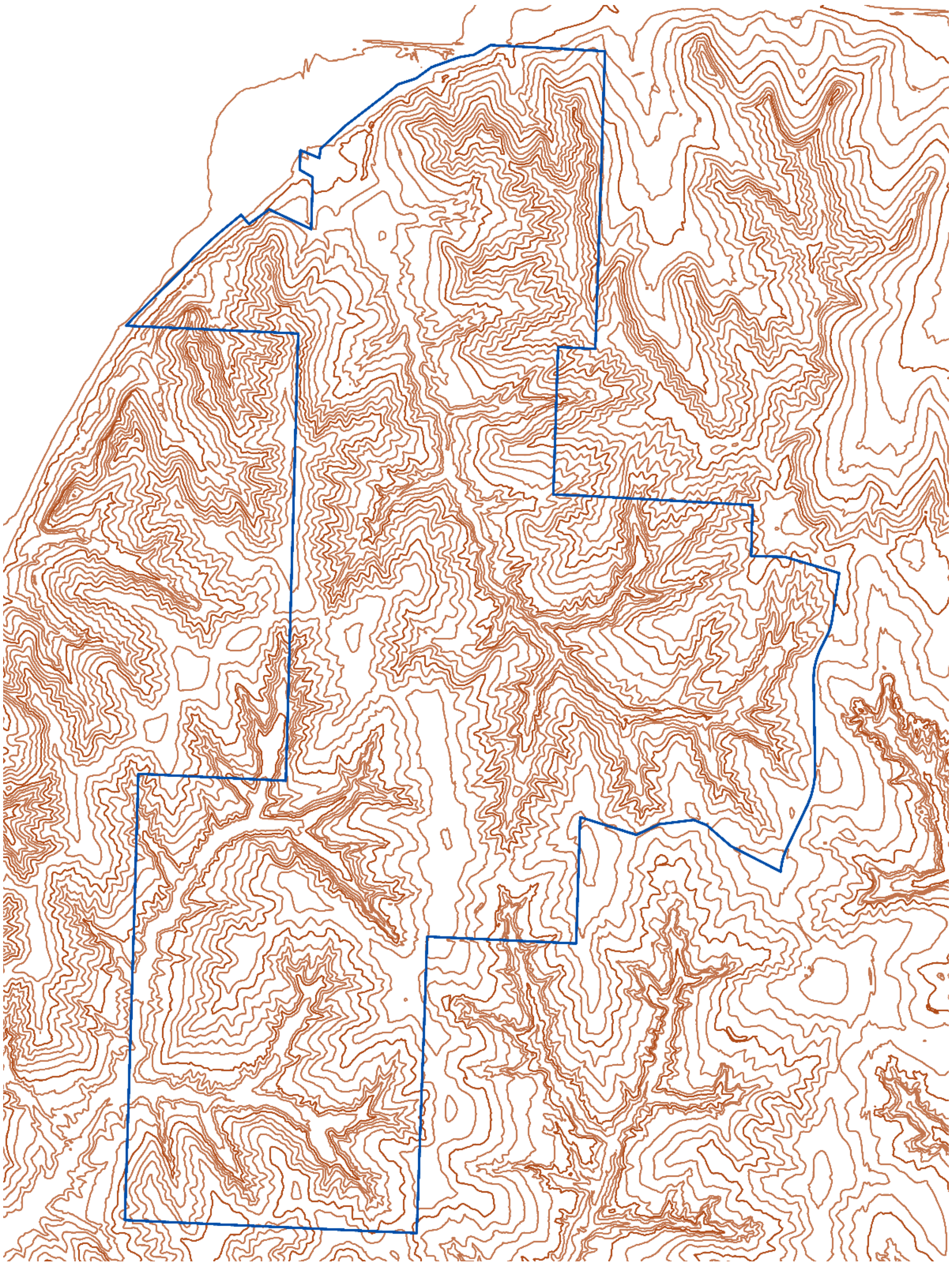

Figure 4-6: Contour datasets produced from the DEM_ft.

The last dataset is the Trail feature class which contained the existing trail system on the BHA property. This is illustrated in Figure 4-7.

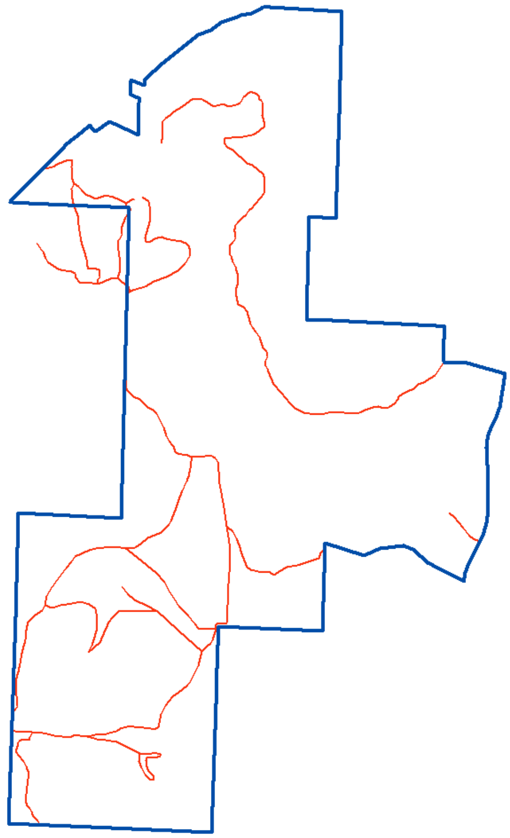

Figure 4-7: Trail feature class.

The following datasets were generated for creating the maps and were not involved in the analysis for locating areas to build sustainable trails. By reclassifying the green channel of the image into two classes – above and below 80 – a dataset (forested_80) was produced that simulated a forest layer with a mottled, natural appearance. SurveyPath is the dataset that contains the approximate route taken during the field survey of the property. The PinePlantation feature class contains the area of the pine plantation, and the Lake feature class contains the boundary of the lake. Lastly, the cleared_area feature class contains those areas that were cleared in 1930. The name, description, and data types of the files located in the Source Geodatabase are presented in Table 4-2.

4.5 Field Survey Data

The project team conducted a field survey on the BHA property to validate the results of the suitability model. During the survey on September 28, 2014, sample points were taken along mowed trails, as well as off the trails, by recording global positioning system (GPS) locations.

The project team began the field survey by meeting with Ms. Lindsey Barney, Mr. Bill Beeler, and three additional BHA members. Ms. Barney and the BHA members, who are all familiar with the property, enabled the project team to conduct the field survey quickly and efficiently. Additionally, Ms. Barney provided her expertise in natural resource management to better verify the ground conditions of the suitability model output. A GPS Trimble Juno unit was used for data collection when conducting the survey. The data collected at each sample point were: the type of forest stand, the type of soil, and the slope.

The field survey began at the cabin on the north side of the property on the existing mowed trails. Walking south from the cabin provided a greater variability of suitability values and passed through areas the BHA members frequented most. Traveling on these mowed trails allowed the project team to walk with more ease than through shrubs in forested areas. Sample points were taken randomly along the trail and when walking off the trail, and the survey was considered complete when the sample points sufficiently represented the property. Figure 4-8 illustrates the approximate path taken during the field survey as well as the sample points collected.

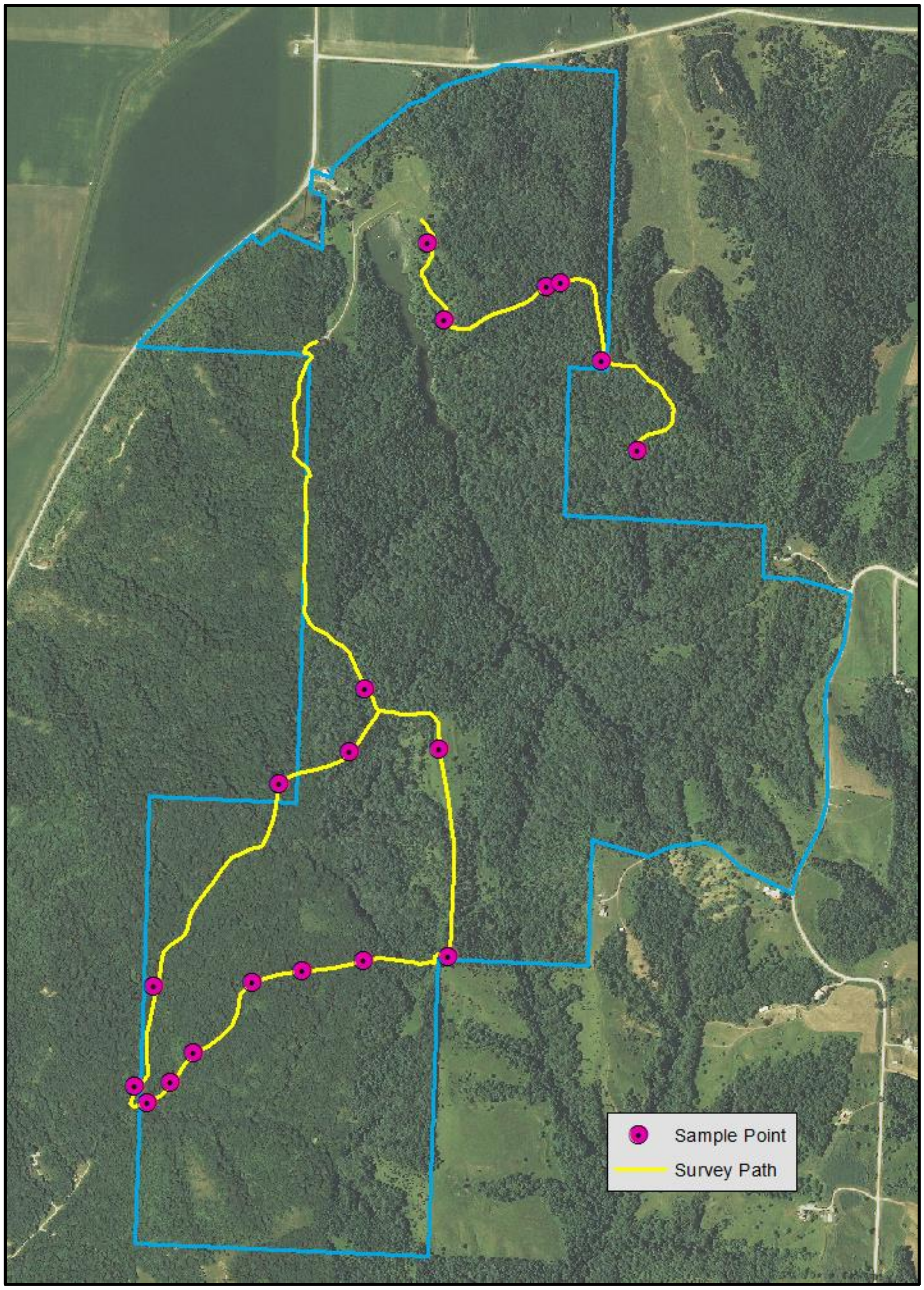

Figure 4-8: Approximate path and sample points collected during survey.

During the field survey, 19 sample points and four interest points were collected, and the project team walked approximately 5.6 miles. Thirteen of the sample points and two of the interest points were taken in the southern portion of the property. The remaining points were collected in the northeastern portion of the property. Three sample points fell outside the boundary of the property and were excluded from all analyses.

4.6 Summary

This chapter discussed the conceptual and logical data models of the project. The conceptual data model provided an overview of the relationships that exist between the environmental factors that contribute to soil erosion and trail suitability. The logical models described in Section 4.2 illustrated the Model Geodatabase created for this project. Section 4.3 explained that the data used to develop the project deliverables came from the IDNR. Field data collection methods and results were discussed in Section 4.4 where a GPS Trimble Juno unit was used to collect the sample points. After completion of the project's data models, creation of the geodatabases, and collection of data on the ground from a field survey, the project team began producing the deliverables.

Chapter 5 – Implementation

Once the project planning was completed, the project team began to create and produce the final deliverables. This chapter is divided into five sections, one for each deliverable and another for the chapter summary. Section 5.1 discusses the creation of the printed maps and Section 5.2 explains the process for creating the 3D terrain model. Section 5.3 describes the procedure for generating the suitability model. Section 5.4 concludes the chapter with a summary of the project implementation.

5.1 Printed Maps and 3D Terrain Model

Before production of the maps could begin, the project team held several meetings with the client to determine which property features would be highlighted in the maps. After establishing the map requirements and map layout discussed in Chapter 3, production of the different maps began. Esri's ArcMap 10.2.2. software was used to produce all of the maps. There were a total of nine maps created where each highlighted a different feature of the property such as the elevation, all points of interest, the existing trail system, and the proposed sustainable trail locations.

A base map was produced that included the 2013 aerial photograph, the BHA property boundary, and a one meter resolution hillshade to emphasize the topography (Figure 5-1). The property boundary was symbolized with a wide dark blue line to draw the reader to the area of interest, but not distract from the main point of the map. To do this, the aerial photograph was displayed as a transparency to provide background surrounding the hillshade of the property. It was important that the ordering of the layers in the table of contents be arranged in a way to highlight the topography. Although the terrain was the main focus of this map, it was last in the ordering so that it did not overwhelm the reader. To do this, the aerial photograph was layered above the hillshade to diminish the color impact, but the transparency on the aerial photograph allowed the terrain to still be the main focus of the map.

