2.0 INTRODUCTION

The Bonne Femme Watershed covers approximately 93 square miles in southern Boone County, Missouri. The watershed contains several significant features including former prairie, Ozark karst, and wooded floodplain. Extensive areas of publicly owned land provide recreational opportunities for people to enjoy this special landscape. One unusual feature of the watershed is that it contains two major surface water drainage basins (Bonne Femme and Little Bonne Femme) that are interconnected via subsurface flow through the Devil's Icebox Cave Branch. Under most flow conditions, all of the water from the upper part of Bonne Femme flows through this cave system and into the other drainage basin.

Undisturbed presettlement natural communities in the area worked in unison to manage precipitation and provide excellent water quality conditions. Following European settlement in the early 1800s, much of the watershed was altered for agricultural purposes. This resulted in the clearing of woodlands and prairies and, eventually, the establishment of towns and cities. These changes resulting in degraded stream conditions including channel instability from changes in hydrology and non-point source pollution as a result of poor agricultural land management practices and inadequate treatment of urban runoff. Because surface water infiltrates into many of the cave systems, it has a direct impact on the water quality and ecological condition of this special resource.

Local awareness by concerned citizens and governmental agencies resulted in grant funding for watershed planning. In 2003, Boone County was awarded a four-year grant titled *Land Use Planning and Water Quality Restoration in Bonne Femme Creek Watershed*, from the Environmental Protection Agency through the Missouri Department of Natural Resources. The grant is administered through the Boone County Planning and Building Inspection Department, and the name of the grant-funded work is the Bonne Femme Watershed Project. More information on the project can be found at www.CaveWatershed.org.

In 2004, Applied Ecological Services, Inc. (AES) was retained by the Boone County Planning and Building Inspection Department to complete an analysis of the Bonne Femme Watershed. The study was performed to provide GIS information from a variety of sources that could be used to communicate information with stakeholders. In addition, the GIS data were used to develop sub-watershed models that will be used in the development of a watershed-based land management plan.

2.1 Bonne Femme Watershed Project Committees

The Project's committees (Steering, Policy, and Stakeholder) are discussed in the order they were created.

Steering Committee

In 2001, directors of both the Missouri Department of Natural Resources and the Missouri Department of Conservation appointed a group of people to address stream protection in the area. This group, the Southern Boone County Karst Team, decided to pursue a Clean Water Act, Section 319 grant in order to protect the streams from nonpoint source pollution. After being awarded the grant, this team became the Project's Steering Committee.

The Steering Committee oversees the entire workings of the project and its staff. They represent local, state, and federal governmental agencies that provide scientific, technical, and administrative assistance to help coordinate the other two committees' work. The Steering Committee is responsible for meeting the terms of the grant which includes facilitating the development of the land-use plan, educating the public, promoting the project to the local media, and administering the cost-share funds.

Policy Committee

Realizing that there was a need for strong input and support from local political decision-makers, the Steering Committee identified agencies that affect the timing and location of development in the Watershed. These agencies were invited to participate through membership on a Policy Committee, and each agency designated a representative.

The Policy Committee plays several key functions throughout the life of the project. They promote the project and act as liaisons with their agencies. Since the watershed includes many different jurisdictions, interagency coordination is critical to ensure a productive planning process. Another purpose of this group is to communicate with each other at their regular meetings regarding actions or planned actions that could impact the greater Bonne Femme Watershed. They also provide input on the watershed plan and related policy and ordinances. Finally, they are a key component in acquiring broader community support and for legally accepting and implementing the final plan.

Stakeholder Committee

To insure success in the planning process, the Steering Committee formed a Stakeholder Committee to include all of the various interests of the community in crafting the plan. The Steering Committee decided that the Policy Committee was best-suited to appoint members of the Stakeholder Committee, since they are in the best position to understand the various interests of their constituencies and select appropriate representatives for those interests.

The Stakeholder Committee gives a balanced, diverse perspective and provides community input to the planning process. This breadth of representation on the committee is essential to creating a successful plan that the entire community can support. They are also important for making sure the plan gets implemented by garnering community support and speaking at public hearings.

