A Survey of Ground Water Resources in the Cashiers, North Carolina Vicinity

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North Carolina Department of Environment and Natural Resources
Division of Water Resources
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Executive Summary

In late 2000, the Cashiers Water Council (the Council) contacted the North Carolina Division of Water Resources (DWR) regarding the availability of ground water in the Cashiers vicinity. In response to the Council's request, DWR undertook a survey of the ground water resources in the Cashiers vicinity. Through this survey, we sought to estimate the ground water recharge rate, prepare a semi-quantitative water budget, and perform a fracture trace/well yield analysis in the study area.

The study area is comprised of approximately 18.9 square miles surrounding the Town of Cashiers. Its boundaries, for the most part, follow natural hydrologic boundaries. Ground water comprises the sole supply of potable water, with a small amount of irrigation water coming from area ponds and lakes.

The study area is located in the Savannah River Basin. It receives an estimated average of 84 inches of precipitation per year, based on precipitation data from a gage in the nearby town of Highlands. The geology is comprised of igneous and metamorphic rocks of the Blue Ridge Belt overlain by clay-rich saprolite. The fractured bedrock of the area comprises the primary aquifer from which residents and businesses acquire their water. Likewise, the saprolite can provide usable quantities of water, but is apparently used very little as a water source. The saprolite and fractured bedrock aquifers are recharged by rainwater percolating through the earth. This occurs anywhere the water table is below land surface. The ground water naturally discharges into the streams and rivers of the area. At any given time, this ground water discharge, known as baseflow, typically accounts for the majority of the streamflow.

DWR calculated baseflow for three nearby river/stream systems to estimate ground water recharge in the study area. We used stream gaging data and a computer program, PART, both provided by the United States Geological Survey. Our calculations yielded an average recharge estimate of 1.7 million gallons of water per day per square mile (36 inches per year), which yields a total recharge rate of 32.1 million gallons of water per day for the whole study area. We compared this recharge number to the minimum soil infiltration rates and found that the soils in the Cashiers vicinity would easily allow this recharge rate. We also compared this recharge rate to one calculated by Ralph Heath in his 1994 calculations of recharge for the whole state of North Carolina. Our rate is much higher than Heath's rate of 600,000 gallons per day per square mile (13 inches per year), or 11.3 million gallons of water per day for the whole study area. Heath's baseflow rate is an average value obtained from much larger river basins than those basins we used for our calculations. Therefore, our baseflow value is more likely to be correlative to the study area due to similarities in climate, physiography, land use, and land cover between the basins we used and the study area.

To derive a natural water budget, DWR estimated precipitation, overland runoff, and ground water recharge/runoff (baseflow) using precipitation and streamflow data from nearby gaging stations. We then calculated total annual evapotranspiration in the region as the difference between precipitation and total runoff. Based on these calculations and estimations,

evapotranspiration comprises approximately 49 percent (41 inches per year) of the discharge of the study area's average annual precipitation. An additional 43 percent (36 inches per year) of precipitation is discharged through ground water recharge/runoff. The final eight percent (seven inches per year) of the average annual precipitation is discharged through overland runoff.

We also performed an analysis of fracture traces and how they relate to the yields of existing wells in the study area. Reported well yields ranged from just a few gallons per minute to over 100 gallons per minute. Not surprisingly, the majority of the area's highest yielding wells are located in the Cashiers Valley along a series of major fracture traces that run from the northwest to the southeast. The density of the locations of reported wells is highest in the Town of Cashiers. Further study is needed to determine if additional ground water withdrawals in this area will be harmful to existing users. However, there are promising fracture traces that may be underdeveloped along the Horsepasture River valley and also near High Hampton, Wade Hampton, and the southern part of Highway 107.

While this survey indicates that ground water availability for the study area as a whole should be more than adequate for current ground water use, we identified three key ground water management issues that the Cashiers area faces.

- Well interference – Well interference occurs when pumping in one or more wells affects water levels in other wells located in the same aquifer. Simultaneous pumping from wells that interfere with one another causes greater water level drawdown than pumping in each well individually. As a result, well interference reduces the amount of water available to all affected wells. DWR recorded well interference in the Bear Log Road well in the Found Forest subdivision. Over a period of less than two weeks, we observed numerous instances of nearby pumping wells causing water level declines in the Bear Log Road well. These declines were as large as 18 feet over a time period of less than two hours. Because most of the documented wells in the study area are located along the Cashiers Valley, well interference will become increasingly problematic in these wells as water demands grow. Proper planning will be required to minimize the impacts of well interference. Possible solutions for minimizing well interference include locating new wells in areas with fewer existing supply wells and forming a local water system so that ground water withdrawals may be spread out as much as possible over the entire area.

- Proper well construction – Improperly constructed wells can result in inadequate well yields and poor water quality. Often, these problems do not show up until long after a well is installed. Wells should be installed deeply enough to intersect enough water-bearing fractures so that the wells yield sufficient water even in times of drought, when ground water levels decline. Likewise, pumps should be installed in the wells deeply enough so that they provide adequate water in times when water levels decline due to natural climatic cycles, droughts, and well interference.

- Proper well placement – Proper well placement is key to obtaining adequate well yield, minimizing well interference, and minimizing water quality impacts. To have the greatest chance of drilling through sufficient water-bearing fractures, wells should be placed in topographically low areas, preferably along fracture traces exhibiting regionally identified orientations, and especially near the intersection of two or more such fracture traces. Additionally, to minimize well interference, new wells should be placed in areas with low well density or in areas where aquifer testing has shown that existing water withdrawals are not causing adverse well interference. Finally, wells should be placed upgradient and as far as possible from potential contaminant sources, such as septic tanks, spray fields, and underground storage tanks.

The continued viability of the ground water supply in the study area can be assessed only through a well-planned network of monitoring wells that are monitored over a long period of time. Monitoring wells should be installed in several locations in the study area, including areas of high ground water use and areas with no ground water use, to assess the long-term impact of climate and ground water withdrawals on the ground water supply. DWR offers assistance to the Council in developing such a plan and may be able to offer assistance in monitoring a portion of the network.

While this survey makes educated estimates and calculations of hydrologic variables in the study area, the Council may wish to more accurately quantify the hydrologic variables. Such variables include streamflow, precipitation, evapotranspiration, ground water levels, and ground water use. Accurately measuring these hydrologic variables is costly and time consuming. We offer assistance to the Council in exploring its options in commissioning such a detailed study, should the Council desire to do so.

Introduction

In late 2000, the Cashiers Water Council (the Council) contacted the North Carolina Division of Water Resources (DWR) regarding the availability of ground water in the Cashiers vicinity. In October 2000, DWR met with the Council to address its inquiry. We undertook a survey of the area's ground water resources to help the Council determine if the area's water use was approaching its maximum sustainable yield. Over the next year, the Council assisted us in collecting data on the location, construction, and yield of supply wells in the Cashiers vicinity. We used these data in conjunction with streamflow and precipitation measurements, baseflow calculations, and other data described later in this report to ascertain the likelihood that ground water use in the Cashiers vicinity is approaching unsustainable levels. In August 2002, we presented preliminary findings to the Cashiers Water Council. These findings are largely unchanged as presented in this report, but have been updated with additional climatic data collected since 2002.

Purpose and Scope of Work

This report is not intended to be a comprehensive treatise on the ground water resources in the Cashiers vicinity. Rather, it is a semi-quantitative assessment of the potential availability of ground water in the study area. Accurately quantifying all the hydrologic parameters and geologic factors affecting sustainable aquifer yield is an expensive, long-term process that still has a large margin of error. We chose to perform the following tasks to fulfill the survey's intended purpose:

1. Estimate the ground water recharge rate in the study area.
2. Prepare a semi-quantitative water budget.
3. Perform a fracture trace/well yield analysis.

Regardless of the findings of these tasks, we also set out to identify obvious ground water management issues likely to impact the residents of the Cashiers vicinity so that they can plan their water use accordingly. Since ground water use in the area is comprised largely of unmetered withdrawals from private wells, we did not estimate or calculate current water use in the study area due to time limitations. The findings of this study will, however, give planners a means to gage current use with respect to ground water availability.

Previous Studies

Compared to other parts of North Carolina, relatively little hydrogeologic research has been conducted in the Cashiers vicinity. Three notable examples that were helpful to this survey are:

Heath, Ralph C. (1994), GROUND-WATER RECHARGE IN NORTH CAROLINA, North Carolina Department of Environment, Health, and Natural Resources/Division of Environmental Management/Groundwater Section, 52 p.

Marsh, Owen T. (1966), RECONNAISSANCE OF THE GROUND-WATER RESOURCES IN THE WAYNESVILLE AREA, NORTH CAROLINA, North Carolina Department of

Water Resources/Division of Ground Water, Bulletin 8, 131 p.

Wright Consultants, Inc. (2000). PRELIMINARY WATER RESOURCE INVENTORY AND WATER BALANCE STUDY – UPPER CULLASAJA RIVER WATERSHED, Upper Cullasaja Watershed Association, 33 p. (used by permission)

Acknowledgements

This survey relied upon the voluntary submittal of well construction and location information of countless residents and corporate entities in the Cashiers vicinity. We thank all those involved in this endeavor for their willingness to share their time and information. We also thank the Cashiers Water Council for its tireless assistance in locating, contacting, and meeting with the numerous landowners from whom we collected data. We would especially like to thank Bud Smith and Vanna Montgomery of the Cashiers Water Council, and Dewayne Ward for the many days they spent with us during the data collection phase of this project. This work would not have been possible without their patience and hospitality.

Study Area Selection and Description

The Town of Cashiers is an unincorporated community with a year-round population of 196 and a land area of 1.1 square miles (United States Census Bureau, 2000). However, the greater Cashiers area is home to numerous vacation homes, golf communities, thousands of part-time and hundreds of year-round residents.

DWR decided to make the study area boundaries follow hydrologic boundaries as much as possible (Figure 1) to minimize separating different physiographic regions of the sub-basins. The study area includes most of the subdivisions and smaller communities that consider themselves part of Cashiers, while including only portions of the area that are in the Savannah River Basin. It includes portions of three sub-basins of the Savannah River Basin, but is bounded by stream valleys or divides between sub-basins wherever possible.

The study area covers approximately 18.9 square miles. It is located in the Mountains physiographic province of North Carolina. Elevations range from approximately 2,700 feet above mean sea level (AMSL) in the Chattooga River valley to over 4,600 feet AMSL on Sheep Cliff (USGS Topographic Maps – Big Ridge, Cashiers, Glenville, Highlands quadrangles). The elevation of the Cashiers Valley, the location of the town proper, and many of the area's businesses and residents, ranges from approximately 3,400 to 3,600 feet AMSL.

The residents and businesses in the Cashiers area obtain their water supplies exclusively from domestic and private community wells. There is no publicly controlled water system within the study area. The Tuckasegee Water and Sewer Authority operates a wastewater treatment system in the Cashiers Valley, but many of the residents and businesses have private septic systems and other means of on-site wastewater treatment and disposal.

Hydrogeologic Setting and Description

The study area is located in the Savannah River Basin. It contains portions of three sub-basins, the Whitewater, Horsepasture, and Chattooga Rivers.

During our research, we found many informal sources stating that the average annual precipitation of the study area is in excess of 85 inches per year. However, the nearest precipitation gages, Lake Toxaway and Highlands 2S (Figure 2), record average annual precipitation of 90.12 inches per year and 83.95 inches per year, respectively (National Weather Service, 2002). We could locate no precipitation gages within the study area. Regardless of the actual figure, the Cashiers vicinity without a doubt receives far more annual precipitation than most of North Carolina. For the purposes of this survey, we chose the Highlands precipitation figures due to the station's proximity and physiographic similarity to the study area, and the similarity of its data to the informal data for Cashiers.

The study area is located in the Blue Ridge Belt (North Carolina Geological Survey, 1985). The three major rock types found in the area are amphibolite, biotite gneiss, and quartz diorite/granodiorite (Figure 3). The latter comprises the majority of the study area.