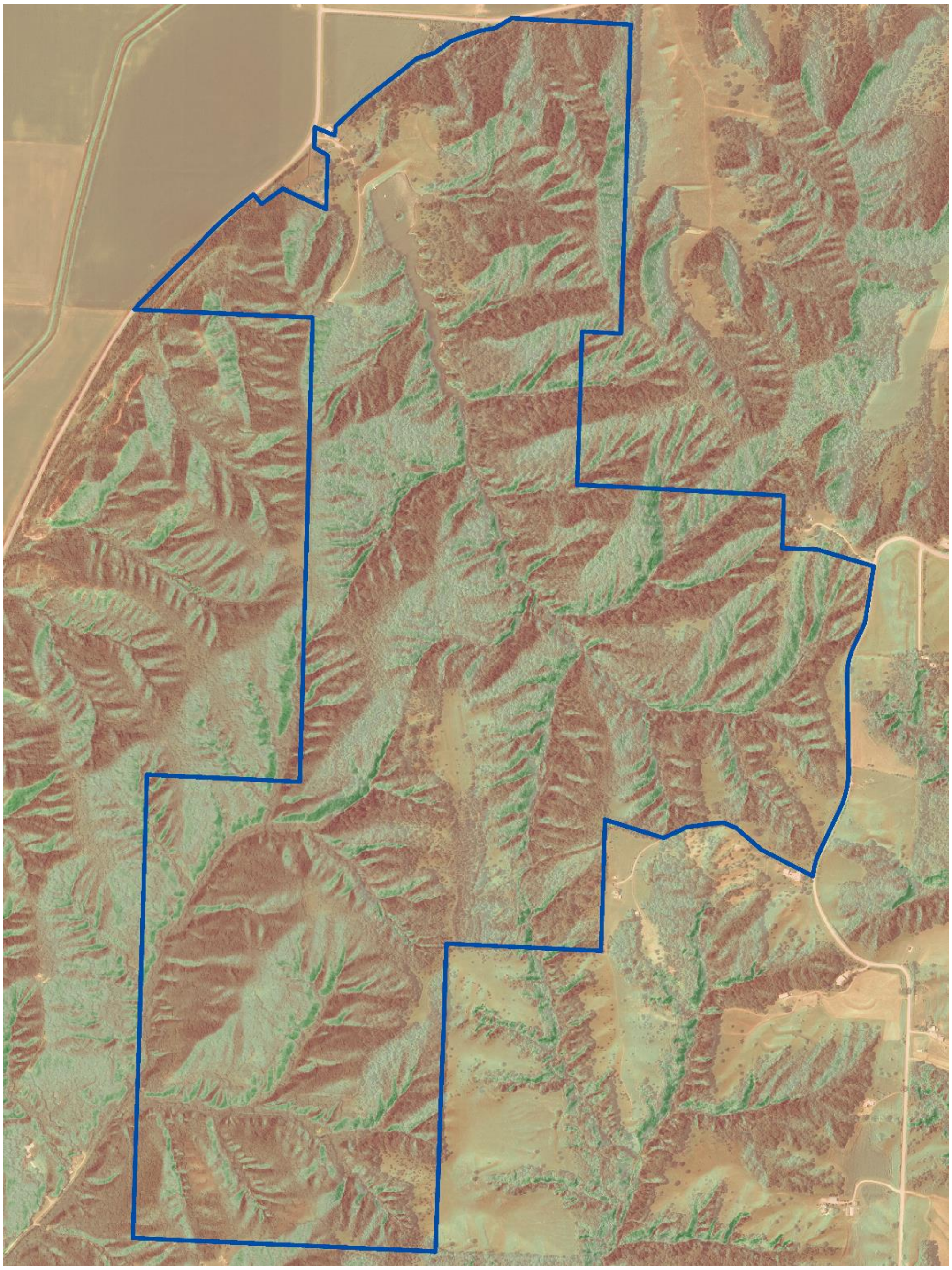

Figure 5-1: Hillshade image with 2013 aerial image.

A similar map was created to show just the BHA property boundary and the 2013 aerial photograph (Figure 5-2). The simplicity of the map allows the reader to be drawn in to the photograph and focus on what exists on the property. The reader is able to see the natural features on the property.

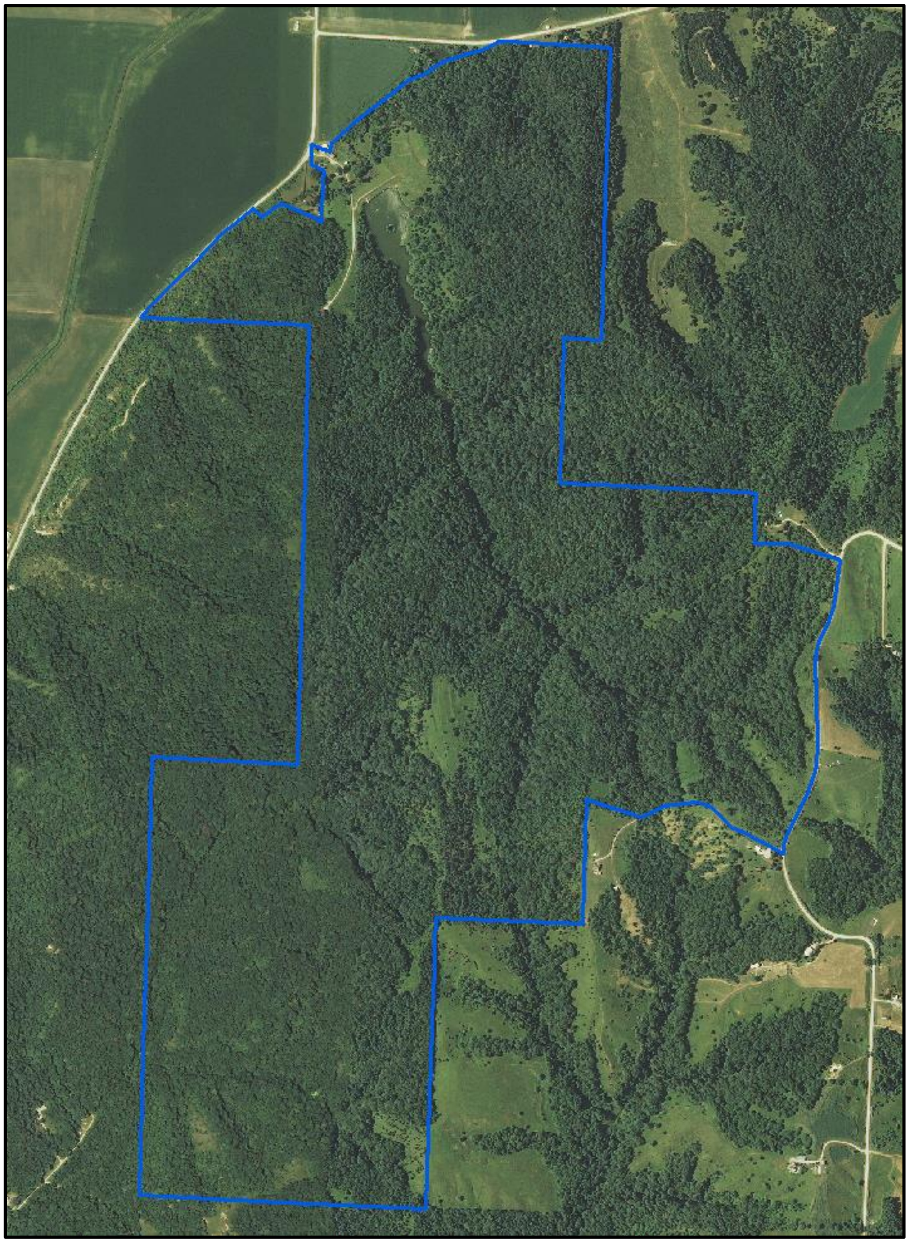

Figure 5-2: BHA boundary with 2013 aerial image.

Another map was created to emphasize the changes that occurred on the property between the years 1930 and 2013 (Figure 5-3). To do this, the project team changed the symbology of the 2013 aerial photograph to be comparable to the 1930 photograph. Displaying the images with similar colors allowed the reader to more easily identify areas within the property that had changed over time. This map highlighted four of the changes that occurred on the property by providing a description explaining each change.

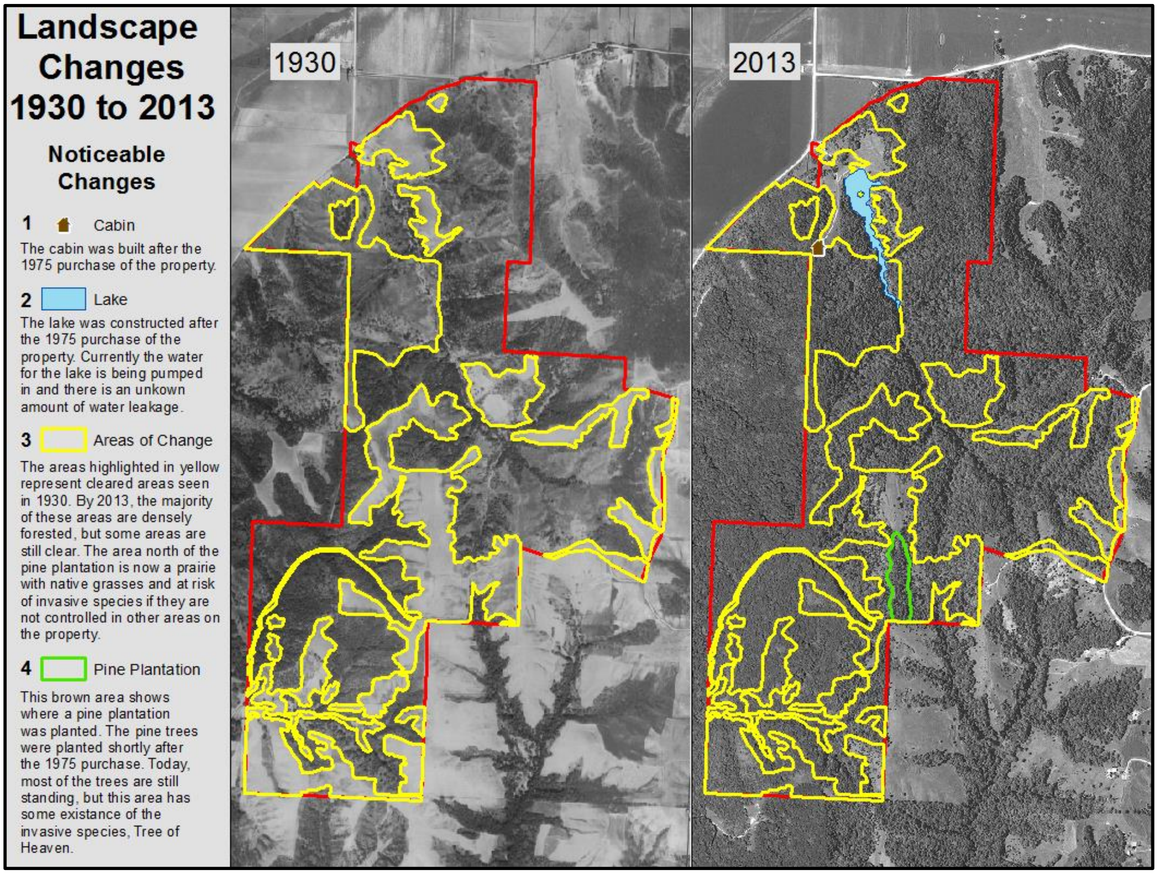

Figure 5-3: Change of the landscape between 1930 and 2013.

The remaining maps featured the property and the trail system on the BHA property. The BHA Property Highlights concentrated on displaying the features that the BHA felt were points of interests and how the current and proposed trails connect these points. Since there was no existing shapefile containing the points of interest, the project team created a point feature class in the Model Geodatabase. In an edit session, the points of interest identified by the client were added to the feature class. A new field in the attribute table was then added to include the name of each point. Adding the name attribute allowed for users to identify each point by the name given to it by the BHA members. In addition, there were no existing or previous trail shapefiles, so the project team created a feature class of the trails. Mr. Bill Beeler provided a map of the trails that he knew currently or previously existed. The same workflow for creating the points of interest was applied to creating the existing or previous trails. When creating this polyline feature class in the Model Geodatabase, the project team hand digitized the trails using ocular clues from the map provided by the client and the aerial photograph on the screen.

The 3D terrain model was created in two steps. The first step included creating a 3D image in ArcScene and exporting the image to a VRML data format. By using the elevation data retrieved from the digital elevation model (DEM), the ArcScene image consisted of the BHA property feature class and the 2013 aerial photograph. To better illustrate the rugged topography, a vertical exaggeration of 1.5 was applied to the model. The resolution for the image was set at 1 meter to ensure a clear image once printed. The measuring units for the x, y, and z axes were in meters and the elevation data came from the digital elevation model at a 1 meter resolution. Figure 5-4 provides a 2D version of the 3D terrain model.

Figure 5-4: A view of the 3D terrain model from the northwest.

5.2 Suitability Model

To create the Suitability Model, ModelBuilder in ArcMap 10.2.2. was used. Due to the complexity, a total of two models were created – Suitability Model and Sustainable Trails Model. In order to generate the Suitability Model, the inputs were the three environmental factors – soil type, slope, and forest stand type – and the existing trails, all of which were in raster format. The trails was included in the analysis because it would be more sustainable and cost efficient to reconstruct an existing trail than it would be to create an entirely new trail. To include the trails dataset, the shapefile was converted from a polyline to a raster. The trails output was then reclassified into two values, where a value of one represented a trail and a zero was the rest of the dataset. Figure 5-5 illustrates the trails raster used in the analysis.

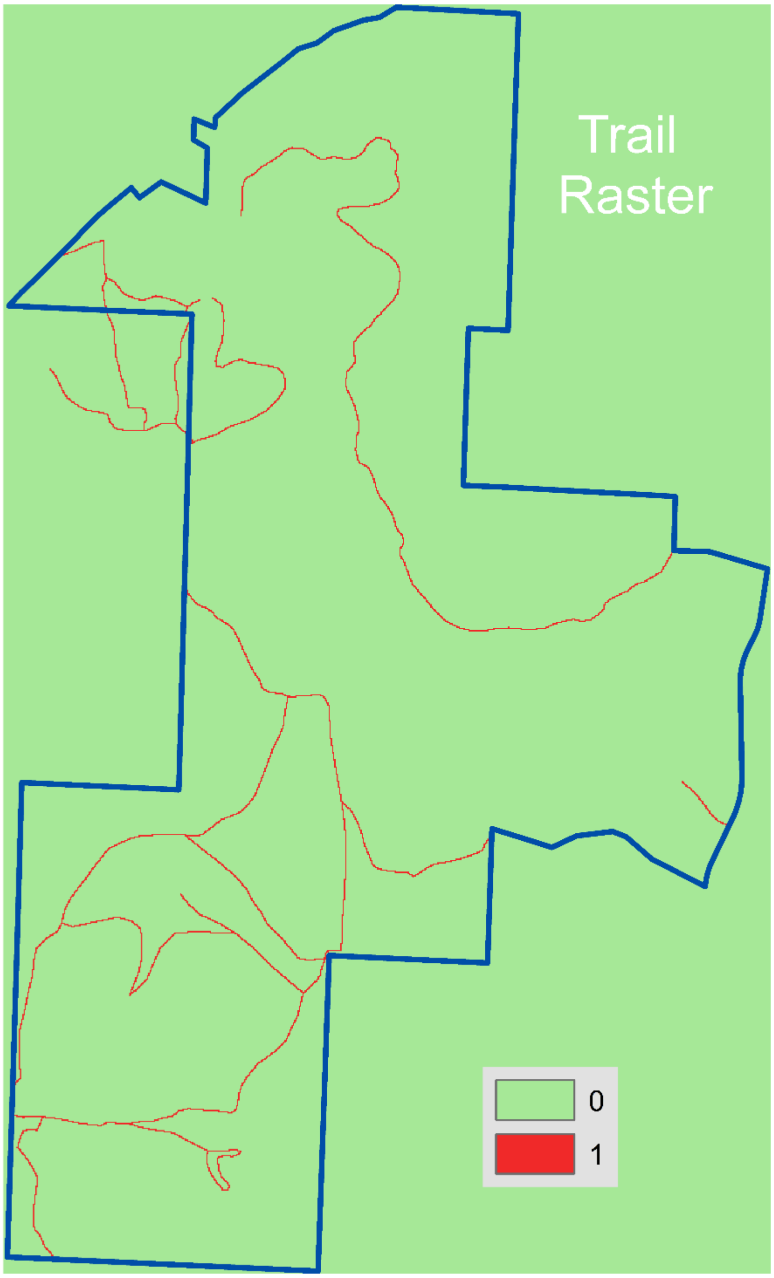

Figure 5-5: Trails raster used in the weighted overlay analysis.