2.2 Scope and Analysis Approach

The scope of services as described in Boone County's Request for Proposals (RFP) emphasized the creation of a GIS database to be used primarily for communicating information to stakeholders, as well as the development of a watershed sensitivity analysis to be used in developing a watershed-based land management plan. AES agreed to complete the following work in addition to work described in the RFP:

- Define and quantify the ecological carrying capacity of the project area using the subwatershed sensitivity model;
- Provide an interactive model in which trained users will be able to model how proposed land use changes would affect landscape function;
- Provide strategies for balancing the needs of humans with the maintenance of basic ecosystem functions;
- Produce a GIS database complete with base data as well as watershed and stream assessment layers;
- Provide IKONOS Pro imagery data for the Bonne Femme Watershed, Boone County, Missouri;
  - 1-meter resolution, orthorectified to Missouri State Plane Coordinate System, Zone 4426, Units Feet, and referenced to NAD 83
  - 4-band multispectral data (true color and color infrared imagery can be produced)
  - Tonally balanced and mosaiced
  - Space Imaging AutoWarp will be used to rectify IKONOS imagery to the County orthobase
- Use impervious surface map of Bonne Femme Watershed based on 1-meter IKONOS imagery;
- Modify the 1992 30-meter land cover data with the 2004 impervious surface data and use the "updated" layer to drive watershed models;
- Use a variety of watershed metrics to assess the sensitivity of subwatersheds to projected land use changes;
- Intertwine the skills of high-level GIS analysts, ecologists and engineers to create models and summaries that provide useful information at the planning level.

The project team approached this work as follows: AES staff attended a **Kickoff Meeting** with watershed partners to clarify analysis goals and objectives, receive available data, and learn of additional data sources. **Existing Data** were gathered, synthesized and summarized as appropriate for the watershed work. New data layers were created as necessary. Existing and new data layers were synthesized into a **GIS Database**.

AES completed a **Watershed Vulnerability Assessment** that included three main components:

1. AES completed a **Stream Sensitivity Analysis** based on existing and projected impervious cover, natural resource criteria, and some field verification of natural resource data.
2. AES completed a **Stream Carrying Capacity Analysis** based on existing and predicted flows relative to the measured cross sectional area of receiving streams.
3. AES completed an **Landscape Function Model** in an attempt to capture landscape functions not adequately represented in the Stream Sensitivity Analysis or Stream Carrying Capacity Analysis.

Using results generated from the Watershed Vulnerability Assessment, AES developed a **Best Management Practices (BMP) Model** to classify the entire watershed into regions that would receive similar BMP treatments. AES then provided **Policy Recommendations** on how proposed BMPs could be incorporated into regulations.

Work described above was summarized in this **Final Report**. Instruction on how to work with the interactive models AES developed will occur during a **Technical Assistance** phase of the work that has yet to be completed.

2.3 Watershed Setting

Study Area

Bonne Femme Watershed is comprised of two major subwatersheds, the Bonne Femme and Little Bonne Femme (Figure 2.3-A). They are both included in this project even though their surface streams do not converge. As previously mentioned, all low to normal level flows from the upper portion of Bonne Femme Creek flow underground through the Devil's Icebox Cave Branch to the Little Bonne Femme. In higher flow conditions, water is split between the two subwatersheds, with some surface flow remaining in the Bonne Femme subwatershed.

These watersheds, which cover about 93 square miles, comprise approximately 15% of Boone County. The Bonne Femme Watershed was shaped through geological processes, with oceans and glaciers forming its landscape. Beginning approximately 250 million years ago, a shallow ocean covered most of the Midwest, resulting in extensive limestone deposits throughout the region. More recently—about one million years ago—glaciers progressed from Canada south through Missouri, stopping in southern Boone County. The glaciers sculpted the land and deposited till material as they retreated. This till material was later covered by soil that was deposited by the wind. This wind-borne soil—called loess—then became covered by great expanses of prairie.

Because of the land's natural contours, the watershed drains to the southwest. The highest point in the southwestern portion of the watershed is approximately 930 feet above mean sea level, while the lowest point in the southwestern portion of the watershed is approximately 554 feet above mean sea level. This landscape was once dominated by prairies resting atop the glacial till in the eastern portion of the watershed; karst features, including caves, sinkholes, springs, and losing streams in the central and southern portions; and big-river floodplain and loess-covered hills along the Missouri River.