Amphibolite and biotite gneiss are high-grade metamorphic rocks. Metamorphic rocks are rocks whose original properties have been changed by being subjected to heat and/or pressure. The quartz diorite/granodiorite in the study area is igneous, but may be slightly metamorphosed (NCGS, 1988). Regardless, all three rock types form fractured bedrock aquifers, which are described in more detail later. Additionally, these three rock types weather to form saprolite, a clay rich, overlying, residual material that often contains relict structures and mineral assemblages from the parent rock material. Saprolite tends to be thickest in valleys and draws and thinnest to non-existent on topographic highs such as hilltops and ridges. This is due to a number of factors, including faster weathering rates on rock in topographically low areas and increased erosion rates in topographically high areas.

According to Marsh (1966), wells in the quartz diorite/granodiorite generally produce higher yields than wells in the biotite gneiss.

Saprolite Aquifer

As in most of the Piedmont and Mountains physiographic regions of North Carolina, the two primary aquifers in the study area are known as the saprolite and fractured bedrock aquifers (see Figure 4). The saprolite aquifer stores and transmits water primarily in and through pore spaces between the clay, silt, and sand-sized particles that are often present in saprolite. Porosity is the percentage of the volume of a material that is void space and available to be filled with water. Due to saprolite's high clay content, its porosity tends to be very high. For this reason, saprolite can store large amounts of water. However, its clay content also makes transmission of water much slower than in other aquifer materials.

The saprolite aquifer was once a primary aquifer from which domestic water supplies were obtained in western North Carolina. Saprolite wells are typically installed by hand digging or boring a large (18 inches or more in diameter) borehole and lining it with rock, brick, or concrete or terra cotta tile. These wells rely on their large volume of storage to compensate for the relatively low yield that typifies saprolite wells. Saprolite wells were once very common in the study area, but relatively few were observed during field reconnaissance. Their popularity has dwindled as the cost of installing bedrock wells has decreased over the years. Additionally, saprolite wells are generally more susceptible to contamination from surface sources such as spills, leaks, and septic systems, than are bedrock wells, a fact that has also contributed to their decline in popularity.

DWR did not consider the placement, construction, and yield of saprolite wells since the vast majority of users in the study area rely on the fractured bedrock aquifer for their water supplies.

Fractured Bedrock Aquifer

In contrast to the saprolite aquifer, the fractured bedrock aquifer transmits and stores water primarily in fractures, faults, joints, and other natural “breaks” in the rock. The porosity of fractured bedrock is relatively low, sometimes only a few percent of the total volume of the rock. Water is present in the pore space around individual crystalline grains in the rock, but these spaces are, for the most part, microscopic and represent an infinitesimal contribution to the water-bearing capabilities of the fractured bedrock aquifer. For this reason, fractured bedrock is able to store a relatively small amount of water. However, depending on the size and orientation of the fractures, the fractured bedrock aquifer can be capable of transmitting very large volumes of water. Well yields of several hundred gallons per minute in fractured bedrock are not unheard of, although they are not common in most parts of North Carolina. Because the saprolite and fractured bedrock aquifers tend to be fairly well connected in most places, the saprolite aquifer often acts as a “storage tank,” while the fractured bedrock aquifer acts as a “transmission pipe” to get water to points of withdrawal.

Depending on the nature of the fractures, it is possible that many users can withdraw water from the same fracture set, even though they may be hundreds, even thousands of feet away from each other. The low storage capabilities of the fractured bedrock aquifer, coupled with its highly transmissive nature, means that users can negatively impact water levels and well yields of other users of the same fracture set. Additionally, several users withdrawing water from the same fracture set will have a much greater combined impact on the water level in their wells and the amount of water in the fracture than the impact caused by each of them individually. This concept is known as “well interference” and is shown in Figure 5. Problems related to well interference are discussed in detail later in this report.

The vast majority of the wells observed by DWR during field reconnaissance are fractured bedrock wells. These wells are typically relatively small in diameter (six inches to ten inches is a common range). They are installed by drilling a borehole to the bedrock, installing well casing through the saprolite to hold the well open, and then drilling a borehole through the casing into the bedrock. Drilling continues until sufficient fractures are intersected by the borehole to give the desired well yield. The well casing is typically sealed by cement grout to prevent contamination from the surface or the saprolite from entering the well.

One other concept worth noting is the spatial relationship fractures and other features possess. The geologic history of this region is one of upheaval, continental collisions, regional uplift, and erosion. As stresses acted on the rock, fractures, faults, and joints formed at certain angles to these stresses. Often, the fractures formed in what are called conjugate sets. A conjugate set forms with each fracture in the set typically forming at a thirty to forty-five degree angle from the direction of greatest stress in the rock so there is a sixty to ninety degree angle between fracture planes. Over time, these rocks were exposed to the surface of the earth and began to weather. Weathering rates are typically greatest in areas with numerous fractures, so these areas became the draws, stream valleys, and other topographic lows in the current landscape. The slowest weathering typically happens in areas of fewer fractures and these areas became the high spots in the current landscape. All this is important because it allows one to study the orientation of fracture traces – expressions of fractures or fracture sets on the earth's surface – and map them so that predictions can be made about the best locations for higher yielding wells. Also, fracture trace analysis can be used to map wells that appear to be connected to the same fracture set and therefore have a greater likelihood of interfering with one another.

Additionally, fracture sets form at sub-horizontal angles as material is unloaded from the rock by weathering and erosion. While these fractures are important for transmitting water, they are generally not visible in fracture trace analysis.

Generalized Ground Water Flow

Figure 4 shows a generalized pattern for ground water flow in the study area. Water typically enters the ground water system as precipitation falls on the earth and a portion of that precipitation percolates downward into the ground. The remainder of the precipitation flows over the land towards the stream valleys as runoff.

Part of the percolating water is used by plants and is discharged as water vapor to the atmosphere through transpiration. The portion of the percolating water that makes it into the aquifer is called recharge. Ground water's natural flow in the study area is towards stream valleys and other areas of discharge. This discharge of ground water into streams is called baseflow. On average, baseflow comprises approximately fifty percent of streamflow in North Carolina. During times of drought and in certain portions of the state, baseflow can comprise nearly all of streamflow. DWR's baseflow calculations for stream basins near the study area show that baseflow comprises almost 84 percent of streamflow, on average.

Recharge is most significant in topographically higher areas, especially to the fractured bedrock aquifer. Recharge in lower areas, closer to the stream to which ground water is discharging, is discharged relatively quickly and is not available for withdrawal through wells.

Methodology

Recharge/Baseflow Calculations

When evaluating whether ground water use is sustainable, a critical component is knowing how much water is recharging the ground water system. DWR approached calculating recharge in two ways.

Recharge calculation using hydrograph separation from nearby stream basins

As previously stated, baseflow is the ground water discharge component of flow in streams. The remaining component of stream flow comes from overland runoff. Using a technique called hydrograph separation, the baseflow and overland runoff components of streamflow can be calculated for a period of time. During any given year, the baseflow component of streamflow can contain the discharge of water that has recharged the aquifers that year and the discharge of water that has been stored in the aquifers during previous years. During dry periods, baseflow is primarily composed of water that has been in storage in aquifers. During these times, baseflow exceeds recharge and water is taken out of storage in the aquifer. During wet periods, recharge may exceed baseflow, resulting in water being added to storage in the aquifer. However, over a long period of time, the changes in storage are assumed to average out to zero. Therefore, with a long enough period of record, calculations of baseflow can be assumed to equal the average ground water recharge rate to the aquifers that contribute baseflow to that stream basin.

DWR could not locate any gaged stream basins in the study area from which data could be used to calculate baseflow through hydrograph separation. We selected three nearby United States Geological Survey (USGS) gaging stations (Figure 2) for baseflow calculations: Brevard, Prentiss, and Rosman. These gaging stations were selected for use because of their proximity to Cashiers, their period of record, and the physiographic similarity of their basins to the study area. Table I lists relevant details for each station.

DWR used the computer program PART (Rutledge, 1998) to calculate average total daily baseflow values for each of the three selected basins. We then divided this daily baseflow value by the land surface area of the basin to obtain an average daily ground water recharge value per square mile for each basin. These values were then averaged to obtain an estimated daily recharge value per square mile to apply to the study area. Finally, we multiplied the estimated daily recharge value per square mile by the total surface area of the study area to obtain a total daily recharge value.

The estimated total daily recharge value for the study area is assumed to be the maximum sustainable amount of ground water that can be withdrawn from its aquifers on an average day. However, there are caveats that must be understood regarding this estimation of the maximum sustainable ground water withdrawal. First, withdrawing this maximum sustainable amount is impossible. It would likely require millions of wells perfectly spaced with perfectly timed withdrawals. Also, if it were possible to withdraw this maximum sustainable amount of ground water, it would mean that there would be no ground water discharge to streams in the study area. This would cut streamflow by up to eighty percent or more, which would have devastating environmental effects in and downstream of the study area.

The value in calculating such a number is that it gives a ceiling to which water use in the study area can be qualitatively or semi-quantitatively compared. If water use is already at a large percentage of the estimated maximum sustainable withdrawal amount, it is a red flag that water use is likely approaching practical sustainable limits. If, however, current ground water use is a very small percentage of the estimated maximum sustainable withdrawal amount, it is less likely that the area's water use is approaching the practical sustainable limits. In this case, local ground water management issues such as well interference may be of more immediate concern.

Recharge Calculation using average recharge values from Heath (1994)

The second way DWR calculated recharge in the study area was by using recharge rates calculated by Ralph Heath in his 1994 report "Ground-Water Recharge in North Carolina." Heath calculated average ground water recharge rates across the state of North Carolina by using baseflow calculations on larger, regional river basins. We used Heath's recharge value for comparison to our calculated recharge rate for the study area. However, because Heath's number is an average value obtained from several much larger river basins, it is unlikely it is directly correlative to actual recharge in the study area, or even our calculated recharge rate. This difference is due to differences in land use, physiography, climate, geology, and other factors that impact recharge in the study area as compared to larger, regional river basins such as the ones used by Heath.

As before, we calculated total average daily recharge by multiplying Heath's recharge value per square mile by the total land surface area of the study area.

Soil Infiltration Rate Analysis

For water to recharge an aquifer, it must first percolate through the soil that overlies the aquifer. DWR evaluated the areal coverage of the soil types of the study area, as found in the Soil Survey of Jackson County, North Carolina (US Natural Resources Conservation Service, 1997). We compared the NRCS's published infiltration rates for the soils in the study area to our calculated recharge rate as another check of the potential validity of our recharge rate. A map of soil infiltration rates is found in Figure 6. If the soil infiltration rates over much of the study area are relatively low, then a calculated recharge rate that is relatively high is less likely to be valid and must be scrutinized. However, higher soil infiltration rates over much of the recharge area would tend to confirm the plausibility of a higher calculated ground water recharge rate.

Natural Water Budget

A natural water budget is a representation of the water inputs to and outputs from a hydrologic system (Figure 7). For the study area, the major water input is precipitation. The major outputs are evapotranspiration (a combination of the evaporation of water and transpiration of water from plants) and total runoff. Total runoff is the sum of overland runoff and ground water runoff (baseflow). Over a period of time, changes in storage due to abnormally high or low inputs into the system are assumed to average out, so in a representative natural water budget for a given area, the inputs will equal the outputs.

Developing a natural water budget is important for understanding the overall hydrologic framework of the study area. Developing a natural water budget involves quantifying each input and output. Independently quantifying as many of these parameters as possible is highly desirable, as it allows more opportunities to check data sets against one another, which gives a more accurate water budget.

Precipitation in the study area comes primarily as rain and snow. Other forms of precipitation, such as fog and mist, also occur in the study area, but they are assumed to be negligible compared to the other two. As previously stated, we were not able to locate an existing precipitation gage with an adequate period of record in the study area. However, as explained in the Hydrogeologic Setting and Description section, we chose to use precipitation data from the Highlands 2S precipitation gage.

