5.0 WATERSHED CHARACTERISTIC ASSESSMENT

5.1 Topography

The topographical contours of the land define the boundaries of the Bonne Femme Watershed, which encompasses approximately 93 square miles in southern Boone County, Missouri. A watershed is defined as the area of land drained by a river or stream system or body of water. Other common names given to watersheds include drainage basins or catchment areas. As simple as the definition sounds, a watershed is actually a set of complex interactions between soil, climate, water, vegetation, and animals. This watershed is particularly complicated by the fact that, most of the time, all of the flow in the upper portion of Bonne Femme flows underground through the Devil's Icebox Cave Branch to the Little Bonne Femme. In some of today's developed watersheds, other elements such as sewage, agricultural drainage, impervious surfaces, and erosion can be detriments to the overall health of a watershed.

The Bonne Femme Watershed was shaped through huge geological processes, with ancient oceans and more recent 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, depositing till material as they retreated. This till material was later covered by wind-borne soil, or loess, that 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 watershed, located in its southern portion, is approximately 930 feet above mean sea level, while the lowest point in of the watershed, located in its southwestern portion, is approximately 554 feet above mean sea level (Figure 5.1-A: Topographical Map). This reflects a 376-foot change in elevation across 0.3 miles of the watershed.

Topographic data were used in the watershed analysis process to develop Hydrologic & Hydraulic (H&H) models, floodplain maps, water quality models, flood mitigation models, subwatershed management units (SMUs), and digital elevation models (DEMs). Ultimately, topography is an essential feature in the watershed planning process.

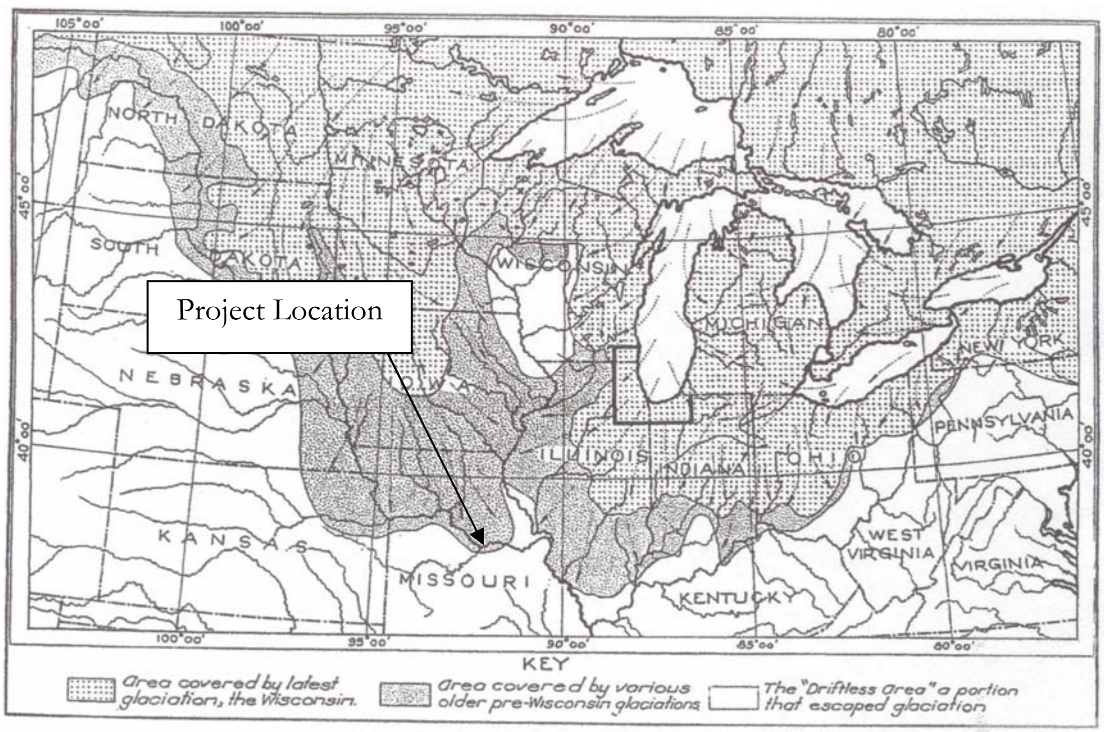
Figure 5.1-A. Topographical Map

5.2 GEOLOGY

Approximately 250 million years ago, the study area was completely submerged in a shallow ocean that was teaming with life. Over millions of years, the skeletal remains of clams and other invertebrates formed a thick layer of limestone bedrock. Approximately 100 million years ago, the land rose above the ocean as a primarily flat landscape in which prairies formed. About 50 million years ago, southern Missouri began to change as streams carved the landscape into the rolling hills created the Ozarks