The Iowa Department of Natural Resources (IDNR) provided the soils and forest stands in shapefile format, so a class field was created as a feature attribute before converting the data into raster format. The class field enabled the user to assign a value to an attribute within the layer. These classes described how much the characteristic contributes to an area being suitable for trail construction on a range from one to five, with one representing most suitable and five least suitable. This scale range allowed the cost path analysis tool to locate the least cost path, which proposed sustainable trail locations from the cabin to points of interest throughout the property.

Before the models could be run, all datasets needed to exclude the lake. In the soils dataset, the lake was its own feature so it was simply deleted from the dataset. In the forest stand dataset, the forest stands were edited as to ensure that the boundaries did not overlap the lake by reshaping the polygons. In order to exclude the lake from the slope raster, the image analysis window was used to clip the lake area from the raster. By excluding the lake from the datasets, the weighted overlay and cost path analyses would not include the area of the lake.

Next, values of the class field were assigned. The forest stand dataset contained five different forest types. By using the Select by Attribute tool and saved Structured Query Language (SQL) expressions, each forest types were assigned a class value between one and five. These values were classified in this matter by a discussion with the client expressing which areas were more desired to walk through. These values can be seen assigned to each forest stand in Table 5-1.

Table 5-1: Class values assigned to each forest stand type.

Forest Stand Type	Class Value
Black Walnut	1
Oak-Hickory	
Central Hardwoods	2
Pine Plantation	
Bottomland Hardwoods	3
Scrubby Oak	4
Conifers	5

The client explained that those forest stands containing a Black Walnut or Oak-Hickory overstories were the most desirable forest to walk through. These areas were located mainly in the southern portion of the property in the old growth forests. The conifer forest stand type was given a value of five because the client did not wish to walk through a conifer stand, except for the pine plantation. The pine plantation therefore was given a value of two instead of five. The type of forest stand the client desired to walk through assigned all other values. Figure 5-6 illustrates the forest stand suitability.

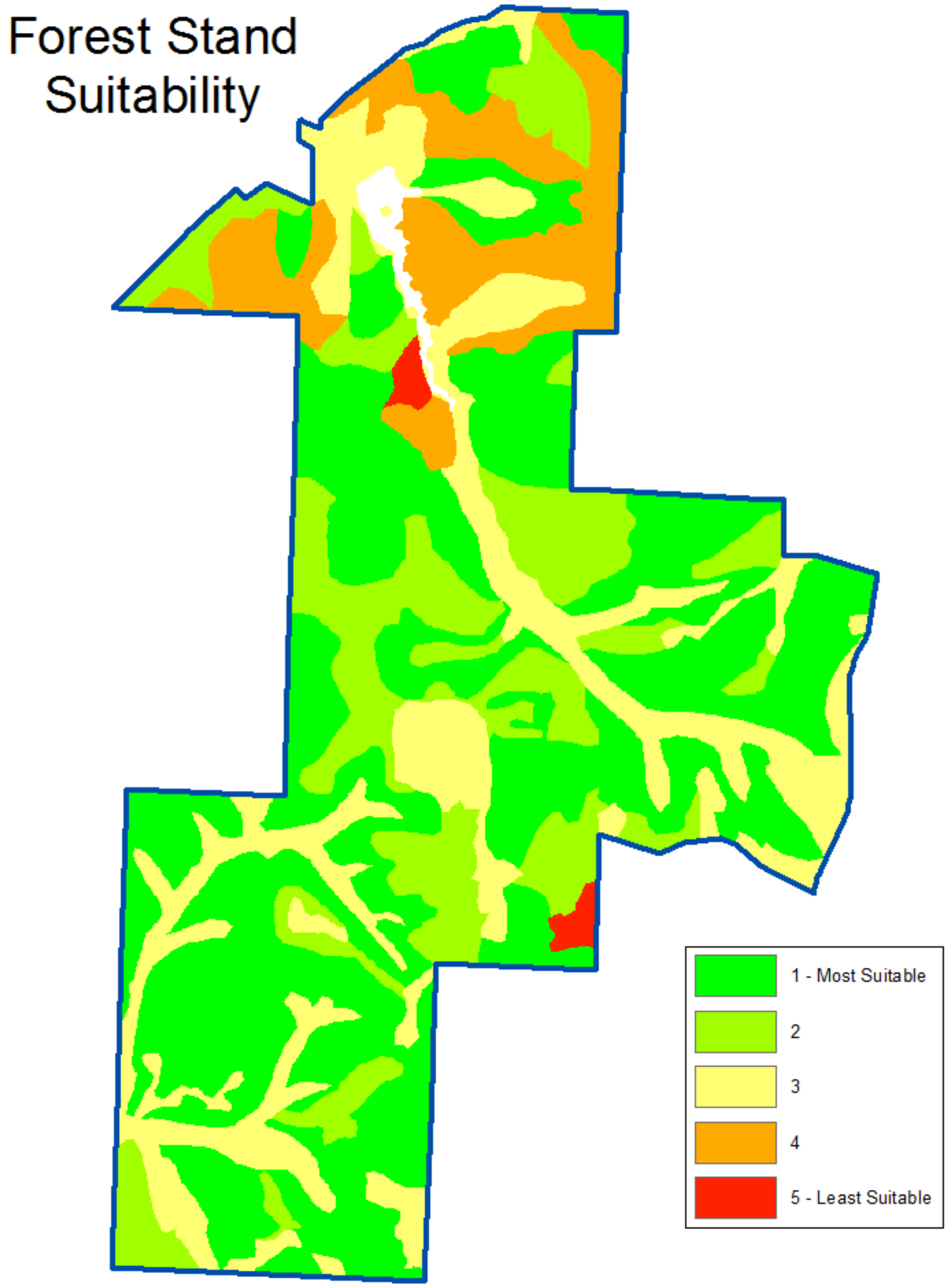

Figure 5-6: Forest Stand suitability.

Similar to the forest stand dataset, class values were assigned to each soil type in the soil dataset. Table 5-2 demonstrates which soil types were assigned which weight value.

Table 5-2: Class values assigned to each soil type.

Soil Type	Class Value
Steinauer Clay Loam	1
Hamburg-Ida Silt Loam	2
Napier-Gullied Land Complex	
Napier Silt Loam	
Ida Silt Loam	3
Monona Silt Loam	4
Ida Silt Loam - Severely Eroded	5
McPaul	

Of all the soils existing on the property, the Steinauer Clay Loam soil tends to be the least susceptible to soil erosion because of its clay content. The Ida Silt Loam – Severely Eroded and McPaul soils tend to be the most susceptible to erosion because the soil particles are small and do not hold together well. Depending on the susceptibility of the remaining soil types, the class values two through four were assigned. Figure 5-7 illustrates the soil suitability.

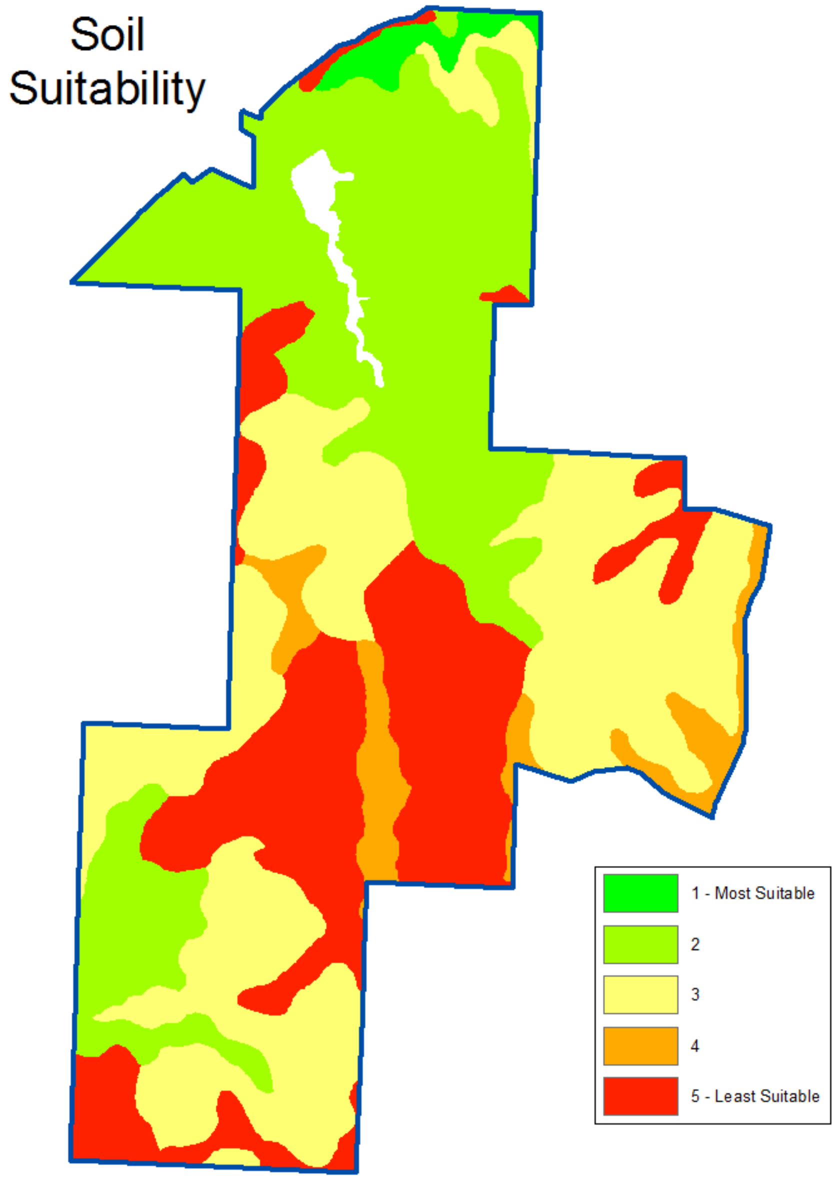

Figure 5-7: Soil Suitability.

Once the soil and forest stand datasets were given class values and converting into raster format, the slope dataset was reclassified to the appropriate class values. The slope was created in raster format so a reclassification was performed by grouping the degree of slope into five different classes and assigned a value. Table 5-3 shows the classes assigned to the different slope ranges.

Table 5-3: Reclassification table used to assign class values to slope ranges.

Slope in Degree	Class Value
0-5	1
5-15	2
15-25	3
25-35	4
>35	5

A slope with a degree between zero and five are the most suitable for sustainable trail construction because there is a lower risk of soil erosion occurring. In addition, slopes at a lower degree are more desired for a leisurely walk. Any slope that exceed 35 degrees are at a greater risk of soil erosion and difficult for a person to enjoy the trail by walking the slope. The remaining values were assigned by the degree of ease it would take a person to walk the slope and the risk of soil erosion. Figure 5-8 illustrates the slope suitability.

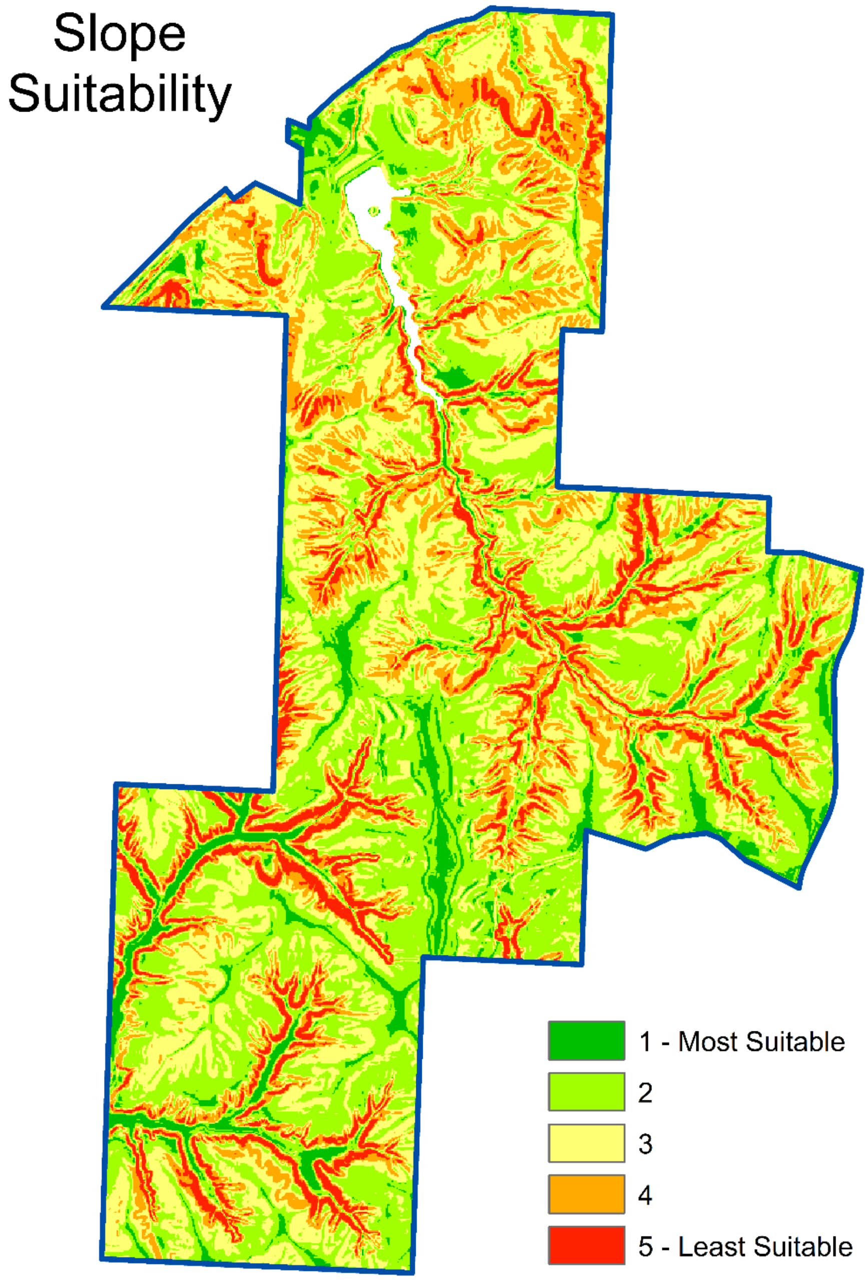

Figure 5-8: Slope suitability.