Surface and ground water runoff combine to form stream flow in a given basin. Stream flow data can be separated into its overland runoff and baseflow components using a technique called hydrograph separation. Hydrograph separation can be accomplished manually or by using computer programs. As explained previously, we chose to use the computer program PART (Rutledge, 1998) to perform our hydrograph separations. We were unable to find any surface water gaging stations in the study area. As explained in the Hydrogeologic Setting and Description section, we chose to estimate baseflow by averaging baseflow calculations for the Brevard, Prentiss, and Rosman USGS stream gaging stations. We also assumed that the ratio of baseflow to total flow was similar in the study area to the baseflow to total flow ratios calculated for these three gaging stations. We used this assumption to estimate overland runoff.

Evapotranspiration is difficult to quantify in the best of circumstances. Some methods of estimating evapotranspiration include evaporation pans, monitoring soil moisture under controlled conditions, and applying known rates of potential evapotranspiration to an area based on its land use and vegetative cover. None of these methods is currently available for the study area. Heath (1994) quantifies annual evaporation from free water surfaces for the Cashiers vicinity as between 36 and 38 inches per year, based on his statewide evaporation contour map. His value does not include transpiration, which has a much greater affect on the study area due to its relatively minimal coverage by free water bodies and its relatively expansive coverage by mature forests. Wright (2000) quotes annual evapotranspiration estimates from Dr. Lloyd Swift (USDA, Southern Research Station, Coweeta Hydrologic Lab) for the Highlands area of 30.1 inches. Wright reports that Dr. Swift's estimates are derived by subtracting annual runoff from precipitation, assuming no ground water infiltration. Wright also reports that Dr. Swift stated that precipitation minus runoff in the upper Cullasaja Basin would probably be no less than 27 inches per year.

We estimated total evapotranspiration by subtracting total runoff, as calculated by averaging the total runoff data from the three previously mentioned stream gaging stations, from total precipitation, as estimated from the Highlands 2S rain gage. While estimating evapotranspiration in this manner leaves much to be desired from a quantitative standpoint, it is more applicable to this survey than the other two methods listed. The method mentioned by

Heath does not take into account transpiration. The method listed by Wright assumes there is no ground water infiltration, which is an invalid assumption.

Fracture Trace/Well Yield Analysis

As previously mentioned, the fractures in bedrock typically form in conjugate sets during periods of stress on the rock body. A conjugate set forms with each fracture in the set typically forming at a thirty to forty-five degree angle from the direction of greatest stress in the rock so there is a sixty to ninety degree angle between fracture planes. Over time, these rocks were exposed to the surface of the earth and began to weather. The weathering rates are typically greatest in areas with numerous fractures, so these areas became the draws, stream valleys, and other topographic lows in the current landscape. The slowest weathering typically happened in areas of fewer fractures and these areas became the high spots in the current landscape. In general, fractures can be traced by observing patterns observed in the orientation of stream valleys, draws, and other topographically low areas.

For this study, DWR studied the Big Ridge, Cashiers, Glenville, and Highlands quadrangles of USGS topographic maps. We observed regional patterns in the orientation of topographically high and low areas in the study region. We also observed the orientation of rock formations and formation contacts as published in the Geologic Map of North Carolina (NCGS, 1988). We did not observe any mapped faults or dikes in the study area on computerized maps provided by NCGS.

Using the referenced quadrangles as a base, we produced a map showing the locations and orientations of apparent fracture traces in the study area (Figure 8). We also produced a map showing locations of apparent fracture traces and selected supply wells and their yields (Figure 9). We used this map to identify productive fracture sets and fracture sets that are potentially overstressed or underutilized. The details for the wells used in the spatial yield analysis are found in Table II.

Findings

Recharge/Baseflow Calculations

Table III and Figure 10 contain DWR's estimate of recharge in the study area based upon baseflow calculations for nearby gaged stream/river basins. We estimate that the study area receives on average 1.7 million gallons of ground water recharge per day (MGD) per square mile. This equates to an average daily recharge total of 32.1 MGD for the entire area.

While we did not estimate ground water use in the study area, it is highly unlikely that it comprises a significant fraction of this amount. Of course, as discussed previously, it is physically impossible to withdraw the entire amount of ground water recharge in any area. Additionally, withdrawing a large percentage of the recharge would be detrimental to stream flow in and downstream of the study area. However, the estimated recharge value is so high that we believe it is very unlikely that regional ground water shortages will be an issue at the present time. It is much more likely that local ground water supply problems, such as well interference, will develop in areas of heavy ground water use long before such use threatens the ground water supply of the Cashiers area as a whole.

Soil Infiltration Rate Analysis

DWR prepared a soil infiltration rate map from GIS data provided by the US Natural Resources Conservation Service (Figure 6). Visual inspection of the map shows that the vast majority of the area has soils with infiltration rates that range from two to six inches per hour. Compared with the area's estimated precipitation rate of 84 inches per year and the calculated ground water recharge rate of 36 inches per year, it is clear that these soils are capable of accepting this amount of precipitation as recharge. Had the majority of the study area contained soils with much lower infiltration rates, the calculated recharge rate may have been suspect.

Natural Water Budget

Figure 7 shows the representative calculated water budget for the study area. We estimated precipitation, overland runoff, and ground water recharge/runoff (baseflow) using streamflow data from nearby stream/river basins, as described in the Methodology section. We then calculated total annual evapotranspiration as the difference between precipitation and total runoff.

Based on these calculations and estimations, evapotranspiration comprises approximately 49 percent (41 inches per year) of the discharge of the study area's average annual precipitation. An additional 43 percent (36 inches per year) of the precipitation is discharged through ground water recharge/runoff. The final eight percent (seven inches per year) of the precipitation is discharged through overland runoff.

At first glance, these numbers are surprising, as one might expect overland runoff to comprise a much higher percentage of the study area's discharge of its precipitation due to the steep slopes that make up much of the study area's topography. However, review of aerial photographs of the area and observations of landcover during field work reveal that the majority of the study area is covered by mature stands of hardwoods and conifers. Research, such as that performed by Kays (1979), has shown that undisturbed forest land tends to yield the highest soil infiltration rates when compared to other land uses. While Kays' work focused on the Piedmont of North Carolina, his findings of how land use and ground cover affect recharge apply to the Mountains province as well. Thus, it is reasonable to accept these very high recharge values as valid.

Additionally, the study area experiences some of the highest annual rainfall rates in the state of North Carolina. This abundance of rainfall will tend to keep "sinks" of water, such as soil moisture, infiltration of vegetation and organic ground litter, etc. full. In more typical circumstances, these sinks would keep a large portion of smaller rainfall events from reaching the aquifer, thus reducing average annual recharge. Since the study area experiences many larger rainfall events in the course of a given year, in addition to frozen precipitation events, the soil, organic debris, and vegetative surfaces are more likely to be kept in a moister state so that they allow more of each rainfall event to percolate through the soil into the aquifer.

One important note here is that land use changes in the study area will almost certainly result in reduced recharge, since the study area is so heavily covered by mature forests. The addition of paved surfaces, buildings, and grassy areas such as yards and golf courses will reduce recharge since published studies on land use effects on recharge show that these types of land uses all have lower recharge rates than does a stand of mature timber.

Fracture Trace/Well Yield Analysis

Figure 9 shows the results of DWR's fracture trace/well yield analysis for the study area. Review of the map shows that most of the supply wells in the area are located in the Cashiers Valley. This should come as no surprise, since much of the population and most of its businesses are located in this valley. Additionally, it is clear that the fracture sets in the Cashiers Valley are well developed and well connected, as the majority of the high yielding wells are located in this vicinity. Again, this should come as no surprise since this well-developed valley is likely the result of preferential erosion and weathering of large fracture sets. One concern regarding the density of wells in the Cashiers Valley is that it may be prone to serious well interference problems with increased development and ground water withdrawals.

In addition to the Cashiers Valley, the map indicates other areas of well-developed fractures, some of which may be currently underutilized. The Wade Hampton area has several high-yielding wells, but we believe that this area may not be the best for future exploitation of ground water resources. The high yielding wells in this area all fall along a few smaller fracture traces. These fractures may not yield much more water without detrimental well interference.

Two areas that are attractive for future ground water exploration are the large fracture traces near High Hampton and the long east-west trending traces that occur along the course of the Horsepasture River. The High Hampton area has produced some high yielding wells and the size of the traces near these wells indicate that they may have the potential of safely yielding even more water. The traces along the Horsepasture River appear to be relatively undeveloped, but are very strong and could yield significant amounts of ground water.

One additional observation regarding the fracture trace analysis is that there are many traces evident that are practically unable to be developed. Many of them are inaccessible and are too far from population centers to make water distribution financially feasible. Additionally, many of these strong traces are on government-owned land, such as National Forest property.

Well Interference

DWR installed an automatic water level recorder on the Bear Log Road Well in Found Forest from April 11, 2001 until May 15, 2001. The hydrograph is shown in Figure 11.

The Bear Log Road Well is approximately 400 feet deep and is cased to approximately 42 feet below land surface. The remainder of the well is open hole in fractured bedrock. It is not currently used for withdrawing ground water, but it is located approximately 350 feet from the Roberta Well and approximately 800 feet from the Mikie Well, both of which are actively used by Found Forest residents.

Review of the Bear Log Road hydrograph shows that the water level in the well changes several times a day, with some changes being almost twenty feet. Since the Bear Log Road Well is not pumped, these changes must be due to pumping in nearby wells with the Mikie and Roberta wells being the most likely sources of interference.

This hydrograph illustrates what is likely to be the Cashiers area's largest ground water supply management problem – well interference. The Roberta, Mikie, and Bear Log Road Wells are all obviously connected to the same fracture sets such that pumping one of these wells will impact water levels in the others. This does not appear to have caused problems in Found Forest, but it should be clear that pumping more water from these three wells might not be a viable solution if water demand in Found Forest increases. Since all three wells are drawing their water from the same fracture set, withdrawing more water from one or more of them will decrease the amount of water available to be withdrawn from the others. Likewise, if additional wells are installed in this same fracture set, the problem will be exacerbated.

Well interference could become a problem in the Cashiers Valley as water use increases due to population growth and business expansion. As stated earlier, analysis of the fracture traces indicates that the majority of the population and businesses in the study area are withdrawing ground water from the same major fracture sets that run through the Cashiers Valley.

Should well interference become a problem in the Cashiers Valley, the first wells seriously impacted will be the shallowest wells in the upper portions of the fracture sets. Well interference will likely cause intermittent water supply problems in such wells as water levels occasionally drop below the lifting limit of the pumps in the wells or below the pumps' intake depths. If the well interference grows more severe with increased ground water withdrawals, these shallower wells may become totally unusable. Additionally, deeper wells may lose portions of their yield or become unusable during periods of severe interference.

Recommendations

Ground Water Management Issues

Well interference

As stated previously, well interference is one of the most likely management issues that will affect ground water use in the study area. Well interference is already occurring in the study area. This in itself is not a cause for alarm, but as water use increases, especially in the Cashiers Valley, well interference could have an increasingly negative impact on ground water users.

The best way to avoid detrimental well interference is through proper planning of ground water use. Selection criteria for new well locations should include an evaluation of the likelihood that the new well will cause or will be affected by detrimental well interference. Additionally, new wells that are installed should be drilled and pumps should be installed at sufficient depths such that well interference will not make the wells unusable shortly after they are installed.

Another way to limit the negative effects of well interference is the formation of a water system in the study area, especially in the Cashiers Valley. Interconnection of existing wells and water users would allow ground water to be withdrawn from a number of different wells at different times to minimize the impact of well interference on these wells. Certain existing wells would likely not be needed while others that are underutilized could be used to provide more water than they currently produce. Having a water distribution system in place would make the distribution of water from another source (for instance, from Lake Glenville) more feasible should the area's ground water supply prove insufficient in the future.

The exact details of such a water system involve myriad political, economic, and engineering details that cannot be addressed in this survey. However, such details should be considered in the event such a system becomes necessary or desirable in the future.

Proper well construction

North Carolina experienced its worst drought in recorded history during the period from 1998 to 2002. During this drought, many well owners across the state experienced a decline in the water levels and yields of their wells. Some wells literally ran dry while others experienced water level declines below their pumps' lift abilities or intakes. Other wells still yielded water, but at quantities insufficient for their owners' needs.