During the glacial period, about one million years ago, the two-mile thick Kansan Glacier entered Missouri from the north and pushed its way into southern Boone County and the northern edge of the Ozarks before halting. The melting glaciers left a flattened landscape laden with till material, while areas just outside of the glaciated areas retained the hilly, Ozark-like landscape. Each successive glacier following the Kansan fell short of its predecessor. During the most recent glacial period known as the Pleistocene Era or "Ice Age" that began approximately 70,000 years ago and ended 10-14,000 years ago, the Wisconsin Glacier never reached Missouri (Figure 5.2-A Glacial Map).

The retreat of the Kansan Glacier left several layers of soil and rock. The top layer is composed of about five feet of moderately permeable wind-deposited loess. This is settled over a layer of glacial till, which is composed mostly of low-permeability sandy and silty clay. A five-foot layer of residuum (soil formed by weathering of bedrock) resides below the glacial till. And finally, the residuum lies on a thick limestone layer. It took thousands of years, but the glacier-scoured northern portion of Missouri became vegetated with lush prairies and wooded streams.



Source: The Physiography of the Region of Chicago (Fryxell 1927)

Figure 5.2-A. Glacial map of the central United States.

Karst Geology

The Ozark karst topography is a distinctive feature found in Missouri and in the study watershed. A few of the karst features found within the watershed include caves, springs, losing and sinking streams, swallets and sinkholes. These features first began to form about 50 million years ago when the land rose from the shallow sea. Karst features form when rainwater combines with carbon dioxide to form carbonic acid. The carbonic acid leaches through cracks in the limestone bedrock, dissolving the limestone in the process. Over long periods of time, chambers and caves form in the limestone layer. Sometimes the chambers and caves collapse, creating a bowl shaped feature called a sinkhole. When sinkholes are found in a streambed, they are referred to as swallets, which funnel water into the underground karst network via a distinct point forming what is know as a sinking stream. Similarly, sinking and losing stream flows may often resurface as springs in other locations.

The Bonne Femme Watershed contains significant karst topography south of the City of Columbia in an area called the Pierpont Sinkhole Plain (Figure 5.2-B. Karst Topography). The most obvious or exposed karst areas exist where the 350-millon year old Mississippian Period Burlington/Keokuk Limestone within the Kinderhookian Series meets with the limestone of the Osagean Series (Figure 5.2-C. Geologic Map). In this region, several karst features can be found, including losing streams, sinkholes, caves, and swallets (places where water enters the ground in concentrated flows, as through a tube) (Figure 5.2-B Karst Topography). While karst topography is not limited to the following two areas, significant concentrations of exposed karst features are present in and near Rock Bridge Memorial State Park and Three Creeks Conservation Area (Figure 5.2-D. Conservation Lands).

5.3 Hydrology

Within a karst terrain, hydrology becomes complex because of losing and gaining sections of streams. Rough estimates show approximately 33 stream segments composing approximately 23 miles of losing streams (89 miles of gaining stream) within the watershed (Table 5.3-i and 5.3-ii). There are two main recharge areas tied to these losing and gaining sections of stream: 1) The Devil's Ice Box recharge (8,394 Acres of drainage) and 2) Hunter's Cave recharge (8,228 Acres of drainage) (Figure 5.3-A Hydrology). The Bonne Femme watershed is divided by two major drainage areas, when delineated at the 14-Digit Hydrologic Unit scale. A very special situation occurs within the Devil's Ice Box Recharge area where, under normal conditions, all flow of Bonne Femme Creek drains below the major surface watershed divide, into Devil's Icebox Cave Branch, and eventually into Gans Creek. As flows in the Bonne Femme increase to high water levels, the flow network changes significantly as water has been found to flow to both the Devil's Icebox Cave Branch and lower in the Bonne Femme Creek.

Note that for the purpose of the models, both Devil's Icebox Cave Branch recharge area and Upper Bonne Femme subwatershed are both included, even though they overlap somewhat. This is because they can both have water flowing through them. Although Hunter's Cave is also fed by a losing stream (Bass Creek), it does not have inter-watershed transfer (i.e. its recharge area and that of Bass Creek are essentially the same, with the exception of two small tributaries of Turkey Creek).