Geology

One of the most distinctive characteristics of the Bonne Femme Watershed is its karst topography. Karst topography describes terrain resting on a layer of soluble limestones (calcium carbonate) and dolomites (magnesium calcium carbonate.) Karst features are the result of dissolution, a process that starts when rainwater picks up carbon dioxide from the air and from dead plant debris within the soil. The carbon dioxide combines with water to form a weak solution of carbonic acid. This solution percolates through cracks in the bedrock, dissolving the limestone and dolemite in the process. The bedrock becomes saturated with water at some level, and dissolving continues as the water moves sideways along bedding planes (horizontal cracks between rock layers) and joints (or fractures) in the rock. These conduits enlarge over time and move the water via a combination of gravity and hydraulic pressure, further enlarging the conduits through a combination of solution and abrasion of water on the surrounding rock.

Several features affecting the process include local climate and temperature range, and the amount of vegetation and rainfall in a region. The karst of the Missouri Ozarks is characterized by well-eroded rolling hills, deep hollows, springs, caves, sinkholes, losing streams, natural bridges, and tunnels. Eventually, much of this water under pressure reaches the surface of the land as a spring. A spring may emerge high on a cliff, at the base of one, or may be forced upward from below the level of the surrounding surface streams. This all depends on the nature of the surrounding rock and the altitude of the groundwater level with respect to the base level of the controlling stream in a drainage area. Often in Missouri, springs have little relationship to surface drainage, because so much of water movement is underground. In some areas of the Ozarks, more than 70% of all water goes underground via karst processes.

Erosion and dissolution continue underground, and eventually a cave hollows enough for the roof to thin, and the cave collapses. Such cave collapse may actually unroof the cave if it is near enough to the surface, or simply form a slump in the level of the land. In either example, a sink forms. Natural bridges and tunnels can form as resistant remnants of a cave collapse. They also can form independently if a block of bedrock becomes cut off from the main land mass and is hollowed out by wind, ice wedging, and rain.

Many karst areas have poor soil that does not retain water easily, allowing it to go directly underground. Sinkholes act to funnel runoff directly into cave systems, thereby bypassing any pollutant-removing capacity of soil.

Climate

Central Missouri experiences all four seasons. It is located where warm, moist air from the Gulf of Mexico and colder air masses from Canada often converge. The frontal zones formed by these air masses produce a variety of weather conditions.

Winters months are cold but not severe. According to records documented since 1871, the temperature usually only drops below zero a few days per year. The average daily high during the winter months is around 35° F, while average low is 20° F. The record low temperature of -25° F was recorded by the National Weather Service on February 13, 1905. Average snowfall is generally less than 25 inches.

Summers are warm, with daily highs averaging about 85° F. Average daily lows in the summer are around 60° F. The highest recorded temperature, around 113° F, occurred on July 14, 1954. The hottest summer occurred during 1936 when the average high temperature was around 95° F.

Recorded precipitation data for Columbia indicates an average of about 40 inches of precipitation per year, although there is significant variation from year to year. The months of April to June are normally the wettest, with a total precipitation of about 13 inches. The three winter months are the driest with only 6 inches of combined precipitation.

Natural Communities

A natural community is made up of all living things in a particular ecosystem, but it is usually named for its dominant vegetation or characteristic type. Prior to European settlement in the early 1800s, the Bonne Femme Watershed exhibited a mix of natural communities including prairies, savannas, woodlands, karst, and floodplains. Prairies, savannas, and wooded stream corridors formed over thick deposits of loess in the eastern portion of the watershed following the retreat of the glaciers. Karst and floodplains are located in the central, western, and southern portions of the watershed. These areas are located just outside of where the glaciers stopped and receded. Much of the karst topography is located in protected, publicly-owned lands; however, much of the water that flows through the caves originates outside of these public lands.

Early settlement resulted in many forests and prairies being cleared in the northern, eastern, and southern portions of the watershed in an attempt to establish farming and livestock operations. More recent residential settlement in the towns of Columbia and Ashland have resulted in the conversion of open agricultural fields into areas dominated by houses, streets, and buildings. This development increases the amount of impervious surface and has adverse effects on the ecological conditions of the landscape since there are few BMPs to help protect streams. Today, remnants of natural communities still exist, but most are highly fragmented.