From discussions with numerous well owners, it is obvious that the Cashiers area was similarly impacted by the drought in experiencing these problems with supply wells. We noted that in many instances, the ground water supply problems caused by the drought could have been alleviated with alterations to well construction. While these alterations can be performed after a well is installed, it is simpler and less costly to construct wells in the proper manner at the start. Common well construction deficiencies observed include:

- *Well was not drilled deeply enough*. Obtaining a reliable, sufficient yield from a bedrock well is contingent upon the borehole intersecting enough fractures of sufficient yield to supply enough ground water for the well owner's intended purpose. It is not uncommon that a well that does not yield enough water in a drought can become serviceable again if it is deepened an additional 100 or 200 feet or more. Drilling the well deeper not only increases the chances of intersecting additional water-bearing fractures, it also increases the storage capacity of the well itself so that it can provide more water at peak demand periods. When installing a new supply well, it is often desirable to drill it deeper than one thinks necessary, particularly if sufficient yield is encountered fairly shallowly.
- *Pump was not installed deeply enough*. This problem is probably even more commonly encountered than the first. When a well is installed, the driller will typically install the pump at a certain depth below the water level in the well based upon his observation of that well's yield during drilling and the anticipated water use requirements of the owner. If the well is installed during a wetter than normal period, the water level will likely be abnormally high. If the abnormally high water level is not accounted for when the pump is set, it will likely be set too high to reliably provide water during drier periods of time, or even during years with average rainfall. The pump should normally be set deeper than the anticipated need and conditions warrant, providing a safety factor during periods of reduced yield and/or lower

water levels in the well.

Proper well placement

Many landowners never consider the possibility that a well drilled on their property will not yield a sufficient supply of water. In most building or development projects, it is assumed that the well can be placed anywhere and it will yield sufficient water. Placement of wells to achieve optimal well yields should be a primary consideration in any project, whether it is building a house or store or developing a golfing community. No one wants to build a house on the side of a mountain only to find water must be piped thousands of feet because the nearest well that yields water is in the valley. Particularly as the population of the study area increases, proper well location will be key in successful developments of any size. Well sites should be selected to address the following concerns:

- Adequate yield – As discussed previously, the well sites with the greatest chances of providing adequate yield will be found in topographically low areas: valleys, draws, saddles, etc. Additionally, well sites will ideally be placed where these features follow regional trends and where two or more of them intersect. This will give the greatest likelihood that numerous well-connected fractures will be intersected by the well, resulting in higher well yield.
- Minimization of well interference – As discussed previously, wells should be placed such that pumping in them will have minimal effect on surrounding wells and that pumping in those surrounding wells will have minimal effect on the new well. In areas with a high well density, it may be necessary to perform aquifer tests or monitor static water levels in nearby wells to assess the likelihood that well interference will be a significant problem in the area. It may also be necessary to install a well farther from the point of water use (house, restaurant, development) to minimize well interference.
- Minimization of water quality impacts – While ground water quality in the study area is not covered in the scope of work of this survey, it is always wise to consider how the surrounding area might negatively impact ground water quality of the new well. Wells should be placed uphill from potential contaminant sources (such as septic tanks and underground storage tanks). Additionally, the well site should be graded to prevent runoff from flowing around the wellhead or surface water from standing near the wellhead, as both occurrences will increase the likelihood of contamination of the well. Finally, the current and former land use of the surrounding area should be considered. Are chemicals or waste materials handled nearby that could contaminate the new well? Are there any old ground water contamination sites near the new well?

Ground Water Monitoring Plan

Ultimately, the viability of the ground water supply can be assessed only through monitoring ground water levels in the area over time. To do this, monitoring wells will need to be installed at various sites in the study area. Water levels will have to be routinely collected, either by manual measurement or using automatic water level recorders. These water level data can be plotted so that trends can be established that will show whether ground water is being used at a sustainable or unsustainable rate.

DWR currently monitors over 500 such wells across the state, but none of these will directly address ground water conditions in the Cashiers vicinity. If the residents of Cashiers desire a local monitoring well network, DWR will offer assistance in planning, designing, installing, and monitoring such a network.

Future Work

By their nature, surveys of ground water resources always leave many questions unanswered. While we are confident that this survey adequately addresses its scope of work, the citizens of Cashiers may wish to better quantify hydrologic variables through a specific ground water resource study. Such a study would include accurately measuring as many of the following variables in the study area as possible:

- Streamflow
- Precipitation
- Evapotranspiration
- Ground water levels
- Ground water use

Accurately measuring these hydrologic variables is costly and must be done over a long period of time to ensure statistical relevance of the data. While DWR cannot commit to undertaking such a study for the Cashiers vicinity, we will assist the Council in exploring its options for commissioning such a study should the Council desire it.

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Figure 1: Map of Study Area
Cashiers, North Carolina Vicinity

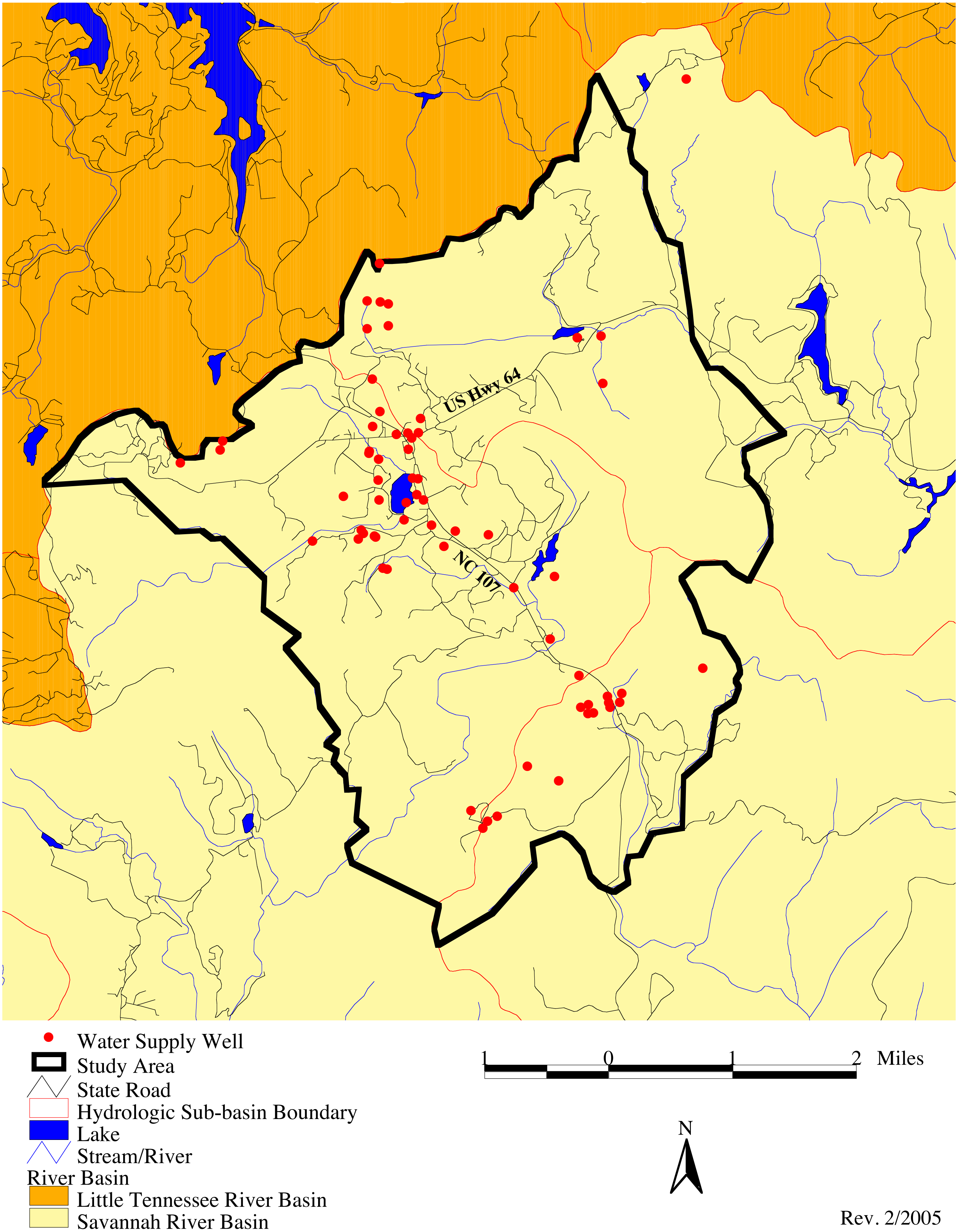

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Figure 2: Locations of Precipitation and USGS Stream Gages Cashiers, North Carolina Vicinity

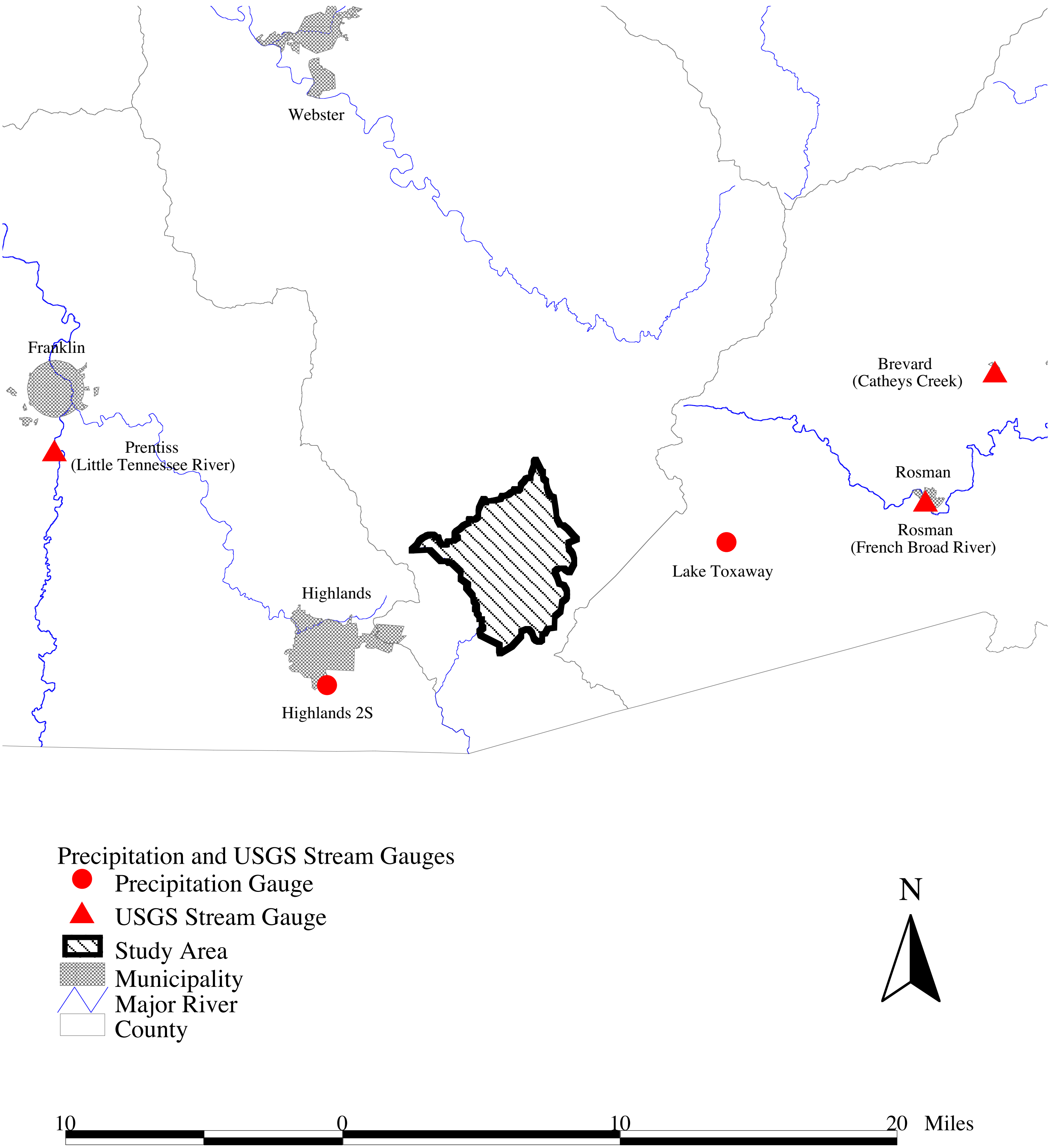

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Figure 3: Geology of Study Area
Cashiers, North Carolina Vicinity