Table 5.3-i. Total stream segments and lengths (Miles) according to stream channel creation. Analysis is based upon a 30 meter DEM. Note: This is modeled stream segment line which is representative of surface flow only. * Pierpont or Devil's Icebox Cave Stream is approximately 4 miles (including its tributary length).

Subwatershed	Stream Count	Sum Length	Ave Sinuosity
Bass Creek	20	15.2	0.16
Bass/Hunters Confluence	2	0.9	0.33
Bonne Femme Lower I	9	6.5	0.15
Bonne Femme Lower II	4	0.4	0.19
Bonne Femme Middle	10	6.8	0.21
Clear Creek	8	5.3	0.13
Fox Hollow Branch	11	6.6	0.10
Gans Creek	12	8.3	0.16
Gans Creek North	8	4.7	0.12
Gans Creek South	1	3.7	0.20
Hunters Cave	2	0.4	0.14
Lower Little Bonne Femme	18	13.6	0.10
Middle Little Bonne Femme	6	1.8	0.15
Missouri River Tributary	1	0.5	0.36
North Branch Little Bonne Femme	6	4.0	0.16
Pierpont*	2	2.3	0.14
Smith Creek	8	8.0	0.18
South Branch Little Bonne Femme	3	2.8	0.15
Turkey Creek	14	9.9	0.18
Turkey/Bass Confluence	4	1.3	0.39
Upper Bonne Femme	11	11.2	0.12
Upper Bonne Femme Lower	2	2.8	0.36
Upper Little Bonne Femme	5	2.0	0.18
TOTAL	**167**	**118.9**	

Bonne Femme study area is divided in half east to west by two main sub-basins. To the north is the Little Bonne Femme, which is subdivided into 11 subwatersheds; and to the south is the Bonne Femme watershed which is subdivided into 12 additional subwatersheds. In total there are 23 subwatersheds, ranging in size from 280 to 7760 Acres (Figure 5.3-A Hydrology). The subwatershed delineation process required two steps in which the first step delineated boundaries simply based upon topography and surface flow. This was a computer automated process that utilized a digital elevation model (DEM) and ArcView's ArcHydro extension. The second step required the addition of cave recharge areas and an understanding of subsurface flow characteristics. By overlaying the subwatershed boundaries generated by the DEM with the recharge boundaries wherever a recharge boundary existed without a subwatershed boundary, an additional subwatershed divide was added.

Both the Bonne Femme and Little Bonne Femme flow from east to west in a dendritic alignment into the Missouri River. Where Gans Creek meets Clear Creek, the Little Bonne Femme begins and flows south toward the Mayhan Branch. The Little Bonne Femme enters the Missouri River about a half-mile south of this confluence. To the south, Bonne Femme meets with the Fox Hollow Branch and then flows into the Missouri River.

Mapped streamlines show that the Bonne Femme Watershed has approximately 167 stream segments, making up about 119 miles of stream. Sinuosity values range from 0.39-0.10 with the highest values being in the Turkey/Bass Confluence subwatershed and the lowest values found in the Fox Hollow and Lower Little Bonne Femme. Sinuosity evaluates the meandering frequency or bends in a stream. A stream with a high degree of meandering provides a variety of habitats for aquatic organisms. Straight streams are characterized by a more "monotonous habitat" and are more prone to flooding (Lazorchak et al, 1998). An overly high degree of sinuosity can be an indicator of a disturbed stream as meander frequency and their shape is strongly influenced by how fast water runs from the land and into a stream. Where runoff from agricultural or urban lands is prevalent, sinuosity will typically indicate a healthy stable stream condition. An appropriate degree of sinuosity creates a variety of pool to riffle transitions and reduces the energy from surges when stream flows fluctuate. The absorption of this energy by meandering protects the stream from excessive erosion and flooding (Lazorchak et al, 1998). Sinuosity of a stream is measured by its ratio of stream length to valley length. In this case a straight stream has a sinuosity of 0. The larger a steam's sinuosity the more a stream meanders. To measure stream sinuosity stream segments were generated using the 30 meter DEM and the ArcHydro extension in ArcView. This data was the most detailed and comprehensive available at the time of study. Each stream section was determined by the confluence of adjoining streams or tributaries; where ever two streams came together a "pour point" was created. The "pour point" served the following purposes in the stream analysis: 1) most downstream location of each management unit, 2) break between each stream tributary and 3) a measurable valley distance between a "To" and "From" stream reach. For the sinuosity analysis, values were automatically calculated by ArcView and the stream sinuosity extension which is available on the ESRI downloadable webpage.