Once each environmental dataset was prepared for the weighted overlay analysis, the Suitability Model was run to create a cost surface locating areas suitable for sustainable trail construction. To find these areas, the Raster Calculator tool uses a map algebra expression to create the output. The expression used in this weighted overlay is as follows:

$$(soil * 0.4 + slope * 0.4 + forest * 0.2) + trails * 0.25$$

A 40% weight was applied to the soil and slope datasets because they have a larger influence on how suitable the area is for sustainable trail construction. The forest stand dataset weight was 20% because in this project the forest types were more for an aesthetic value and did not have a large influence on an area. The trail dataset used in the expression was a raster and was multiplied by 0.25. Table 5-4 illustrates the weighted overlay analysis.

Table 5-4: Weighted overlay analysis table.

Raster	% Influence	Field	Scale Value
Soil_Raster	40	Value	
		1	1
		2	2
		3	3
		4	4
		5	5
		NODATA	NODATA
slope	40	Value	
		1	1
		2	2
		3	3
		4	4
		5	5
		NODATA	NODATA
Forest_Raster	20	Value	
		1	1
		2	2
		3	3
		4	4
		5	5
		NODATA	5

The output ranged from 1.65 to 6.05 and the Suitability Model is illustrated in Figure 5-10.

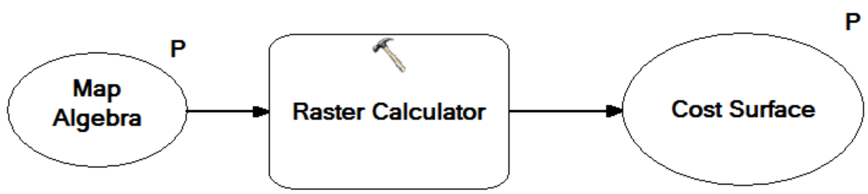

Figure 5-10: The Suitability Model.

The suitability map or cost surface produced from the Suitability Model was the input for the Sustainable Trails Model and is illustrated in Figure 5-11.

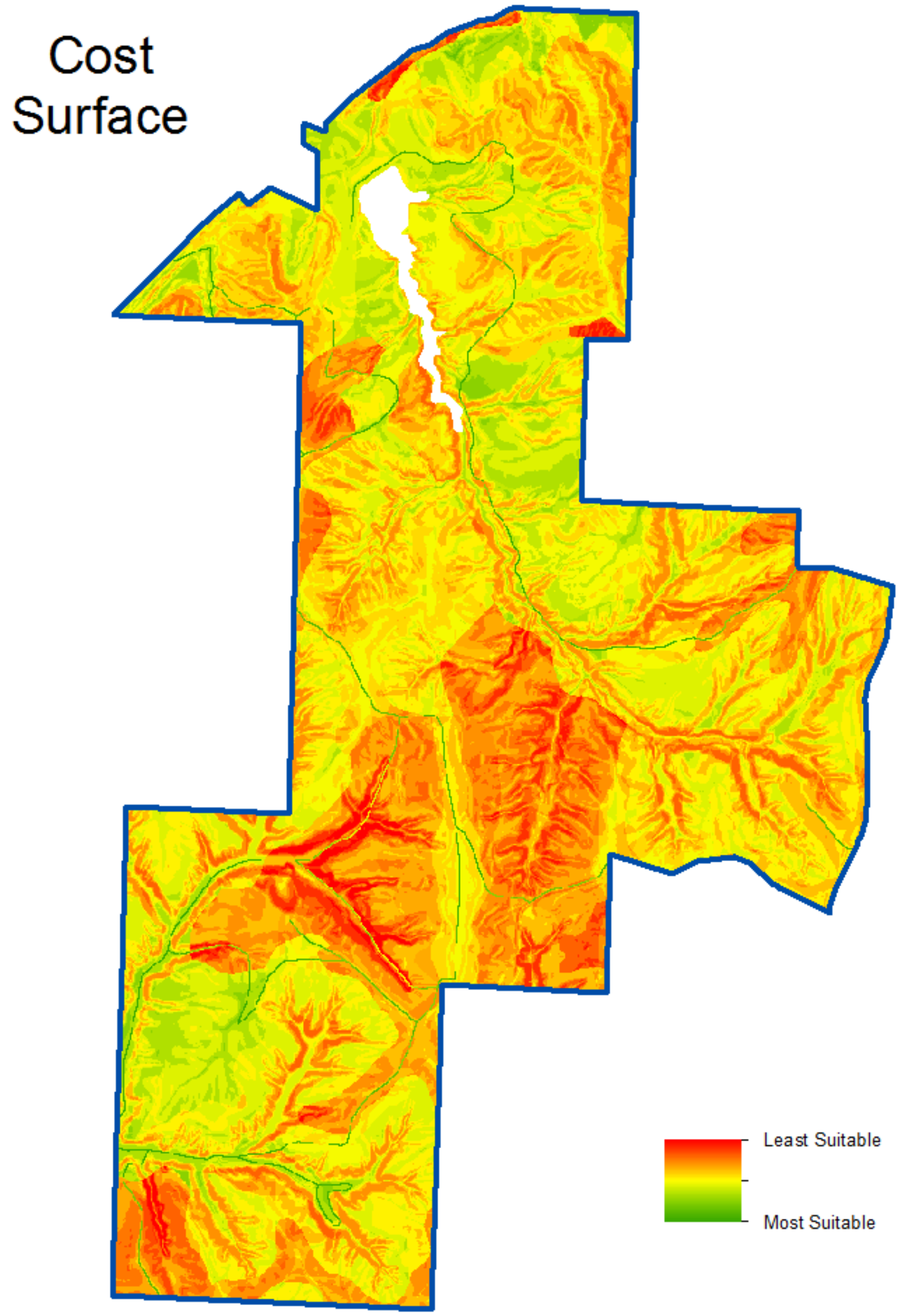

Figure 5-11: Cost surface produced from the weighted overlay analysis.

The tools used in the Sustainable Trails Model were: Cost Distance Analysis, Cost Path Analysis, and Raster to Polyline. The Cost Distance tool determined the least total cost distance for each cell from a starting feature. The starting point in this analysis was the cabin because it was expressed that the BHA members would like to start the walks at the cabin. This analysis tool produced two outputs: a cost distance and a cost distance backlink. Both of these outputs were needed as inputs for the Cost Path Analysis. The Cost Path Analysis produced a raster identifying the least cost path from the cabin to the various points of interest throughout the property. The last component of the model converted the least cost path output from a raster to a polyline. Figure 5-12 illustrates the Sustainable Trails Model.

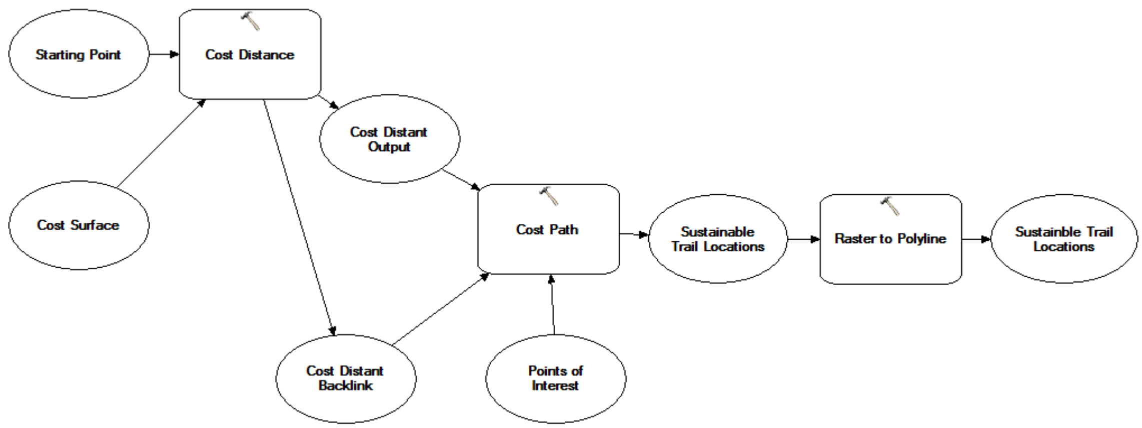

Figure 5-12: Sustainable Trails Model.

5.3 Summary

The project team used Esri software to produce the deliverables for this project. ArcMap 10.2.2 was used to create the printed maps, the models were developed within ModelBuilder, and the layers were created for the interactive web map. ArcScene was used to produce the 3D terrain VRML file that UPS printed into a 3D model, and ArcGIS Online was used to develop the BHA Interactive Web Map. Once the deliverables were completed, the project team began analyzing the results to determine whether the problem statement was satisfied.

Chapter 6 – Results and Analysis

This project included four deliverables, which were presented to the Bartlett Hills Association (BHA) at the completion of the project. Chapter 6 describes the final results and analysis of each deliverable. Section 6.1 explains the nine maps and provides a figure of each map. Section 6.2 discusses the 3D terrain model and Section 6.3 describes the suitability model results and analysis. The chapter concludes with a summary in Section 6.4.

6.1 Printed Maps and 3D Terrain Model

The BHA was provided with two opportunities to use the nine maps created: one for learning and the other for future land management decisions. Each map highlights a different feature of the property and the completed maps will be displayed in the BHA cabin.

The first map highlights features on the property in the year 1980 (Figure 6-1). This map contained a 1980 aerial image that illustrated the pine plantation planted (green polygon), the man-made lake, the cabin, and the areas that were cleared by 1930 (yellow polygons). The landscape changes and pre-1980 maps illustrate the history of the property.

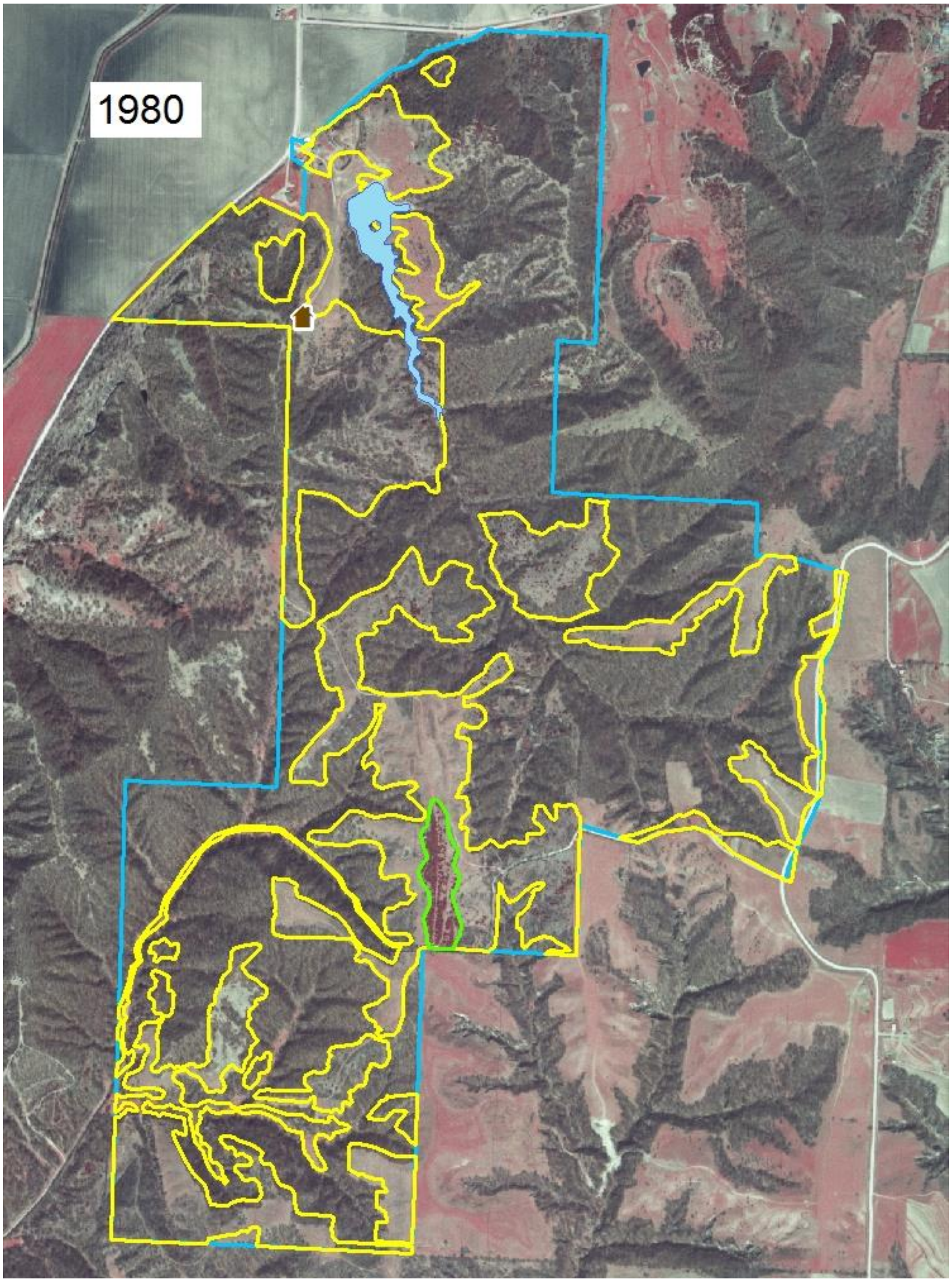

Figure 6-1: 1980 Map.