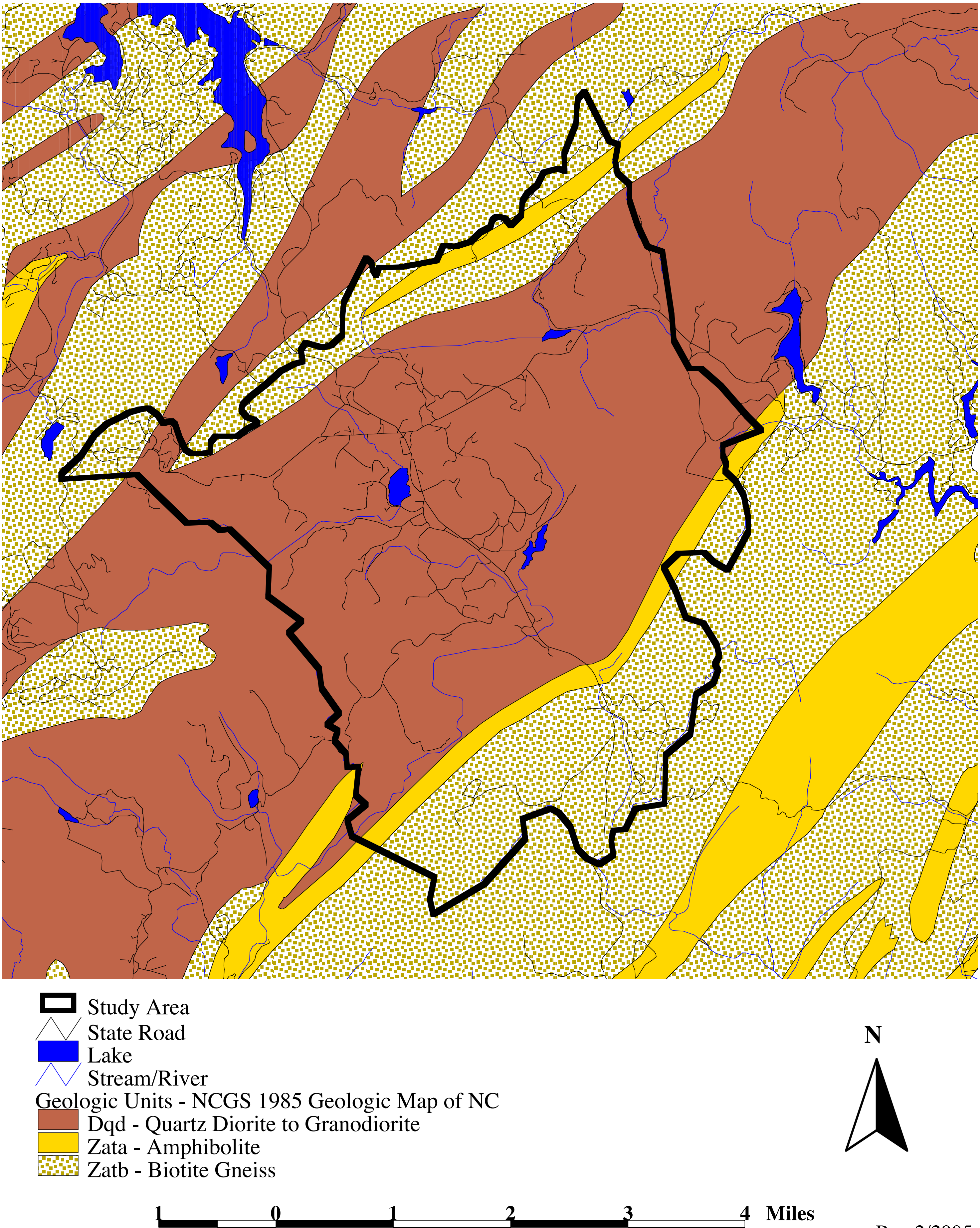

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Figure 4: Idealized Hydrologic Cycle of Piedmont and Mountains of North Carolina

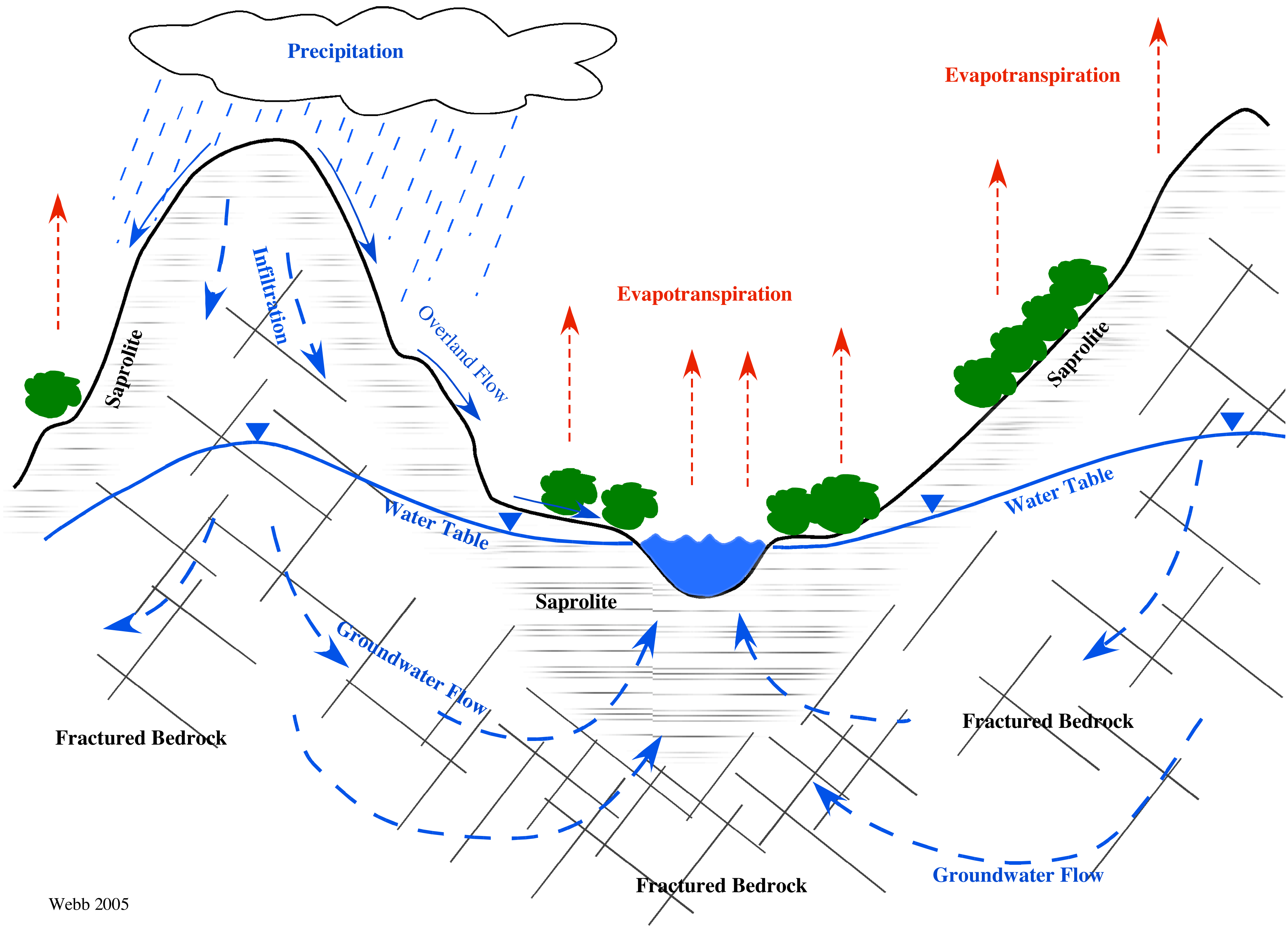

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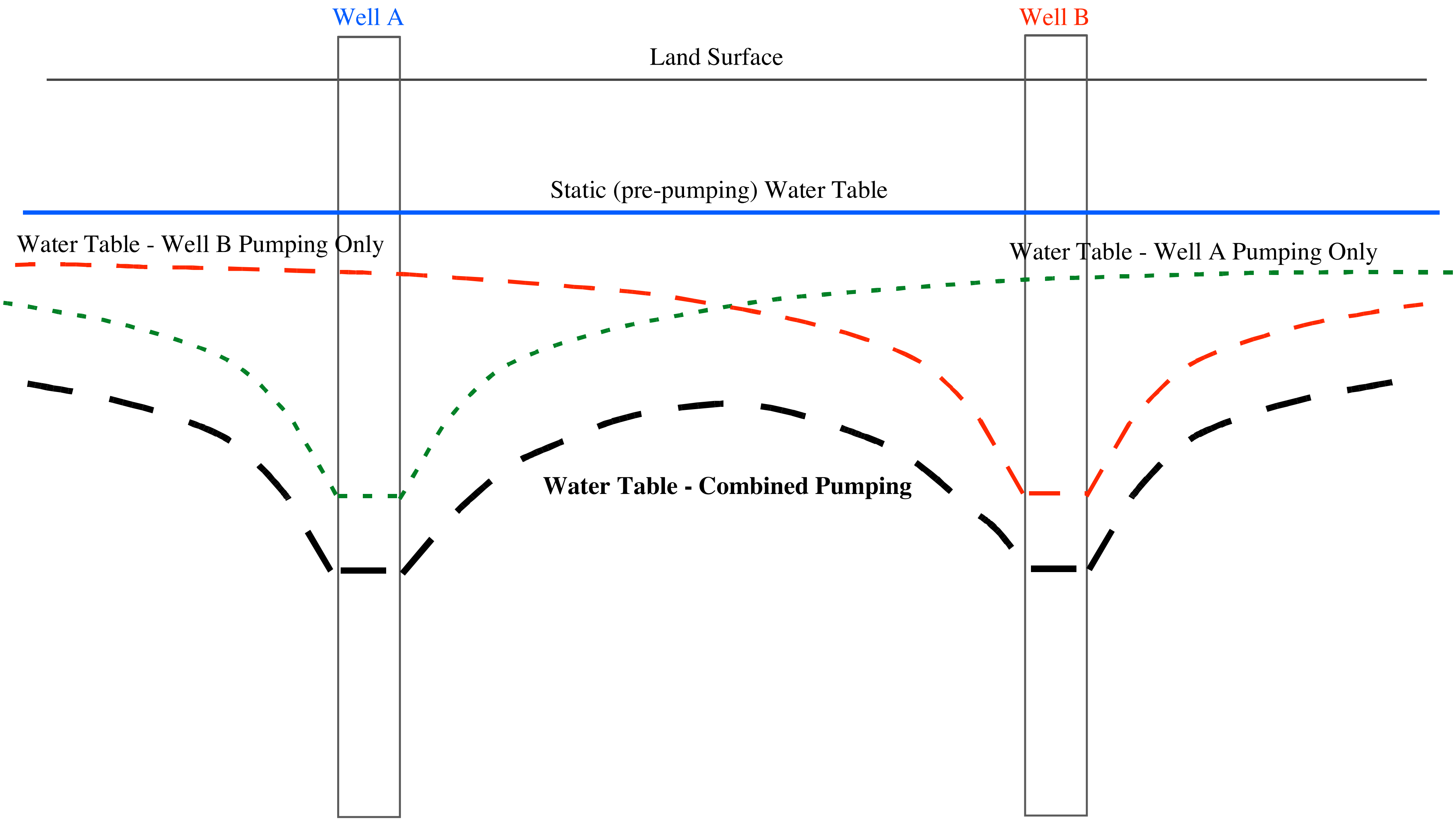
Figure 5: Well Interference Diagram



A diagram of well interference. Pumping from both Well A and Well B results in a combined aquifer drawdown that is greater than if either well was pumping alone.