Table 5.3-ii. Losing and gaining stream segments and lengths and subwatershed areas.

Subwatershed	Number of Gaining Segments	Gaining Lengths (MI)	Number of Losing Segments	Losing Lengths (MI)	Subwatershed Area (Ac.)
Bass Creek	19	14.5	1	0.7	7486.0
Bass/Hunters Confluence	1	0.7	1	0.2	274.5
Bonne Femme Lower I	8	5.7	1	0.8	2792.8
Bonne Femme Lower II	4	0.4	0	0.0	279.1
Bonne Femme Middle	8	4.1	2	2.7	2925.3
Clear Creek	7	4.9	1	0.4	2926.4
Fox Hollow Branch	0	0.0	11	6.6	3469.2
Gans Creek	8	4.9	4	3.4	3052.9
Gans Creek North	7	4.7	1	0.0	2606.8
Gans Creek South	1	3.7	0	0.0	2781.0
Hunters Cave	0	0.0	2	0.4	754.1
Lower Little Bonne Femme	18	13.6	0	0.0	7149.2
Middle Little Bonne Femme	6	1.8	0	0.0	360.3
Missouri River Tributary	1	0.5	0	0.0	804.9
North Branch Little Bonne Femme	6	4.0	0	0.0	2216.0
Pierpont	0	0.0	2	2.3	1804.3
Smith Creek	8	8.0	0	0.0	3229.8
South Branch Little Bonne Femme	3	2.8	0	0.0	1377.9
Turkey Creek	12	2.8	2	0.2	4752.2
Turkey/Bass Confluence	4	1.3	0	0.0	310.8
Upper Bonne Femme	8	7.8	3	3.4	6303.5
Upper Bonne Femme Lower	1	0.9	1	1.9	954.5
Upper Little Bonne Femme	4	1.7	1	0.3	842.5
TOTAL	**134**	**88.8**	**33**	**23.2**	**59454.1**

5.4 SOILS

Soils provide the key to several aspects of watershed analysis, including wetland restoration potential, water-holding capacity, infiltration capabilities, and erosion potential. AES utilized information from the Boone County GIS Department to conduct a soil analysis for the Bonne Femme Watershed. The data were utilized to determine the diversity of soil types and the extent of hydric (wet) and erodable (fragile) soils.

Many of the soils in the Bonne Femme Watershed are loess, meaning "deposited by the wind." Nearly one million years ago, the glaciers that advanced through the area grinded underlying rock into a fine, powder-like sediment. As temperatures warmed, the glaciers melted and enormous amounts of water and sediment rushed down the Missouri River valley. The sediment was eventually deposited on flood plains downstream, creating huge mud flats.

During winters, the melt waters receded, leaving the mud flats exposed. As the mud dried, fine-grained material called silt was picked up and carried by strong winds. These large dust clouds moved eastward by prevailing westerly winds and were redeposited over broad areas. The heavier, coarser silt was deposited closest to the Missouri River floodplain and finer, lighter silt was carried further east where it was deposited, creating gently sloping hills. This process was seasonally repeated for thousands of years, resulting in a five-foot or greater layer of loess that became the dominant feature of the terrain.

Soil types (soil series) are differentiated based on the amounts and sizes of particles making up the soil, its water-holding capacity, the slopes on which they occur, permeability characteristics, and organic content. Every soil series is given a different name. Weller, Leonard, Mexico, and Armstrong soils are the dominant series in the Bonne Femme Watershed. Historic native vegetation communities growing on these areas consisted of prairies and hardwood trees on upland soils and water tolerant grasses, forbs, shrubs, and trees in lowland, hydric soils. Figure 5.4-A Soil Series displays each of the soil series coverages as determined from soil records. Table 5.4-i contains information on these soil series including hydric status, total acres, and percent of watershed covered.

Figure 5.4-A Soil Series

Table 5.4-i. Dominant soil types in the Bonne Femme watershed.