Since there had been minimal land management conducted since the BHA's purchase of the property in 1975, the project team created a map to highlight the changes that occurred between the years 1930 and 2013 (Figure 6-2). This map highlighted three natural features that existed in 1930 and no longer exist or have changed in 2013. The most prominent change was the appearance of forests in areas that were prairies in 1930.

Other features, such as the cabin, man-made lake, overgrown roads, and the abandoned trailer site are highlighted.

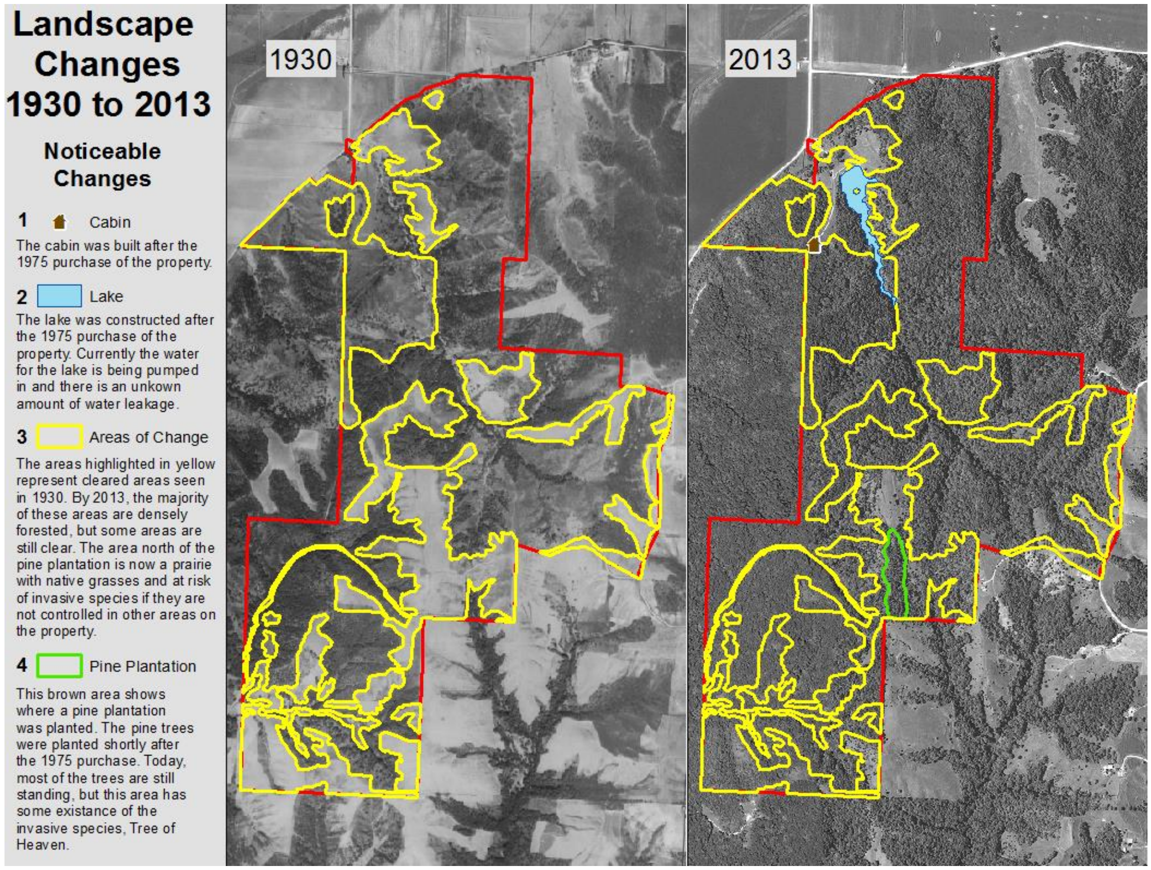

Figure 6-2: Landscape Changes 1930 and 2013.

One simple image map created depicted an aerial image and the property boundary to show the BHA members the extent of the property and the features contained within the boundary (Figure 6-3). Those not familiar with the area can use this map to familiarize themselves with the features of the property. It can also be used by land managers to determine the existing natural features.

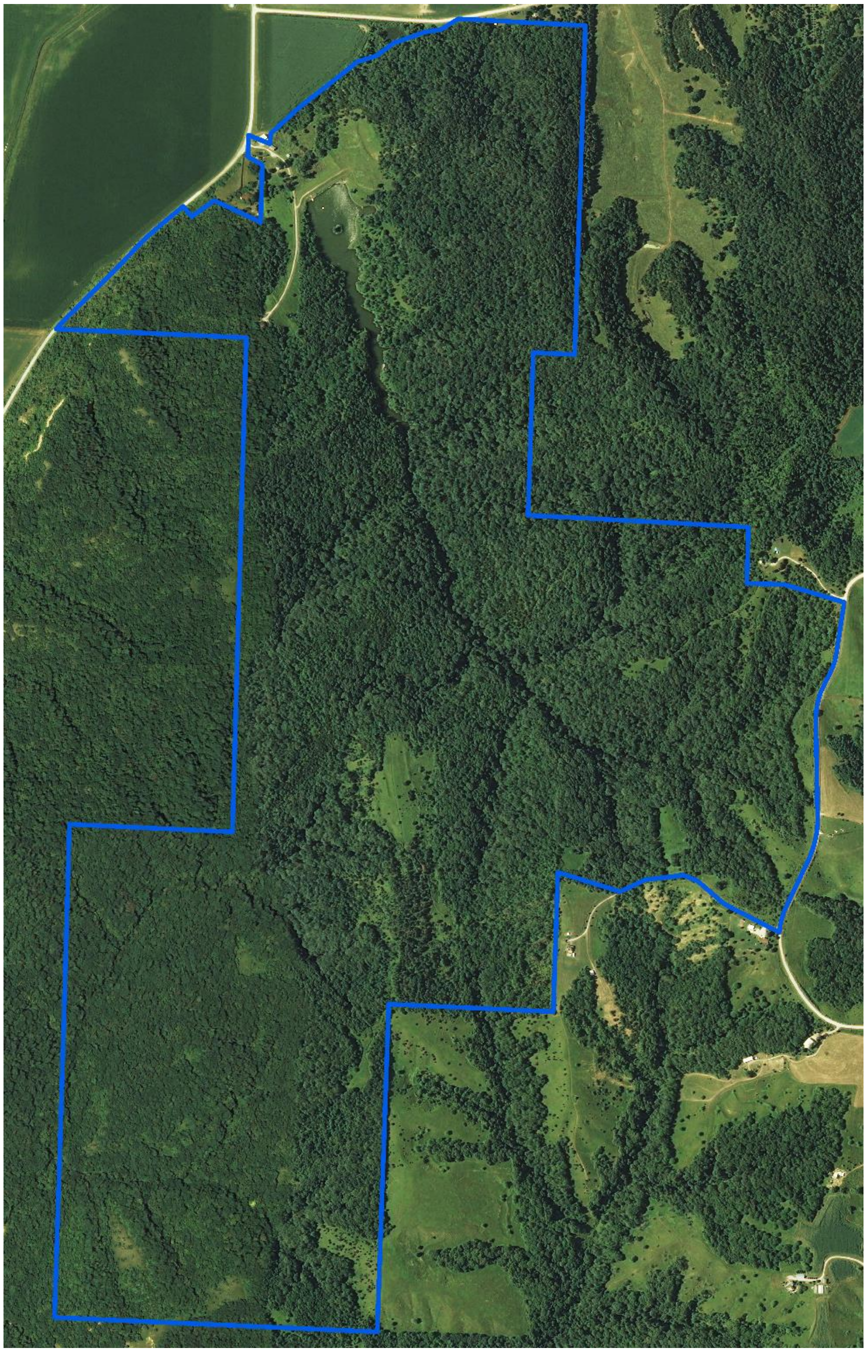

Figure 6-3: BHA Property Map.

Another map illustrated the points of interest that exist on the property that the BHA members enjoy visiting (Figure 6-4). This map provides reference of the natural features that surround the points of interests and an overview of how the trails connect to the various points.

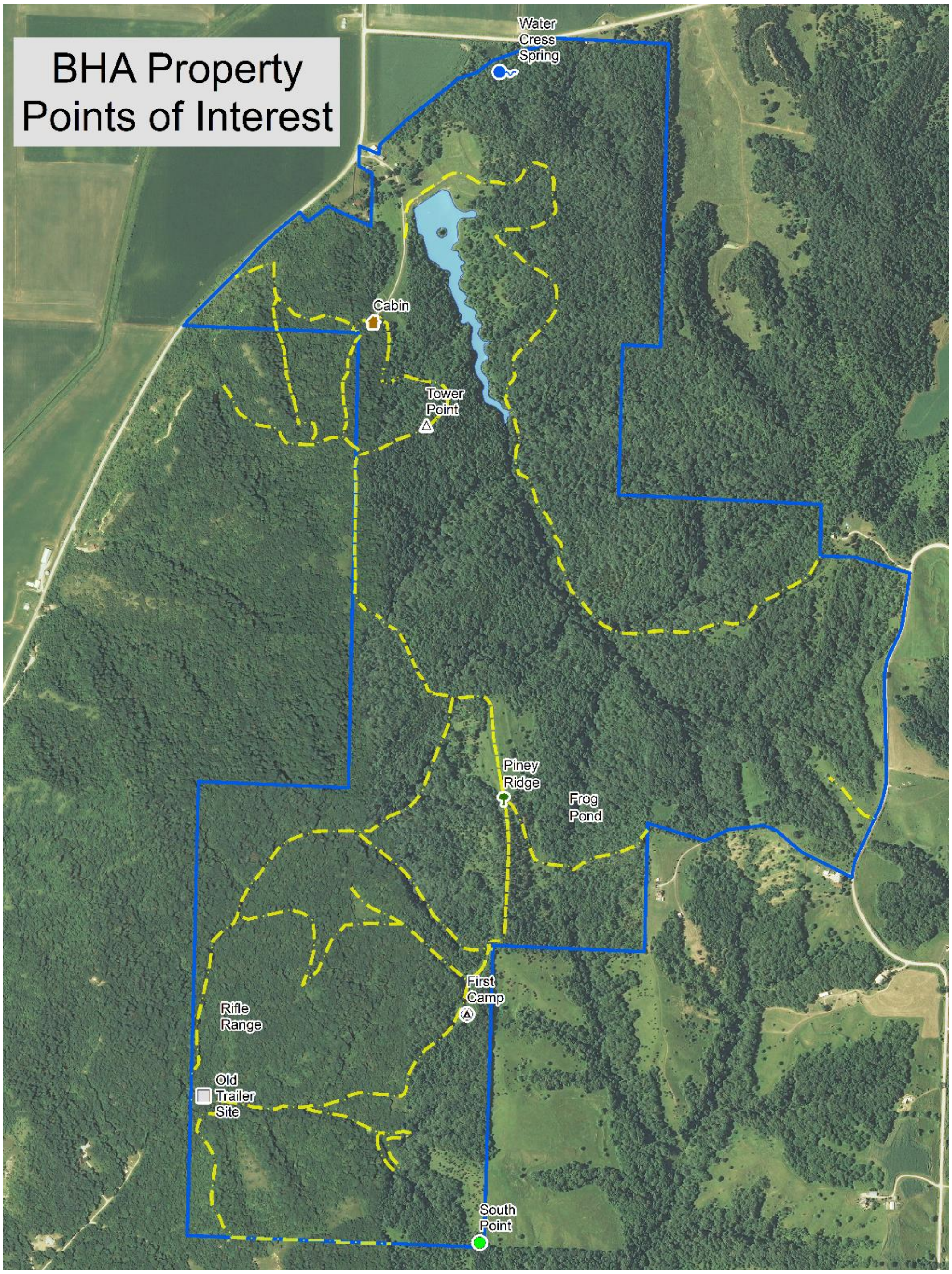

Figure 6-4: BHA Property Points of Interest.

The next map highlighted the topography of the property. A shaded relief map, created from a digital elevation model, illustrated the elevation, hilllsides, ridges, valleys, and gullies (Figure 6-5). This map provided additional information by representing how the terrain changes throughout the area. In addition, land managers can use this map for reference when traversing the property and for determining areas too steep for logging equipment.

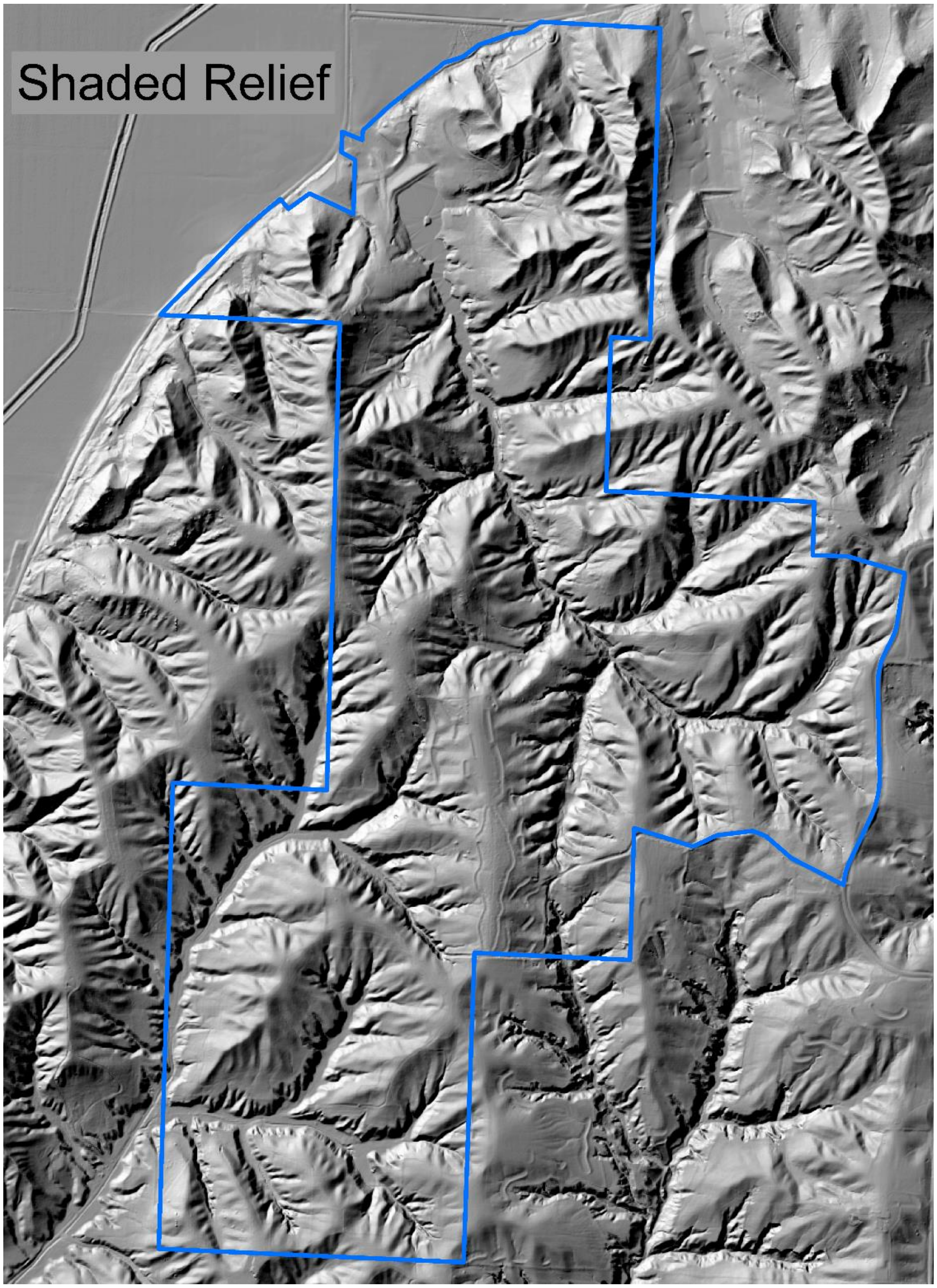

Figure 6-5: Shaded relief map of the BHA property.