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Figure 6: Soil Infiltration Rates of Study Area
Cashiers, North Carolina Vicinity

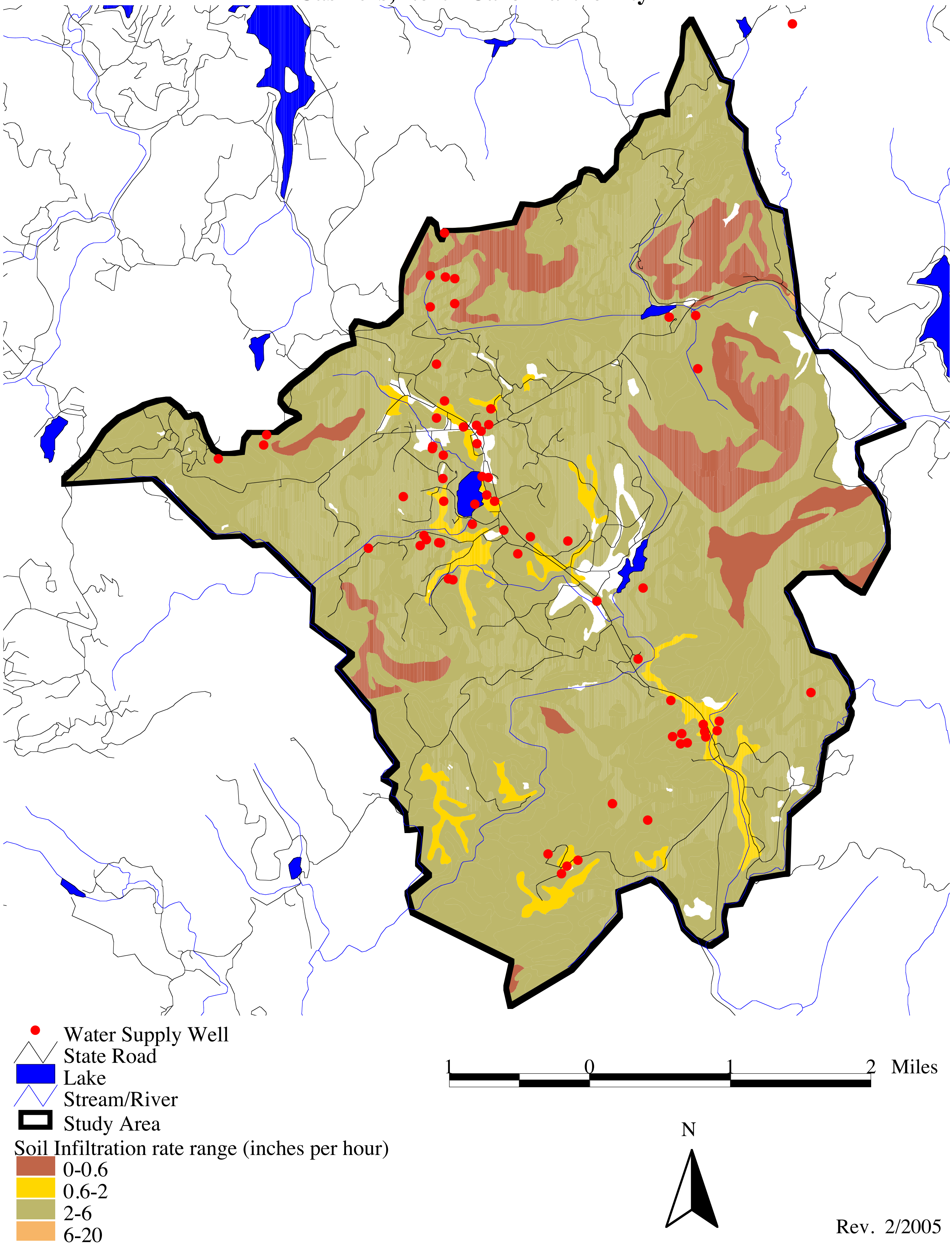
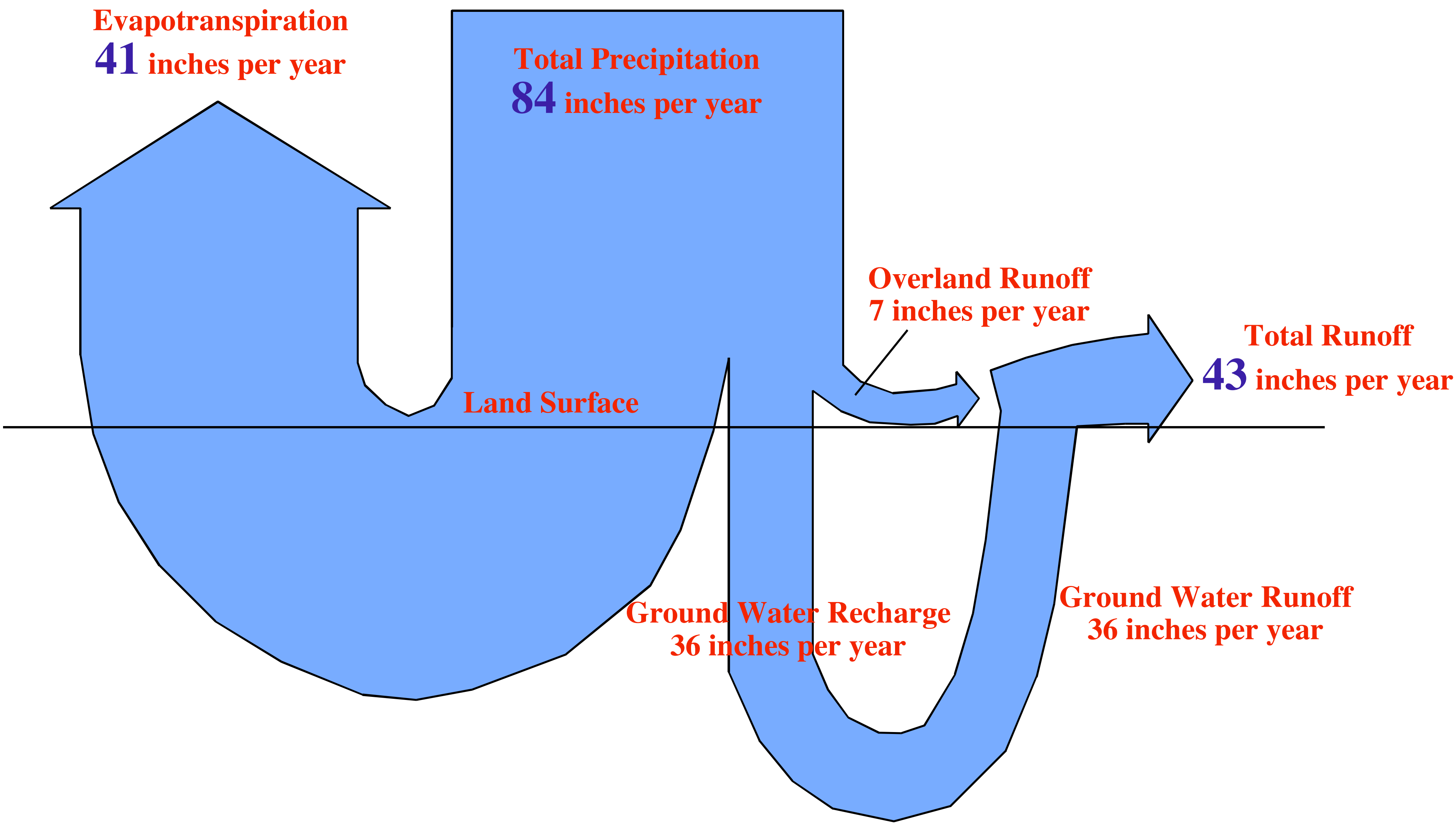
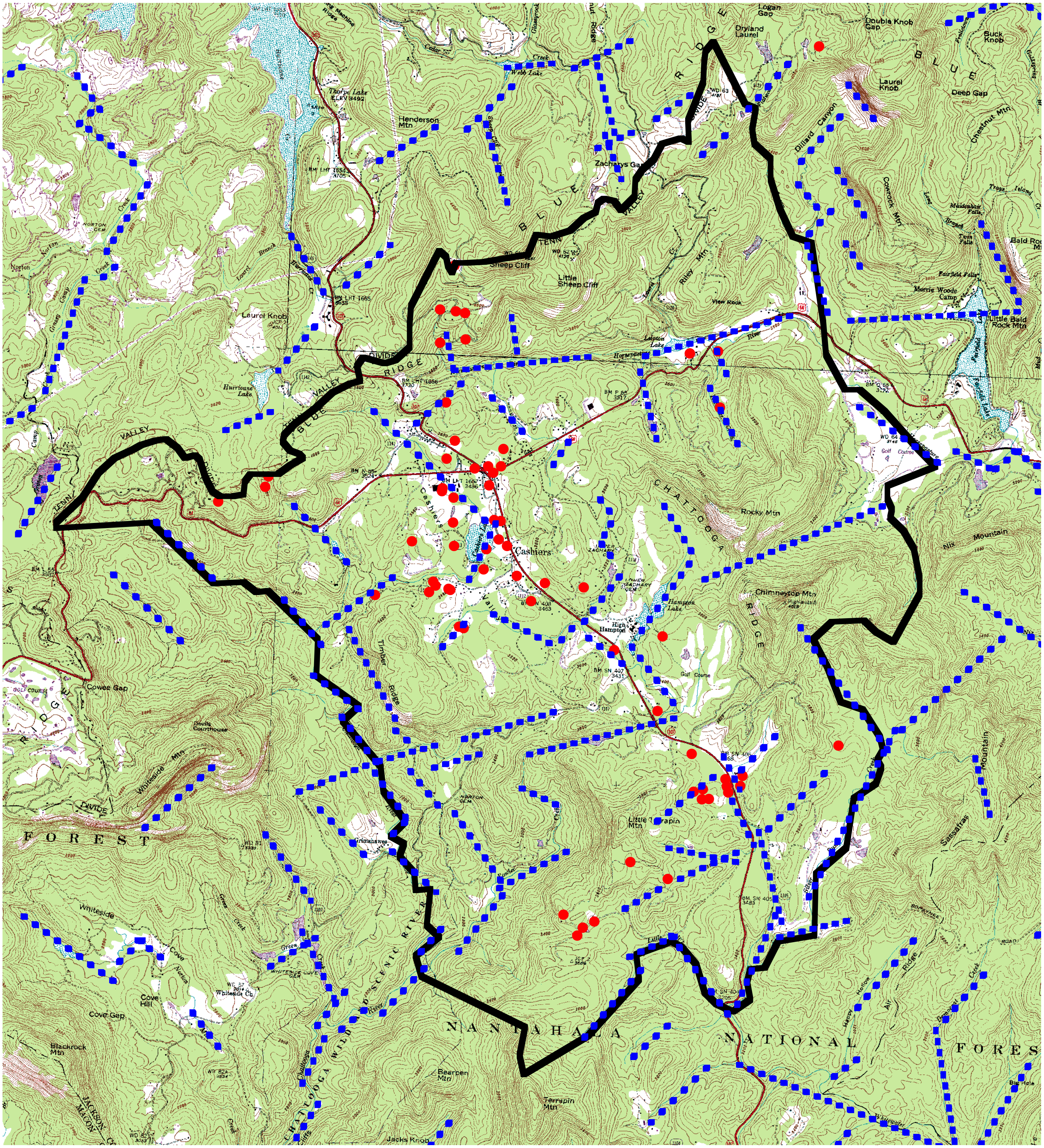


Figure 7: Representative Calculated Natural Water Budget
Cashiers, North Carolina Vicinity



Average Precipitation from Highlands 2S, North Carolina Station, 8/1/1948 - 3/31/2004. Data provided by Southeast Regional Climate Center website.
Total runoff calculated by averaging data from stream gauges at Rosman, Prentiss, and Cathey's Creek gauging stations. Data provided by USGS website.
Ground water recharge and overland runoff calculated by hydrograph separation using USGS program PART and stream gauge data from above gauging stations.
Evapotranspiration calculated by subtracting total runoff from total precipitation.