Soil Series	Hydric?	Acres	% of Watershed
Armstrong	No	6004.4	10%
Auxvasse	No	133.3	0.2%
Clinkenbeard	No	1600.0	2.7%
Clinkenbeard silt loam	No	1792.1	3.0%
Freeburg, rarely flooded	No	449.7	0.8%
Hatton	No	54.1	0.09%
Haynie	Yes	52.2	0.09%

Keswick	No	82.6	0.1%
Leonard	Yes	8045.1	13.5%
Leta	No	112.8	0.2%
Menfro	No	1248.4	2.1%
Menfro silty clay loam	No	1234.0	2.1%
Mexico	No	7010.6	11.8%
Moniteau	Yes	437.1	0.7%
Perche	No	2122.2	3.6%
Rocheport	No	2964.6	5.0%
Rock outcrop	No	5805.6	9.7%
Sandover	No	0.9	0%
Tanglenook	Yes	6.9	0%
Urban land	No	1114.6	1.9%
Vanmeter	No	517.6	0.9%
Weller	No	8577.9	14.4%
Winfield	No	5566.7	9.4%
Wrengart	No	1652.1	2.8%
Wrengart silty clay loam	No	1734.8	2.9%

Hydric Soils

Hydric soils are important because they indicate the presence of existing or drained wetlands as well as groundwater recharge areas. Historically, wetland soils formed over poorly drained clay material associated with wet prairies and other wetlands and accumulated organic matter from decomposing surface vegetation. Figure 5.4-B shows the location of hydric soils in the watershed while Table 5.4-i identifies all the hydric soils in the watershed. Hydric soils comprise 8,541.3 acres (14.4%) of the total watershed. Most of the hydric soils are located in the headwater reaches of streams in the eastern portion of the watershed and along larger stream reaches and associated floodplains in the western portion of the watershed.

Highly Eroded Soils

Soil characteristics, especially their tendency to become detached and mobilized by water runoff, have considerable impacts on water quality. For instance, sandy soils are more prone to erosion than clayey soils, although pollutants are more likely to be attached to clay particles. Erodible soils along stream channels, on poorly managed agricultural lands and on construction sites lacking proper erosion control measures are extremely susceptible to erosion. Severely eroded soils are important to map because they represent areas that will potentially contribute high amounts of total suspended solids (TSS) to streams. High TSS levels can result in stream degradation as a result of silt deposition and pollution. Pollutants can attach to TSS particles and wash into streams, adding nutrients and pollutants and decreasing water clarity.

Severely eroded soils are mapped on Figure 5.4-B. Severely eroded soil series in the watershed include Wrengart silty clay loam and Menfro silty clay loam. Based on the mapping, 2,968.8 acres (5% of watershed) are considered highly erodible. Most of the highly erodible soils are found adjacent to stream channels where topography exhibits steep slopes.

Figure 5.4-B. Hydrology and Ecologically Sensitive Soils Map

5.5 Political Jurisdictions and Demographics within the Watershed

The Bonne Femme Watershed is located in Boone County, which is bordered by Randolph, Audrain, Callaway, Cole, Moniteau, Cooper and Howard Counties. The watershed overlaps with the southern portion of the City of Columbia, which has an approximate population of about 84,531, and the northern portion of Ashland, population 1,869 (Table 5.5-i, Figure 5.5-A Jurisdictions). Although the entire watershed is contained within Boone County, land use decisions are decided upon by the political jurisdiction; thus Columbia, Ashland, and Pierpont make land-use decisions for their respective municipality. According to the County's RFP for this analysis, the Bonne Femme Watershed has a population of about 4500 people, which would put its population density around 48 people per square mile.

Table 5.5-i. Bonne Femme Watershed jurisdictions

City	Area (mi.^{2})	Population	Population Density	Number of Acres in Watershed
Columbia	53.1	84,531	1592.8 people/ mi.^{2}	4,267 Ac.
Ashland	0.9	1,869	2107 people/mi.^{2}	956 Ac.
Boone County	691.0	135,454	198 people/mi.^{2}	59,457 Ac.
Bonne Femme Watershed	93.0	4500	48 people/mi.^{2}	59,457 Ac.

Figure 5.5-B Using the center point of Boone County's parcel information linked to the tax assessors' data base to map out the temporal and spatial distribution of building structures both within the county as well as within the watershed. This graphic provides a suggestive representation as to where the greatest population densities exist within the study area as well as indicating when these densities occurred. Generally, clusters of structures can be seen throughout the north and eastern parts of the county as well as along highway 63. It appears that the majority of building within the rural areas of the watershed occurred in the 1970s, with the exception being in the urban fringes of Columbia and Ashland. Most of the development in the urban fringes has occurred more recently, from about the year 2000 up to the present (Figure 5.5-B Buildings).