2.4 Prior Studies and Plans

This section is meant to highlight the most applicable and comparable documentation found for the Bonne Femme Watershed. Prior studies within the watershed are generally focused upon specific stream reaches rather than the overall watershed assessment approach taken in this report. Significant research and monitoring have been conducted on the Devils Icebox and Hunters Cave recharge areas (Lerch et al. 2001). This information reinforces the complexity and sensitivity of hydrology within a karst terrain, identifying land management as a significant contributor to degraded water quality. Pavlowsky (2003) focused upon Gans and Clear Creeks, assessing channel stability and water quality for the Philips Property. Conclusions point to historical land clearing and row-cropping as causes for disturbed soils conditions, increased runoff rates, and erosion problems. Pavlowsky also identifies water quality effects on Gans Creek via nutrient loading, as well as increased flows in Clear Creek due to increased impervious cover.

The most comparable research to this study is an unpublished document created by Davis et. al. of the University of Missouri, Columbia. This group looked at the effects of impervious cover on stream macroinvertebrate biodiversity, identifying impervious cover as a strong predictor of stream biological health. Other landscape variables such as watershed forest cover, watershed riparian forest cover and local riparian forest cover were compared, but less statistical support was found for these correlations. The research performed by Davis et. al overlaps with two subwatersheds of this study, the Clear Creek and Gans Creek subwatersheds. Comparable impervious cover percentages were tabulated for the Clear Creek measuring 11% and the Gans Creek 2%. In comparison, AES' calculations were 14% for Clear and 6% for Gans, showing a difference of 3-4 percent. The difference in impervious measures could be attributed to increased urbanization as well as differences in measuring methods for imperviousness.

A previous project, the Bonne Femme Watershed Partnership, was formed by residents of the watershed that have an interest in identifying local water quality problems and developing community-based strategies to reduce non-point source water pollution. More can be learned about this group and their interests at:
http://www.geog.missouri.edu/bonnefemme/

2.5 Using this Document

Information provided in this document is prepared so that it can be used as a tool by land managers, planners, and decision makers to minimize non-source point pollution and restore or protect natural resources. The following summarize what the reader can expect to find in each major section of the report.

Chapter 2. Introduction

The INTRODUCTION includes a summary of the Bonne Femme Committees, Scope and Project Approach, Watershed Setting, and Prior Studies and Plans. The Scope and Project Approach summarizes the emergence and development of this study, while the Watershed Setting summaries provide a general description of the watershed location, geologic features, and other base information. Prior Studies describe work we reviewed during the development of the analysis.

Chapter 3. Goals and Objectives

This section describes the goals, objectives, issues and opportunities associated with the watershed and watershed analysis.

Chapter 4. GIS Data Acquisition and Inventory

This section describes the source and creation of existing and new data generated as part of this project.

Chapter 5. Watershed Characteristic Assessment

This section includes a summary of the existing conditions in the watershed as well as new data created as part of this study as necessary to complete analyses in later sections.

Chapter 6. Stream Sensitivity Analysis Model

The Stream Sensitivity Analysis Model uses existing and future impervious cover data to assess the vulnerability of streams within each of the subwatersheds. Natural resource data and some field confirmation were used to refine the analyses.

Chapter 7. Stream Carrying Capacity Model

The cross sectional area and substrate of major streams within each subwatershed was measured in the field. Existing and predicted flows were measured at the subwatershed level to assess the ability of receiving streams to convey runoff without degrading.

Chapter 8. Landscape Function Model

AES completed a Landscape Function Model in an attempt to capture landscape functions not adequately represented in the Stream Sensitivity Analysis or Stream Carrying Capacity Analysis.

Chapter 9. Implications of Watershed Carrying Capacity Analyses

AES reviewed the results of the Stream Sensitivity Analysis, Stream Carrying Capacity, And Landscape Function models to come up with a comprehensive, multifaceted assessment of the watershed and the relative vulnerability of subwatersheds to changes in land use.

Chapter 10. Best Management Practices

AES developed a Best Management Practices Model that classifies the watershed into zones that would receive similar best management practices. Each specific practice is also listed and assessed as to its efficacy in addressing specific environmental stressors.

Chapter 11. Policy Recommendations

This section describes how proposed best management practices could be incorporated into policies that would protect resources within the watershed.