The next map highlighted contour lines, popular destinations, and the existing trail system (Figure 6-6). The existing trail system and the contour lines make it possible to identify and locate the relationship between the trails and changes in elevation. By looking at this map, one can recognize trails that follow contour lines, which feature a gentle slope and a leisurely walk. Trails that cross contours indicate a hill and a moderate to strenuous walk. Displaying the desired destinations for hiking provided users with information about which trails would offer a more leisurely or strenuous walk depending on the intended destination.

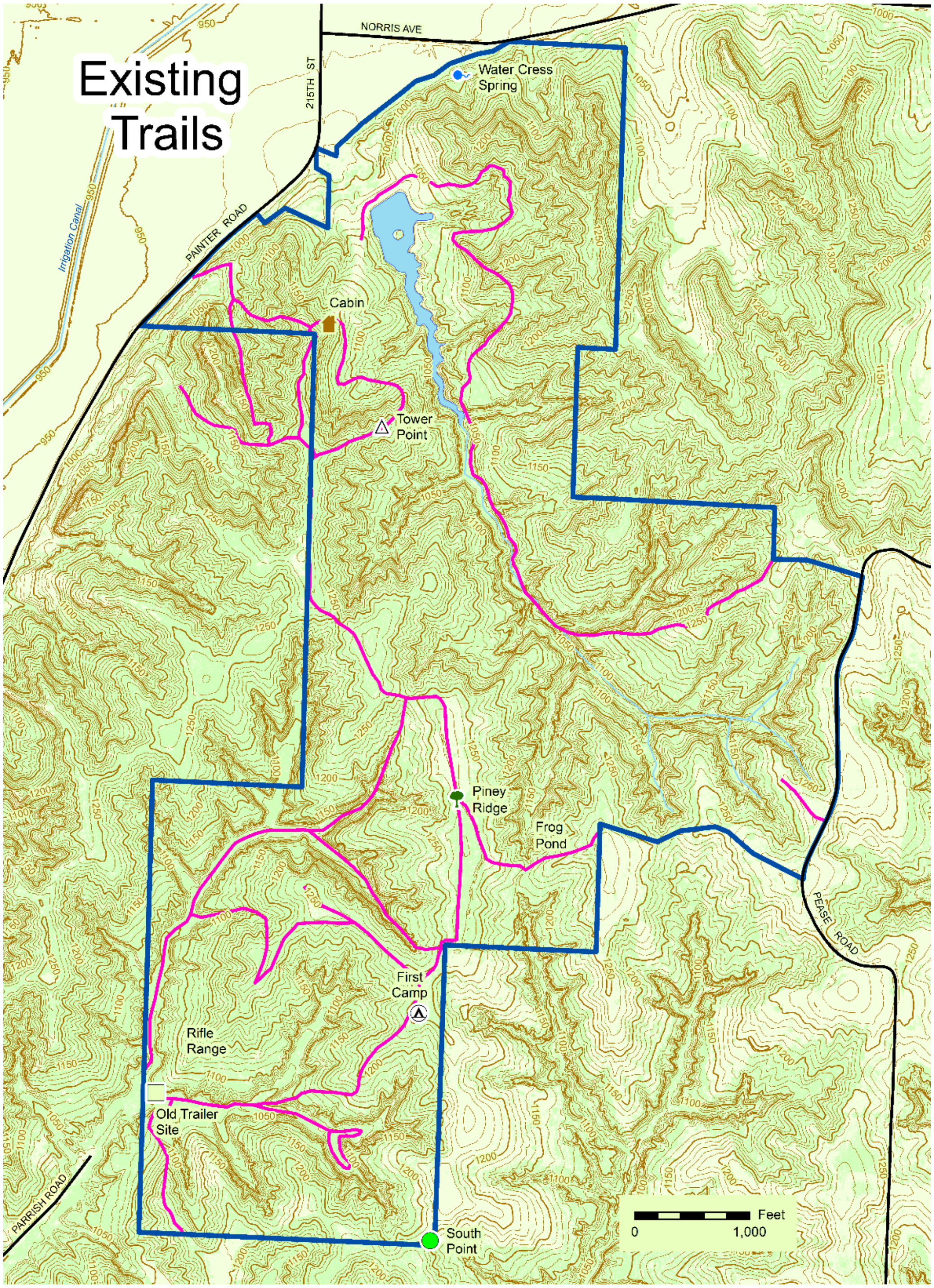

Figure 6-6: Existing Trails Map.

Similar to the existing trails map, the fourth map – Proposed Trail System – featured contour lines, existing and proposed trails, and hiking destinations (Figure 6-7).

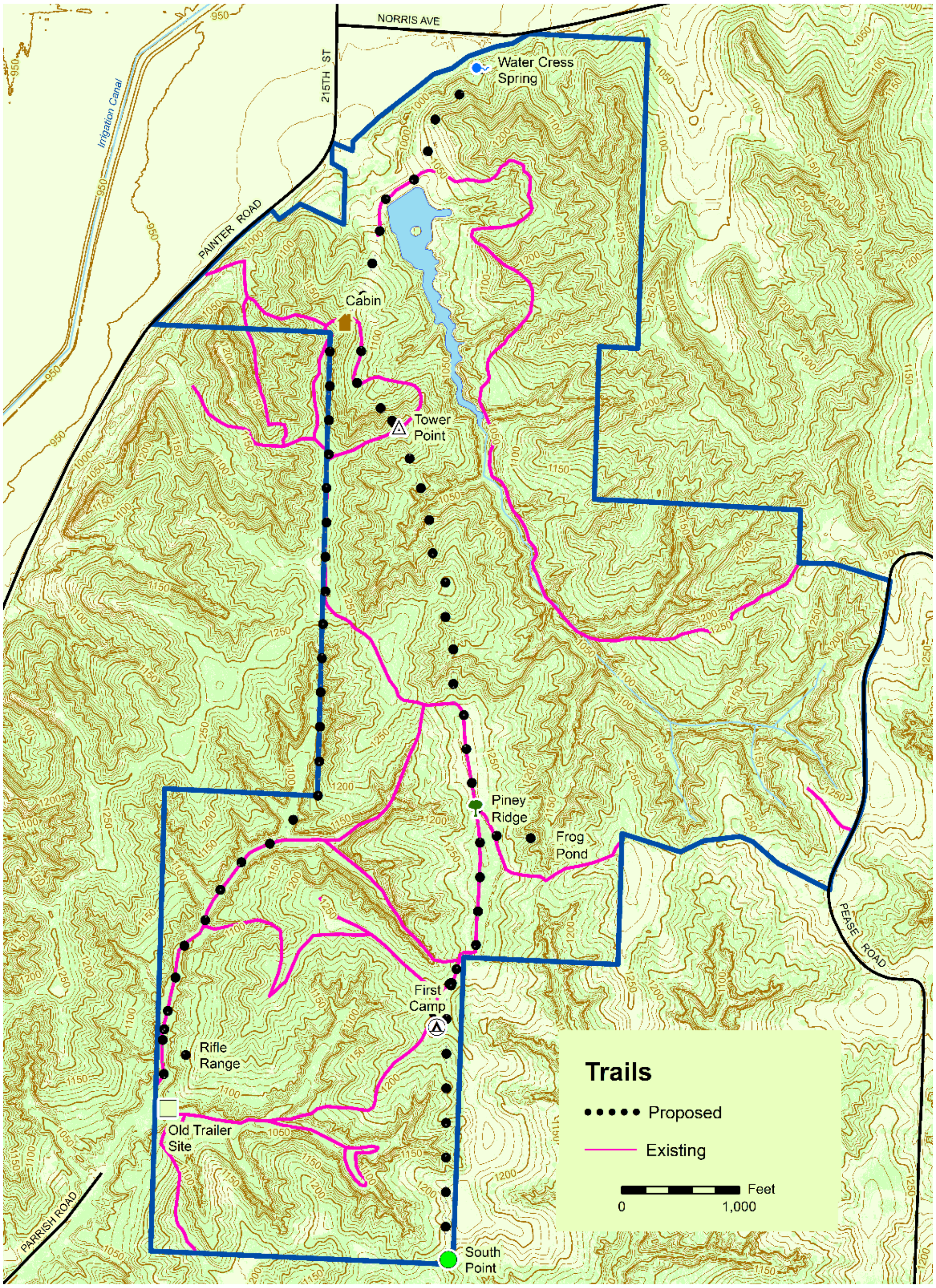

Figure 6-7: Proposed sustainable trail routes map.

Figure 6-8 illustrates the existing trails, proposed trails, points of interest and the 2013 aerial photograph.

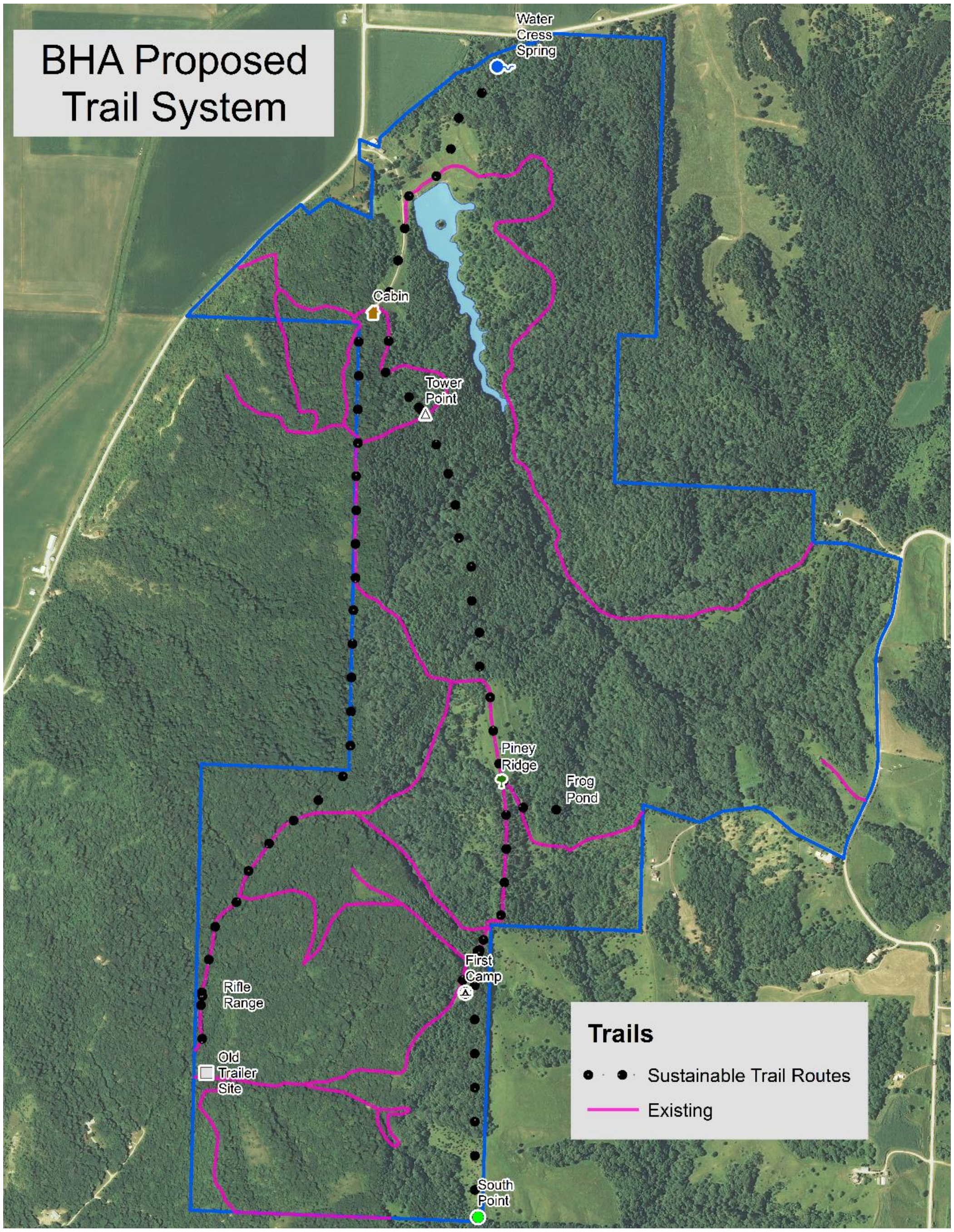

Figure 6-8: BHA Trail System Map.

The last map created for this project illustrates the suitable and non-suitable areas for trail construction on the property (Figure 6-9). This map allowed the BHA members to locate existing trails and determine whether they were located on suitable areas for trail construction. This map could also be used for management decisions in proposing new trail locations. When viewing the suitability map, one can identify that the majority of the existing trails are located in areas with a value of three or higher. A value of one indicates that the area is the most suitable for trail construction while a value of five represents an area the least suitable for trail construction. A further analysis of the suitability and trail locations is described in Section 6-3.