Figure 8: Fracture Trace Map
Cashiers, North Carolina Vicinity



- Fracture Trace/Structural Lineation
- Study Area
- Cashiers wells for arcview.DBF

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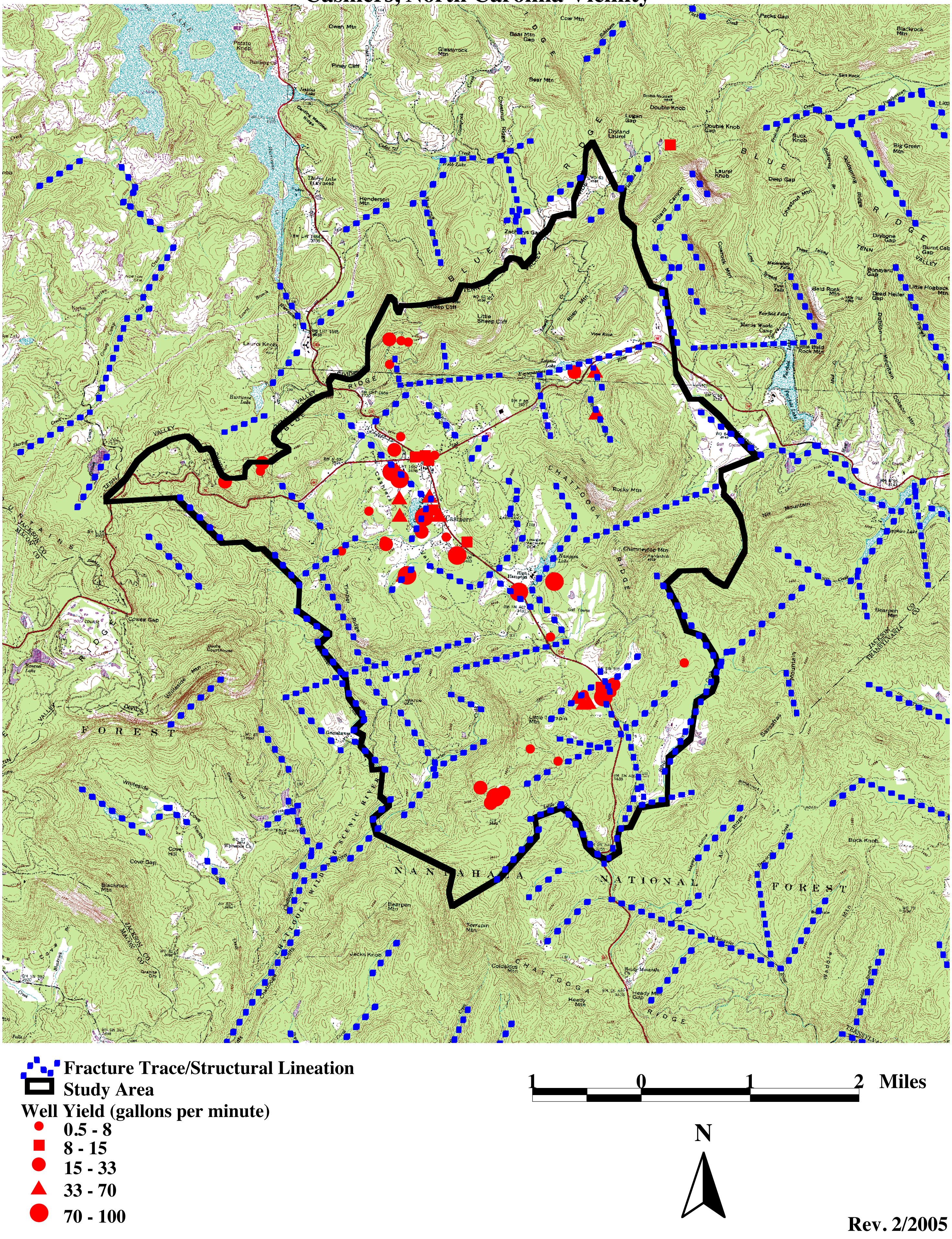
Figure 9: Spatial Analysis of the Yield of Wells
Cashiers, North Carolina Vicinity



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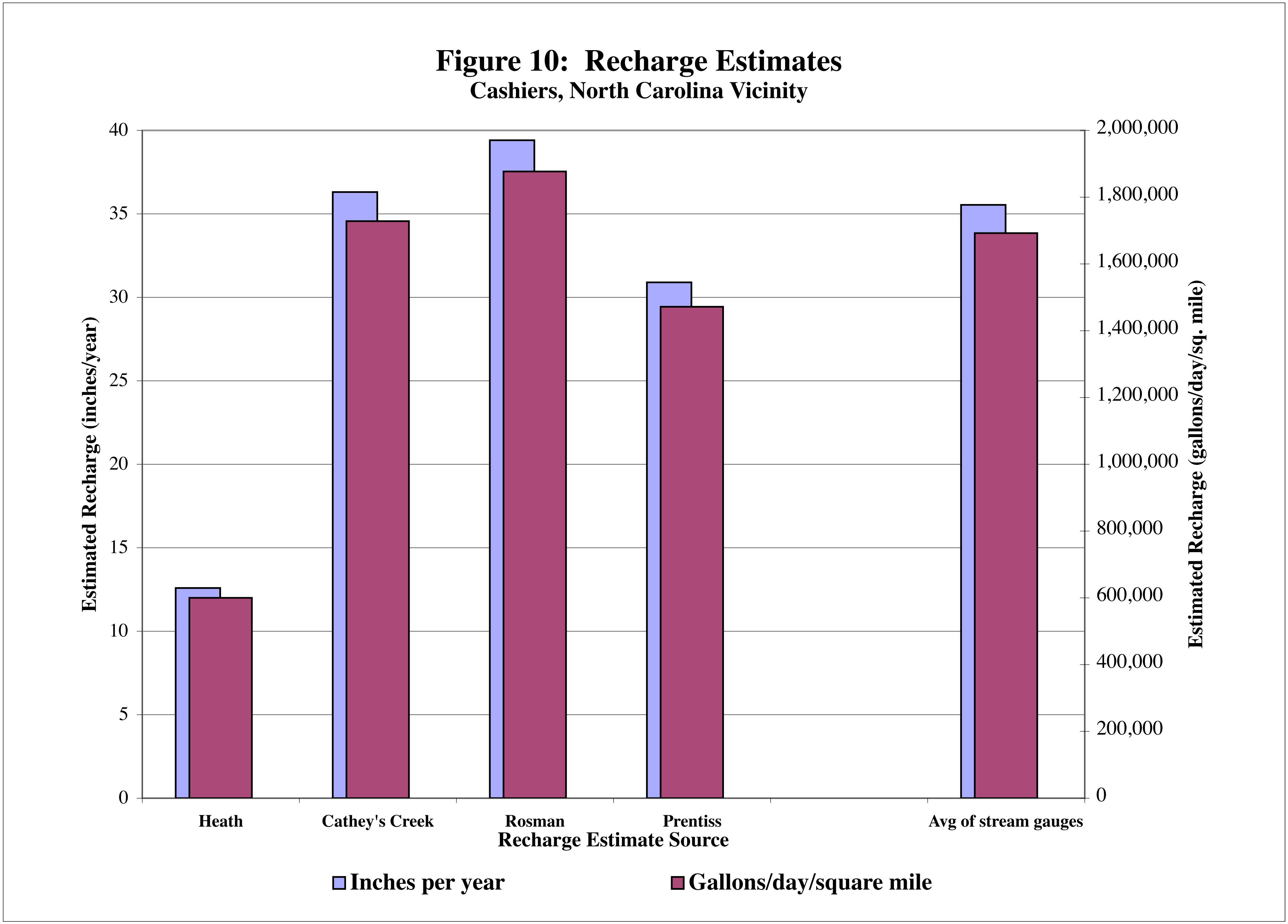

Figure 10: Recharge Estimates
Cashiers, North Carolina Vicinity
Estimated Recharge (inches/year)
Estimated Recharge (gallons/day/sq. mile)
40
35
30
25
20
15
10
5
0
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Heath
Cathey's Creek
Rosman
Prentiss
Avg of stream gauges
Recharge Estimate Source
Inches per year
Gallons/day/square mile

Figure 11: Hydrograph Showing Well Interference
Bear Log Road Well
Cashiers, North Carolina

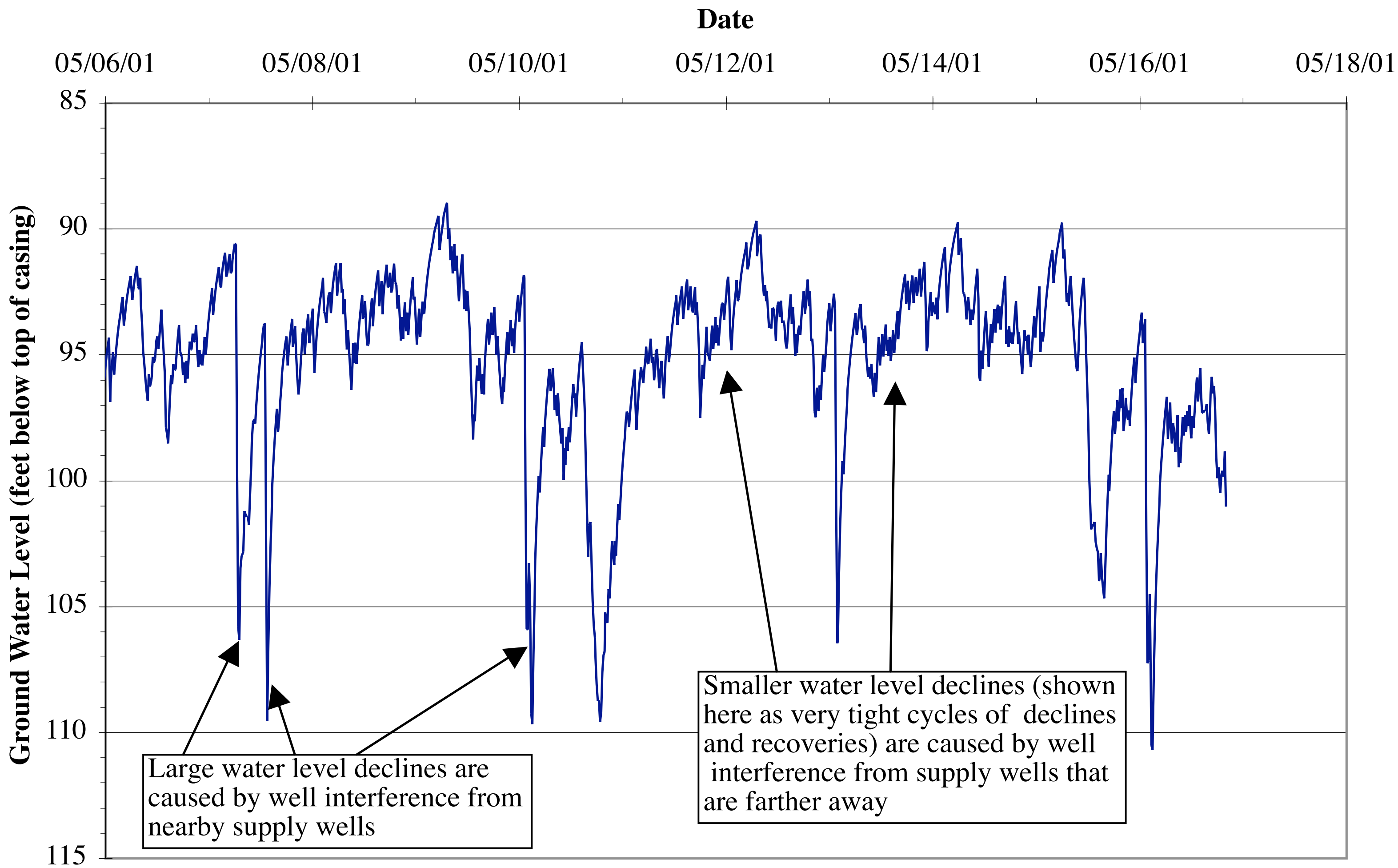

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Table I: Details for Stream Gaging Stations Used in Hydrograph Separation
Cashier, North Carolina Vicinity

Gauge Name	Body of Water Measured	Latitude (degress)	Longitude (degrees)	Drainage Area (sq. miles)	Period of Record
Rosman	French Broad River	35.14222222	82.82444444	67.9	1936-2000
Prentiss	Little Tennessee River	35.14694444	83.37972222	140	1945-2000
Brevard	Catheys Creek	35.21111111	82.78333333	11.7	1987-2000

Gauge Name	Mean Streamflow (cubic feet/second)	Mean Streamflow (inches/year)	Mean Baseflow (cubic feet/second)	Mean Baseflow (inches/year)	Percent of Streamflow composed of Baseflow
Rosman	238.54	47.72	197	39.41	82.6
Prentiss	388.59	37.7	318.47	30.9	82
Brevard	36.66	42.56	31.29	36.32	85.3

Average	**221**	**43**	**182**	**36**	**83**

Note: Averages were rounded to the nearest whole number for ease of comparison to precipitation values.

Table II: Select Details for Wells Used in Spatial Well Yield Analysis
Cashiers, North Carolina Vicinity

Well Name	5-Minute Quad	Latitude	Longitude	Well Owner	Total Depth (feet)	Casing Depth (feet)	Well Yield (gallons /minute)	Comments
Arrowhead Well	S 92Y7	35.090845	83.078517	Wade Hampton	800		1.5	"Dry" well at Wade Hampton
Bear Log Road Well	T 93A2	35.068429	83.087022	Found Forest development	400	42	30	Located in Found Forest
Big Sheepcliff BW1	S 93I1	35.133919	83.105025					No info on well other than yield was unsuitable.
Big Sheepcliff BW2	S 93L6	35.126675	83.103373					No info other than well yield was unsuitable.
Big Sheepcliff Well 1	S 93L2	35.126234	83.106395		350	20	6	
Big Sheepcliff Well 2	S 93L3	35.129397	83.104667		320	20	8	
Big Sheepcliff Well 3	S 93L4	35.129265	83.103519		480	20	8	
Big Sheepcliff Well 4	S 93L5	35.129509	83.106563		400	20	22	
Blozan Well	S 93T10	35.116001	83.098271		50			Well flows 2-3gpm.

Note: Blank fields indicate information was not available.

Table II: Select Details for Wells Used in Spatial Well Yield Analysis
Cashiers, North Carolina Vicinity

Well Name	5-Minute Quad	Latitude	Longitude	Well Owner	Total Depth (feet)	Casing Depth (feet)	Well Yield (gallons /minute)	Comments
Canoe Point Lot #22 Well	S 93S16	35.106295	83.103360	Tim Greene	300	42	60	
Canoe Point Lot #3 Well	S 93S15	35.108594	83.103926	Tim Greene	400	21	50	
Canoe Point Well #1	S 93T12	35.107087	83.098368	Tim Greene	200	28	12	
Cashiers Plastic Well #1	S 93S1	35.111642	83.105420	Cashiers Plastic Company				
Cashiers Plastic Well #2	S 93S2	35.118989	83.105354	Cashiers Plastic Company	375		100	
Cedar Creek Woods Well #1	S 92O1	35.126194	83.076399	Cedar Creek Woods	80		32	Located approx 30 feet from Cedar Creek Woods Well #2
Cedar Creek Woods Well #2	S 92O2	35.126194	83.076399	Cedar Creek Woods	400		14	Located approx 30 feet from Cedar Creek Woods Well #1
Cedar Hill Well #1	S 92O3	35.126513	83.043065	Cedar Hill	300		55	
Cedar Hill Well #2	S 92O4	35.120984	83.072561	Cedar Hill	550	21	38	

Note: Blank fields indicate information was not available.

Table II: Select Details for Wells Used in Spatial Well Yield Analysis
Cashiers, North Carolina Vicinity

Well Name	5-Minute Quad	Latitude	Longitude	Well Owner	Total Depth (feet)	Casing Depth (feet)	Well Yield (gallons /minute)	Comments
Chattooga Well	T 92E4	35.083135	83.069636		500		100	Formerly Wade Hampton Well #6
Chestnut Square Well	S 93T4	35.114334	83.098449		600	175	2	
Continental Cliffs II Well	S 93R3	35.112378	83.126286	Continental Cliffs II			25	
Continental Cliffs Well #1	S 93R1	35.109670	83.132190	Continental Cliffs	800		23	
Continental Cliffs Well #2	S 93R2	35.111322	83.126586	Continental Cliffs	1000	21	7	Drawdown test gave 7gpm. Well plate says 15 gpm yield.
Cornucopia Restaurant	S 93T3	35.106485	83.097340	Scott Peterkin			40	Well construction unknown. Provides water for several properties. Pump 40' down.
Davis Well	S 93S12	35.101615	83.106441	Abe Davis				
Exxon Well	S 93S5	35.114009	83.101615	Ralph and Jim Nichols	160	20	12	
Farmers' Market Well	S 93T5	35.113659	83.099390		450	30	15	Originally 100' deep. Redrilled to 450' in 2000.

Note: Blank fields indicate information was not available.

Table II: Select Details for Wells Used in Spatial Well Yield Analysis
Cashiers, North Carolina Vicinity

Well Name	5-Minute Quad	Latitude	Longitude	Well Owner	Total Depth (feet)	Casing Depth (feet)	Well Yield (gallons /minute)	Comments
Flo Smith Well	S 93S13	35.102275	83.105702	John and Flo Smith	120		20.0	
Found Forest Lot #17 Well	T 92E5	35.074327	83.076469	Found Forest	800	83	7	
Found Forest Lot #24 Well	T 92E6	35.075865	83.081022	Found Forest	700		4	Yield originally 6 gpm. Now 4 gpm
Gene Hooper Well	S 93T7	35.106109	83.099820	Gene Hooper	300		100	No construction data other than depth.
Headwaters "Dry Hole"	S 92Y3	35.086727	83.074200	Headwaters	800			Insufficient yield. Water level collected 1/21/2001.
High Hampton Well #5	S 93U1	35.096657	83.083999	High Hampton Inn and Country Club			100	Construction info unknown. Yield from personal communication.
High Hemlock	S 92D1	35.156950	83.062450	Jim Monahan	300	50	15	Top of bedrock 48 feet BGL
John C. Moore Well	S 93T13	35.102720	83.087940	John C. Moore				No construction info
Lake apartments	S 93S4	35.104073	83.100033		190	63	20	

Note: Blank fields indicate information was not available.

Table II: Select Details for Wells Used in Spatial Well Yield Analysis
Cashiers, North Carolina Vicinity

Well Name	5-Minute Quad	Latitude	Longitude	Well Owner	Total Depth (feet)	Casing Depth (feet)	Well Yield (gallons /minute)	Comments
Len Pleasant Well	S 93S14	35.106562	83.108774	Len Pleasant	500	21	2	
Market Basket Well	S 93T8	35.112356	83.099819	Market Basket				
Midnight Farms	S 93S6	35.116627	83.104113		84	70	8	Well #44 in 1966 GW recon study of area
Mikie Well	T 93A3	35.069869	83.085023	Found Forest development	300	73	30	Located in Found Forest
Moynihan Well	S 93S7	35.102675	83.106039	Paul Moynihan	400	93	3.5	
New well	T 93A4	35.070397	83.088805	Found Forest development			20	
Nichols Well	S 93T6	35.114254	83.099995	Jim Nichols	175		12	Near site of Munson well, well #46 in 1966 GW recon study of area
Oakmont Lodge	S 93S10	35.114842	83.105044	Mike Grille	87	33	33	Well #45 in 1966 GW recon study of area
Old Cashiers School Well	S 93T2	35.103579	83.096039		90		6	Well #47 in 1966 GW recon study of area

Note: Blank fields indicate information was not available.

Table II: Select Details for Wells Used in Spatial Well Yield Analysis
Cashiers, North Carolina Vicinity

Well Name	5-Minute Quad	Latitude	Longitude	Well Owner	Total Depth (feet)	Casing Depth (feet)	Well Yield (gallons /minute)	Comments
Orchard Well	S 93T14	35.103002	83.092656	The Orchard	300	63	10	
Peterkin Well	S 93S11	35.101120	83.112906	Scott Peterkin	300		0.5	Water bearing zone at 100 feet
Print Shop Well	S 93T9	35.108932	83.098265	Marcia Moore				
Pulley Well	S 93S3	35.111042	83.103987	A. William McKee			100	
Roberta Well	T 93A1	35.069221	83.086380	Found Forest development	360	48	75	Located in Found Forest
Ryder Well	S 93S8	35.101956	83.103923	Monica Ryder				
Santi Well	S 93S9	35.102011	83.104148	Jim Santi				
Sheepcliff Wood Well	S 93L1	35.120372	83.105340					No info on well.
Silver Springs Well	S 92X1	35.088147	83.056681	Wade Hampton	1000		2.5	Did not sustain yield. Well not currently used.

Note: Blank fields indicate information was not available.

Table II: Select Details for Wells Used in Spatial Well Yield Analysis
Cashiers, North Carolina Vicinity

Well Name	5-Minute Quad	Latitude	Longitude	Well Owner	Total Depth (feet)	Casing Depth (feet)	Well Yield (gallons /minute)	Comments
South Well	S 92Y8	35.083793	83.068239	Wade Hampton	1000	51	2	"Dry" well at Wade Hampton
Timber Ridge Well #1	S 93V1	35.098229	83.102155	Timber Ridge development	555	91	100	
Timber Ridge Well #2	S 93V2	35.098326	83.102718	Timber Ridge development			70	Tag missing. Yield info from personal communication
Wade Hampton Well #10	T 92E3	35.083026	83.073785	Wade Hampton	800	21	40	
Wade Hampton Well #3	S 92Y6	35.084838	83.068028	Wade Hampton	380		22	
Wade Hampton Well #4	S 92Y4	35.084416	83.070027	Wade Hampton	400		11	Near Headwaters
Wade Hampton Well #5	S 92Y5	35.083689	83.069825	Wade Hampton	400			Never tested for yield.
Wade Hampton Well #7	T 92E1	35.082422	83.071954	Wade Hampton	800	50	40	Located at Headwaters
Wade Hampton Well #8	T 92E2	35.082325	83.072748	Wade Hampton	800	50	40	

Note: Blank fields indicate information was not available.

Table II: Select Details for Wells Used in Spatial Well Yield Analysis
Cashiers, North Carolina Vicinity

Well Name	5-Minute Quad	Latitude	Longitude	Well Owner	Total Depth (feet)	Casing Depth (feet)	Well Yield (gallons /minute)	Comments
Wade Hampton Well #9	S 92Y1	35.098211	83.078275	Wade Hampton	425	42	100	
Wade Hampton Well #9	S 92Y2	35.083345	83.072684	Wade Hampton	800	21	8	Located at Headwaters
Will McKee	S 93T1	35.101163	83.094175	Will McKee			100	Well tag defaced. Couldn't get construction info from it.
Woodshop Barn Well	S 93T11	35.106001	83.099050	Tim Greene	100	42	40	

Note: Blank fields indicate information was not available.

Table III: Summary of Recharge Estimates
Cashiers, North Carolina

Gauge Name	Period of Record Used	Calculated Baseflow (gallons/day/square mile)	Calculated Baseflow (inches/year)
Rosman	1936-2000	1,876,551	39.4
Prentiss	1945-2000	1,471,337	30.9
Brevard	1987-2000	1,728,464	36.3
	Average	1,692,117	36

Estimated Recharge in Study Area

Estimate Source	(gallons/day/square mile)	(inches/year)
North Carolina Division of Water Resources (NCDWR)	1,692,117	36
Heath (1994)	600,000	13

Note: NCDWR estimated recharge for the study area by assuming that recharge in the study area approximates the average of the calculated baseflow for the Rosman, Prentiss, and Brevard stream gauging stations over the stated periods of record. Average baseflow was rounded to the nearest whole number for ease of comparison to precipitation values.