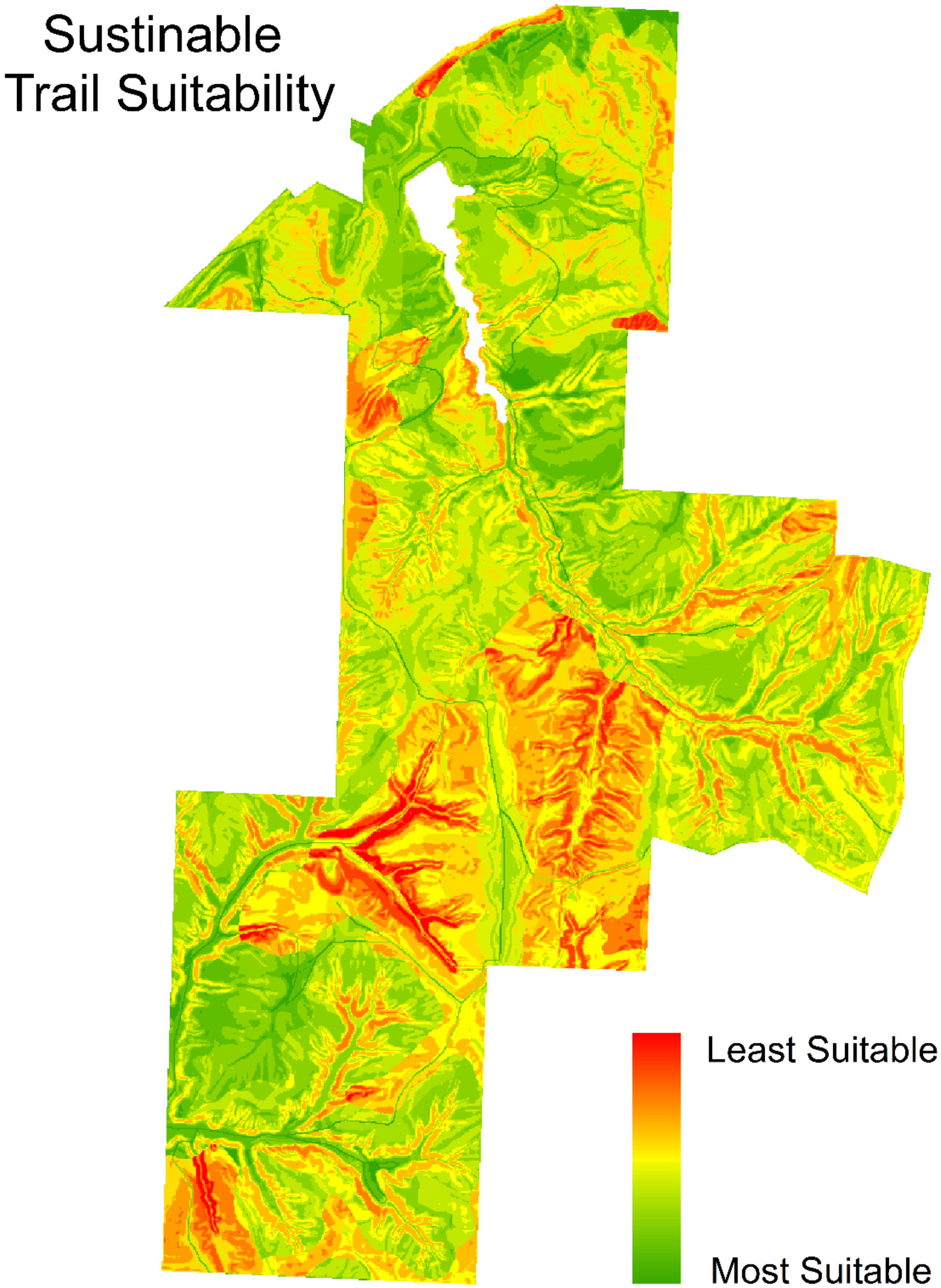

Figure 6-9: Suitability Map.

These nine maps allow the BHA members and land managers to learn more about the property and the possibility to use several of the maps for future land management decisions.

Creating the 3D terrain model provides an opportunity for the BHA members and visitors to learn about the property. This type of model provided a unique perspective of the property. By viewing this model (Figure 6-10), a person can explore the elevation throughout the property and possibly learn new information about a piece of the property.

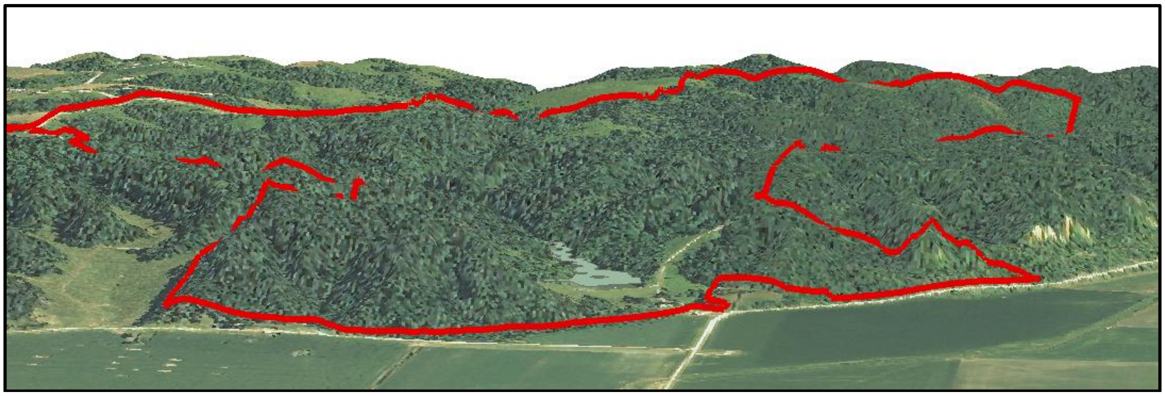

Figure 6-10: 3D Terrain Model.

6.2 Suitability Model

By using the models created during the implementation stage, the overlay identified suitable and non-suitable areas for sustainable trail locations on a scale from 1 to 6.25, with one representing most suitable and 6.25 least suitable. This suitability map was then used to propose sustainable trail locations on the property. To assess the accuracy of the suitability model, the project team conducted a field survey of the property. The GPS sample points collected during the survey were uploaded into ArcGIS and the results were compared to the forest stand type, soil type, and slope data layers and suitability model result. Figure 6-11 shows the sample points taken during the field survey with the suitability layer.

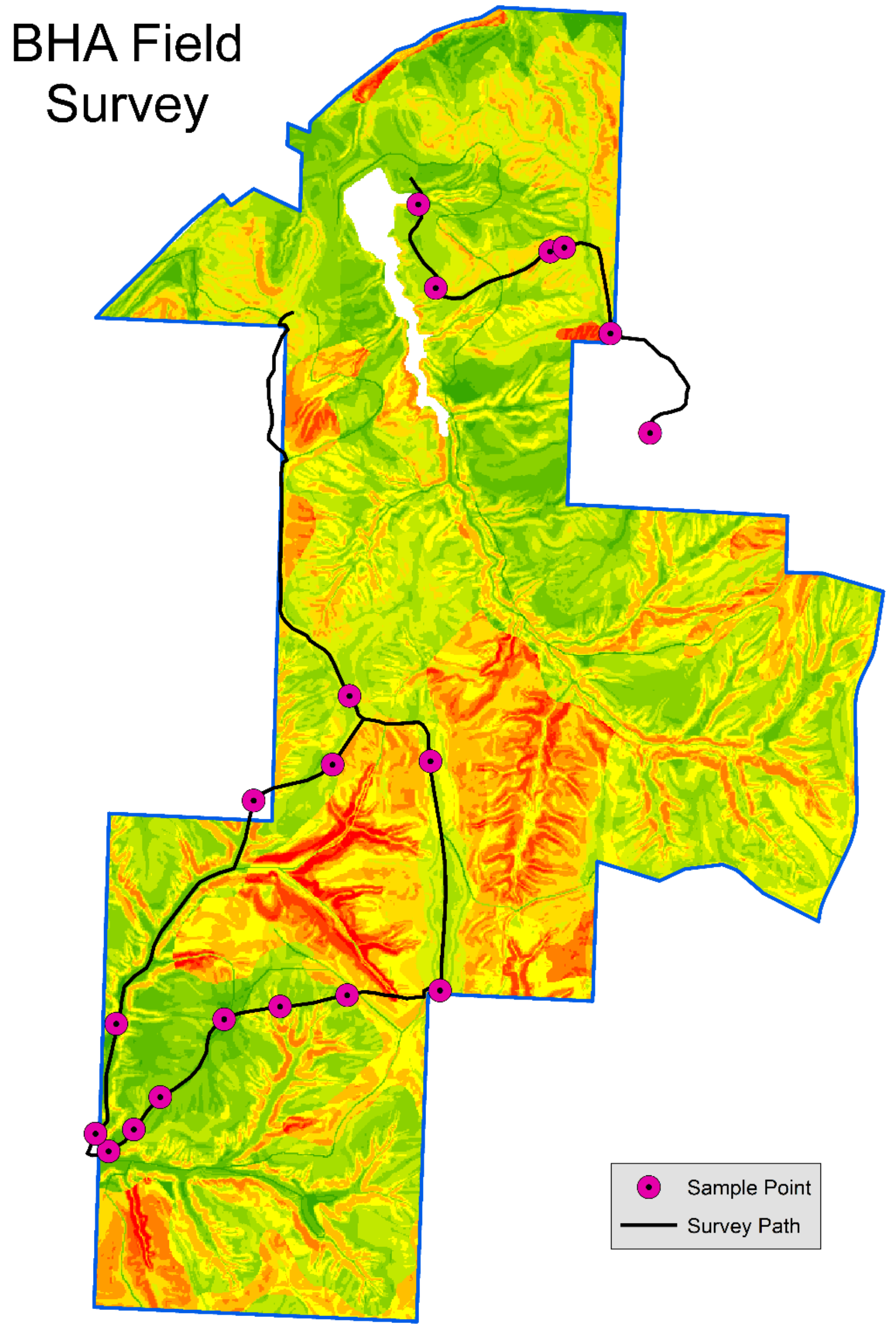

Figure 6-11: Suitability Map and sample points collected during the field survey.

Figure 6-12 illustrates the location of sample points, existing trails, and proposed trails.

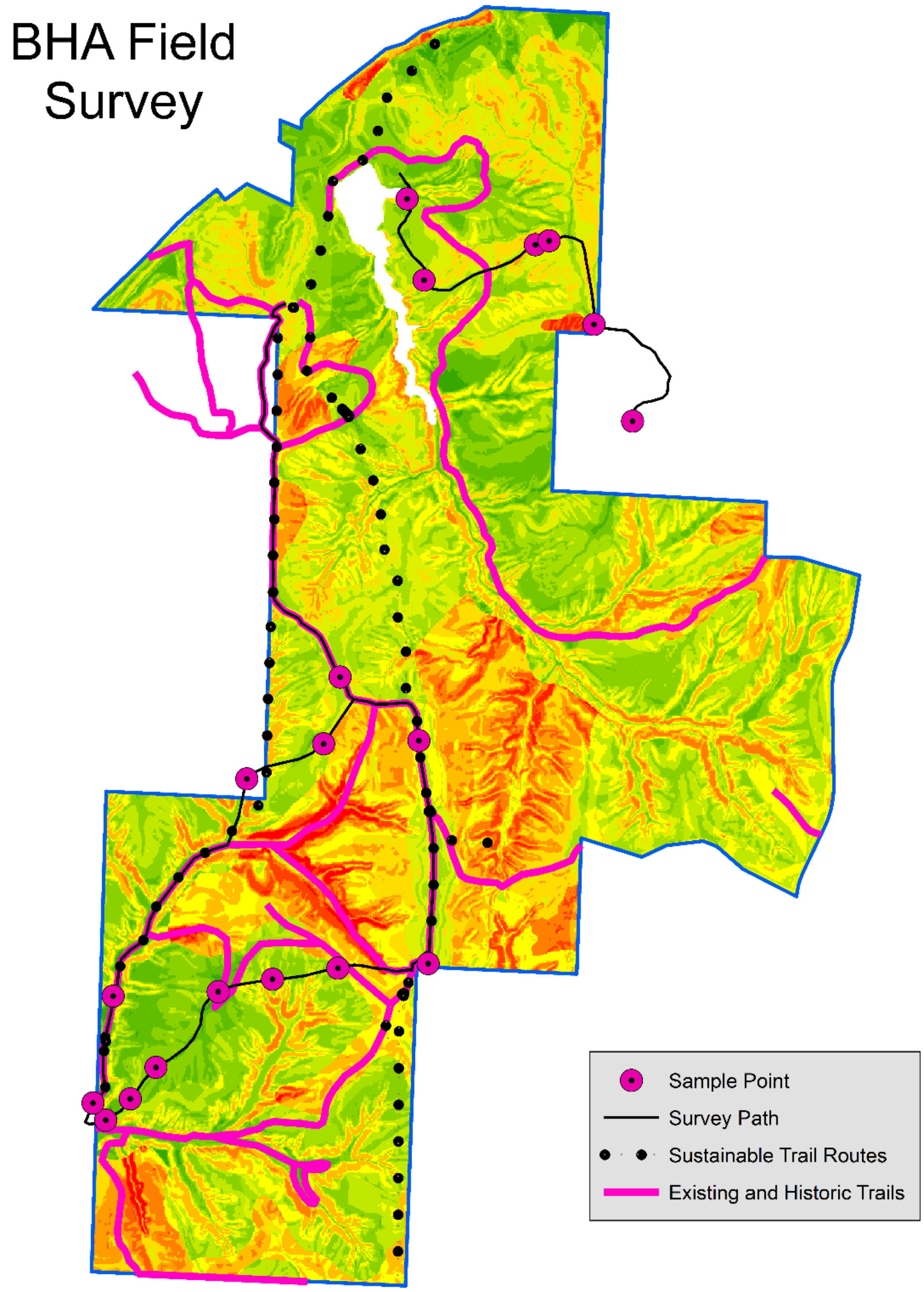

Figure 6-12: Survey results with existing and proposed trails.

When analyzing the field survey, the project team found that six of the 19 sample points collected fell either on or near the proposed trails produced by the suitability model. This was interesting for two reasons. First, the project team did not have the proposed trail locations on the GPS unit when conducting the survey and therefore did not know when the sample points were being recorded near or on a proposed trail. There was little bias in choosing the sample location as the samples were randomly chosen throughout the survey. Secondly, the location of the proposed trail in the north-west portion of the southern area of the property, which is near an existing trail, was considered acceptable since the area had a gentle slope and was previously a road. Therefore, the least cost path identifying an old road as a possible trail location was a reasonable recommendation.

Another finding from the survey was that three of the sample points were collected beyond the BHA property. While conducting the survey, the project team thought the survey would remain on the property, except when traveling on the neighboring BHA member's property to the west of the north-east portion of the property. Ms. Lindsey Barney is the Mills County District Forester for the Iowa Department of Natural Resources (IDNR) and she attended the field survey. Ms. Barney used a Garmin GPS and her knowledge of the property to maintain information on the survey team's location. There are two possible explanations for three of the sample points being collected off the property. One reason could be that the Garmin GPS did not locate the survey team in an accurate location or secondly, the Trimble Juno GPS Unit used by the project team did not collect the sample point in an accurate location. Either GPS unit could have recorded an incorrect location because the accuracy decreases when the GPS receiver is located in a dense forested area. In an open area, such as a prairie, the Garmin GPS records the location on average within 15 meters of the true location while the Trimble Juno Unit records on average within two to five meters of the true location (Garmin, 2014) (Trimble, 2014).

In addition, the project team calculated Kappa Index statistics for the results collected in the field and the data layers used in the suitability model: the forest stand types, soil types, and slope. The Kappa Index is a statistic method in "such a measure of "true" agreement" and "indicates the proportion of agreement beyond that expected by chance" (Sim & Wright, 2005, p. 258). In this project, the index represents the agreement between the data layers and the ground features collected in the field survey. The formula used to determine the index is shown below.

$$k = \frac{diagonal\ total - expected\ \#\ of\ agreements\ by\ chance}{grand\ total - expected\ \#\ of\ agreements\ by\ chance}$$

A resulting coefficient between 40 and 70 percent indicates a respectable agreement. If a sample point recorded a forest stand of Black Walnut and the forest stand data layer also indicated a Black Walnut forest type, a tally mark is placed in the corresponding cell. If the data layer was not a Black Walnut, a tally would be placed in that row and the column of the forest type from the data layer. The total represents the number of samples considered during the analysis while. The forest stand types had an index of 69 percent (see Table 6-1).

Table 6-1: Kappa index table for forest stand types.

		Forest Stand Data							
		Black Walnut	Bottomland Hardwoods	Central Hardwoods	Conifers	Oak-Hickory	Scrubby Oak	Prairie	**Total**
Field Survey	Black Walnut		1			1			**2**
	Bottomland Hardwoods								**0**
	Central Hardwoods			2					**2**
	Conifers				1				**1**
	Oak-Hickory					4			**4**
	Scrubby Oak		1				3		**4**
	Prairie						1	2	**3**
	Total	**0**	**2**	**2**	**1**	**5**	**4**	**2**	**16**

Table 6-2 shows the statistics of the forest stand types. The diagonal total represents the number of forest stand types that were identical from the field survey and the data layer. The probability indicates the chance that the forest stand is identical in both the field survey and data layer.

Table 6-2: Kappa index statistics for forest stand types.

Diagonal Total	**Expected # of agreements by chance**	**Kappa Index**
12	3	69.38%

The three sample points collected off the BHA property were excluded from the analysis. The Kappa Index for the forest stand type is 69 percent, indicating that the forest types in the data layer represent the actual conditions at an acceptable accuracy. The data layer contained accurate forest types because the data were collected in Spring 2014 by Ms. Barney. There were two foresters, Ms. Barney and the project manager, who were present during the survey and assisted in identifying the forest type at each sample point. Both foresters have the training to be considered qualified in the forestry field.

Each sample point also intended to contain the soil type, but since no one on the field survey team was a soil scientist, a soil type was only recorded for ten sample points. Those points contained the soil types suggested by Ms. Barney or by interpretation by the project team. Table 6-3 shows the Kappa Index Table for the soil type.

Table 6-3: Kappa index table for soil types.

		Soil Data						
		Hamburg	Ida	McPaul	Monona	Napier	Steinauer	**Total**
Field Survey	Hamburg							**0**
	Ida	4	2		2	1		**9**
	McPaul							**0**
	Monona							**0**
	Napier					1		**1**
	Steinauer							**0**
	Total	**4**	**2**	**0**	**2**	**2**	**0**	**10**

The statistics in Table 6-4 are for the soil type. The Kappa Index for the soil types was 12.5 percent.

Table 6-4: Kappa index statistics for soil types.

Diagonal Total	Expected # of agreements by chance	Kappa Index
3	2	12.5%

The Kappa Index percent is quite low for two reasons. First, the soil type was not recorded for each of the sample points and that could have resulted in a low Kappa Index. Secondly, the project team was not confident identifying soil types. Although Ms. Barney did provide her professional opinion, she was not present for the entire field survey. Identifying the soil type was inaccurate due to the project team's minimal experience identifying soil type and not having the necessary equipment, such as a soil auger, to more accurately identify soil type. The project team concluded during the review of the survey that since the soil type was not recorded at each sample point, the field survey did not provide sufficient understanding of soil types and a future field survey would require a soil scientist or the proper equipment to more accurately identify soil types. A more detailed discussion of this issue is provided in Chapter 7.

The final piece of information collected during the field survey was an approximation of slope. During the analysis, the project team concluded that the slope values collected in the field tended to be less than the slopes derived from the digital elevation model. Table 6-5 illustrates the Kappa Index Table for slope.

Table 6-5: Kappa index table for slope.

		Slope Data					
		0-4.9	5-14.9	15-24.9	25-34.9	>35	**Total**
Field Survey	0-4.9	3	4	1			**8**
	5-14.9		2	1	1		**4**
	15-24.9			2	1		**3**
	25-34.9				1		**1**
	>35						**0**
	Total	**3**	**6**	**4**	**3**	**0**	**16**

The statistics in Table 6-6 are for slope. The Kappa Index for slope was 34 percent, which is not within the acceptable range, but the index was still adequate to be considered since a Kappa Index tends to underestimate the agreement between the two raters (Nelson, Edwards, Gamishev, & Kozarev, 2007).

Table 6-6: Kappa index statistics for slope.

Diagonal Total	Expected # of agreements by chance	Kappa Index
8	4	33.68%

Each sample point contained a slope value that was included in the Kappa Index analysis except for the three points recorded off the BHA property. Since a digital elevation model derived the slope values used in the suitability model, these data were considered more accurate than the field survey results. One reason the field survey results were not as accurate as the DEM-based slope data values are because the project team collected the slope by visual estimates, instead of using a clinometer. The visual estimates led the project team to underestimate the slope. Similar to the future work for soil type data collected, the slope measurements could be more accurate by using a clinometer. A discussion of this is also given in Chapter 7.

The project team used the Kappa Index for each environmental factor to determine how accurate the suitability model was at identifying suitable and non-suitable areas for trail construction. The sample points were located in areas that had a value between one and three, which indicated that the area was either the most suitable, suitable, or acceptable for trail construction. By comparing the survey results to the suitability model, the project team concluded that the sample points, which indicated suitable areas for trail construction, were sufficiently accurate.

6.3 Summary

Chapter 6 highlighted the final results and analysis of each deliverable. Each printed map provided a unique perspective of the BHA property and enhanced the members' knowledge of the area. These maps will also be used for future land management decisions and for future generations to learn about the property. The 3D terrain model provided a unique perspective and additional information of the property. Conducting a field survey allowed the project team to assess the suitability model results and conclude that the model was accurate in locating suitable and non-suitable areas for trail construction.

Chapter 7 – Conclusions and Future Work

The natural environment is constantly changing through natural processes which are accelerated by human actions. Using a geographic information systems (GIS) helps managers and citizens to better understand the changes occurring. This project allowed the Bartlett Hills Association (BHA) to use GIS to enhance its knowledge of the property and use the outcomes of the project to make informed land management decisions. A Woodland Stewardship Plan provided to the BHA by the Iowa Department of Natural Resources (IDNR) suggests land management prescriptions for the property. The BHA members' concerns regarding the current conditions of the property encouraged them to take the actions necessary to bring the ecosystems back to a sustainable state for future generations. The project team used GIS to produce four deliverables to assist the BHA in its search for more information about the property. These products will also be utilized when developing future land management decisions.

The project team created nine maps, each highlighting a different characteristic of the property, which the BHA members can display in the cabin on the property. These provide a method to teach the future BHA members about the property. In addition, the IDNR can utilize these maps. Production of a 3D terrain model provided a different perspective of the property.

Since the BHA members enjoy walking and exploring the property, the idea was developed to create a suitability model to recommend new recreational trails. Using a weighted overlay analysis, the project team identified areas that were suitable and non-suitable for trail construction. The choice of these areas considered three environmental factors: soil type, forest stand type, and slope. From this analysis, the least cost path tool was used to calculate proposed trail locations. The last deliverable, the BHA Interactive Web Map, provided the BHA members located across the United States with an accessible tool to learn about the property.

Chapter 3 discussed the functional and non-functional requirements of the project. Each requirement was fulfilled by the four deliverables. The suitability model accurately identified suitable areas for trail construction, and proposed at least five miles of new trails. In addition, the model ran with zero errors and finished within five minutes of execution. One map showed the change in elevation and another showed the change that occurred between 1930 and 2013. The interactive web map showed the different trails on the property, displayed the trail characteristics in a pop-up window, and allowed the layers to be edited only by BHA members. The pop-up window also displayed the trail characteristics within two seconds of clicking a trail segment. The Source Geodatabase contained only the original data needed for the project which fulfilled the last requirement.

Section 7.1 discusses four recommendations for future work and Section 7.2 provides a conclusion of the project.

7.1 Future Work

Although this project provided additional information about the BHA property, this project is only the beginning of using GIS as a tool for learning and land management.

The BHA can continue to work with the IDNR to manage the property. Future projects can support the public lands in the state by providing the IDNR with an opportunity to learn how certain land management prescriptions affect the environment by using the prescriptions on the BHA property first. There are four additional avenues the BHA can use to enhance its knowledge.

The first recommendation for future work is to conduct a more thorough field survey of the property. The field survey in this project did not involve accurate data collection when identifying the soil type and slope. Future surveys should include a professional with soil identification experience, a credible book source for identifying soil, a soil auger, and a clinometer. Having the appropriate sample collection equipment will minimize the risk of incorrectly identifying a soil type or slope. In addition, more sample points should be used to assess the model's accuracy. The field survey conducted by the project team consisted of 19 sample points over 800 acres, which cannot adequately describe the environmental conditions of the property. To better represent the property, more sample points are needed to record the soil type and slope. With the completion of an improved survey, the project team can propose new trail segments to connect existing trails in order to create loop trails. In addition, hikers can choose their desired route and length of trail if there are more trails on the property. Conducting a larger field survey and proposing connecting trails will enhance the recreational opportunities and provide a better understanding of the accuracy of the project's suitability model.

Another recommendation is to add additional environmental factors to the suitability model to better incorporate the interactions which contribute to soil erosion. Rainfall, level of trail use, and forest management prescriptions should be considered. The amount, time of year, and location of rainfall all have an impact on soil erosion and the severity to which it occurs. The amount of use a trail receives can contribute to soil susceptibility as hikers and horses can impact a trail by compaction. Forest management prescriptions can also affect in trail placement. Part of the Woodland Stewardship Plan for the BHA property recommended using prescribed fire as a tool to control the understory and invasive species. Trails can contribute to the implementation of this recommendation as trails can be used as fire breaks to control fire spread. Trails can also be placed in areas where tree density will be decreased by forest thinning. Placing trails near areas undergoing forest management will not only allow for easy access for managers, but also allow BHA members to walk to these areas and see how these management decisions are positively impacting the environment.

A third recommendation would be to use GIS to understand how the lake is affecting the property and propose steps to be taken to decrease its environmental impact. It is know that the lake loses water every year, but the amount and the impact on the property are unknown. By collecting data about the lake and using a GIS, the BHA can gain a better understanding of how the lake was built, the impact it is has on the area, and what they can do to rebuild a sustainable lake.

The last recommendation is to add additional layers into the interactive web map to keep the BHA members updated on the land management prescriptions for the property. The project team proposes creating a polygon feature class that includes areas where management prescriptions have previously been implemented, another feature class identifying areas currently under management prescription, and a third feature class displaying future prescriptions. This would be a great tool for the BHA members, as not all members are able to visit the property to observe the management prescriptions or examine the changes to the landscape. Members want to be aware of what is happening on the property regardless of their location. This interactive web map will allow the members to stay updated on the decisions for the property and monitor how those decisions impact the environment.

7.2 Conclusion

This project provided an introduction to GIS and how it can be used to increase ecosystem health by implementing GIS into land management. GIS provides a unique technique for gathering new information and communicating this information in different and informative ways. The project team believes that the BHA will continue to use GIS to better the ecosystems on the property and provide learning opportunities for future members.

Works Cited

Chiou, C.-R., Tsai, W.-L., & Leung, Y.-F. (2010). A GIS-dynamic sementation approach to planning travel routes on forest trail networks in Central Taiwan. *Landscape and Urban Planning*, 221-228.

Garmin. (2014). Retrieved from http://www8.garmin.com/aboutGPS/

Nagarajan, M., & Singh, S. (2009). Assessment of Groundwater Potential Zones using GIS Techniques. *J. Indian Soc. Remote Sens.*, 69-77.

Nelson, K. P., Edwards, D., Gamishev, T., & Kozarev, R. (2007). On Population-based Measures of Agreement. 1-33.

Sim, J., & Wright, C. C. (2005). The Kappa Statistic in Reliability Studies: Use, Interpretation, and Sample Size Requirements. *Physical Therapy*, 257-268.

Trimble. (2014). Retrieved from http://www.trimble.com/mappingGIS/junoS.aspx

Umphress, K. (2011). More than maintenance: Four keys to sustainability: resources, economics, experiences, and politics. *American Trails*, 38.

United States Forest Service. (2008, October 18). *Forest Service Handbook National Headquarters (WO) Washington, D.C.* Retrieved from http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5403600.pdf

Urban, D. L. (2000). Using model analysis to design monitoring programs for landscape management and impact assessment. *Ecological Applications*, 1820-1832.