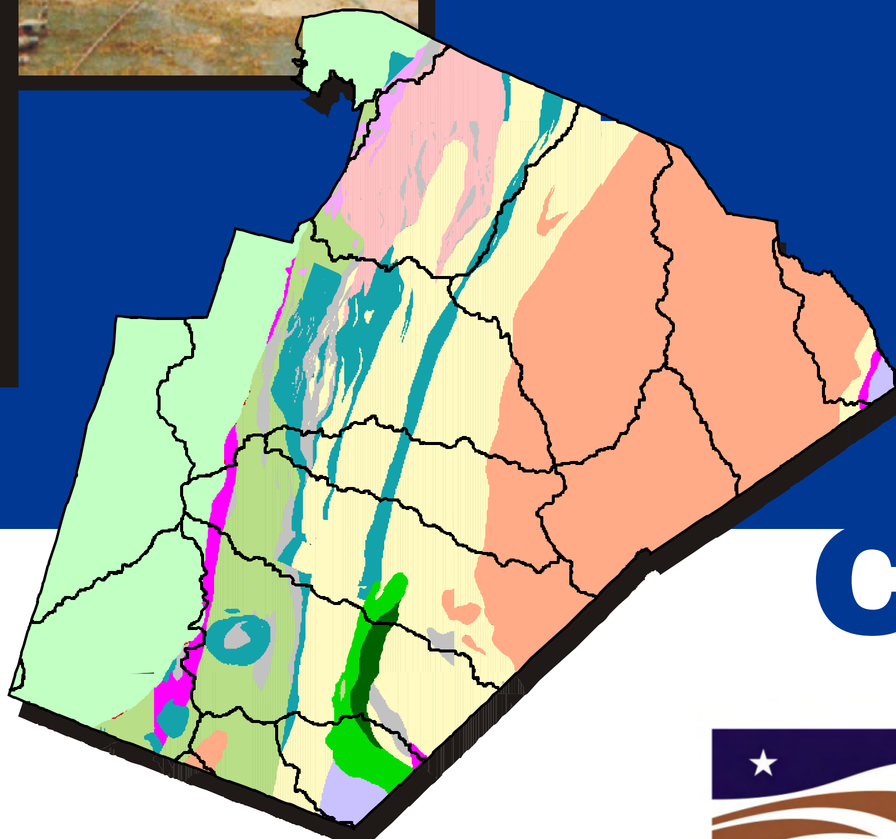

# Wake County

## Comprehensive Groundwater Investigation

June 2003

*Final Report*

CDM

WAKE COUNTY
NORTH CAROLINA

# Executive Summary

Groundwater has been an important component of Wake County's water resources. Almost one-quarter of the County's residents rely upon groundwater for their water supply. Recent Wake County environmental initiatives, including the *1998 Comprehensive Water/Sewer Plan*, the *Land Use Plan*, and the *Comprehensive Watershed Management Plan* have emphasized the importance of groundwater as a crucial current and future water supply, primarily to those areas of the County where the extension of water and sewer service is not planned, such as the Non-Urban Areas (NUA) of the Water Supply Watersheds (WSW).

The County recognizes that proper management of water resources is essential to ensure their sustainability. As an extension of the *Comprehensive Watershed Management Plan*, the County has initiated a *Comprehensive Groundwater Investigation* to ascertain the quality and sustainability of groundwater, and to provide the information necessary to implement proactive efforts for responsible management and use of the resource. This report presents the findings of the yearlong investigation.

### *Defining Groundwater Resource Sustainability*

Groundwater resource sustainability can be generally defined as "*the development and use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences*" (Alley et al, 1999). The definition of "unacceptable consequences" can be largely subjective. As part of this investigation, Wake County has been asked to consider what impacts are deemed unacceptable. Environmental impacts that result from groundwater withdrawals may include reduced baseflow to streams, lower lake and pond levels, and "dry" wetlands. Social and economic consequences can occur when a large withdrawal of groundwater, or the combination of many smaller, localized withdrawals (artificially) lower the water table. This can have the effect of reduced well yields or dry wells for other nearby users.

### *Groundwater Quantity*

Groundwater resource sustainability must be defined within the context of the complete hydrologic cycle. In light of this, a complete water budget was prepared at the 11-digit hydrologic unit code (HUC-11) scale. The 14 drainage basins considered during the investigation are shown in **Figure ES-1**.

A water budget is an accounting of water movement, both natural and artificial, within the hydrologic cycle. As a result of developing the water budgets, a number of estimates and important observations relating to the County's groundwater resources became apparent:

- Approximately 141,000 County residents rely on groundwater for drinking and other everyday uses. Two-thirds of that total (93,000) obtain water from domestic wells. The remaining 48,000 are served by one of 275 community water systems (CWS). The areas of the County where groundwater is withdrawn by domestic and CWS wells are shown in **Figure ES-2**.

- Eighty percent of all groundwater withdrawals occur in the Lower Falls Lake, Upper Neuse, Crabtree Creek, Middle Creek, and Swift Creek basins. The largest amount of groundwater withdrawal occurs in the Lower Falls Lake drainage basin, which also has the highest per capita withdrawal rate, at 100 gallons per person per day. Figure **ES-1** shows the estimated amount of current groundwater withdrawals (in million gallons per year) in each of the 14 drainage basins.

- Groundwater withdrawals in the County (for all uses) currently total about 14 million gallons per day (mgd). Up to 8 mgd of water is estimated to return to the groundwater system through onsite wastewater treatment systems. Accounting for this return of water to the aquifer, the total net groundwater consumption is estimated to be approximately 6 mgd.

- On an average annual basis, approximately 15 percent of precipitation in Wake County recharges the groundwater system. In the western part of the County, the clayey soil of the Triassic basin limits recharge to around six percent (or lower) of precipitation. Up to 19 to 20 of precipitation becomes recharge in areas where more permeable rocks and soils are present.

- Baseflow, the component of streamflow that comes from discharging groundwater typically accounts for between 34 and 55 percent of total streamflow in Wake County, with an average of approximately 45 percent. Baseflow may account for nearly all of the streamflow during periods of drought.

- The natural components of the hydrologic cycle (i.e., precipitation, evapotranspiration, runoff from pervious surfaces, and baseflow) are clearly dominant in Wake County, accounting for over 90 percent of the water on both sides of the water budget equation. The artificial components (i.e., surface and groundwater discharges and withdrawals and runoff from impervious surfaces) are still relatively minor.

- Groundwater withdrawals represent a small percentage of the water budget on an average annual basis, but increase in relative degree during a prolonged drought, such as the one which occurred in Wake County between 1999 and 2002.

- In the Lower Falls Lake drainage basin where groundwater withdrawals are the highest in the County, current net groundwater consumption is less than six percent of average annual recharge. In 8 of the remaining 13 basins, current net groundwater consumption is less than one percent of average annual recharge.

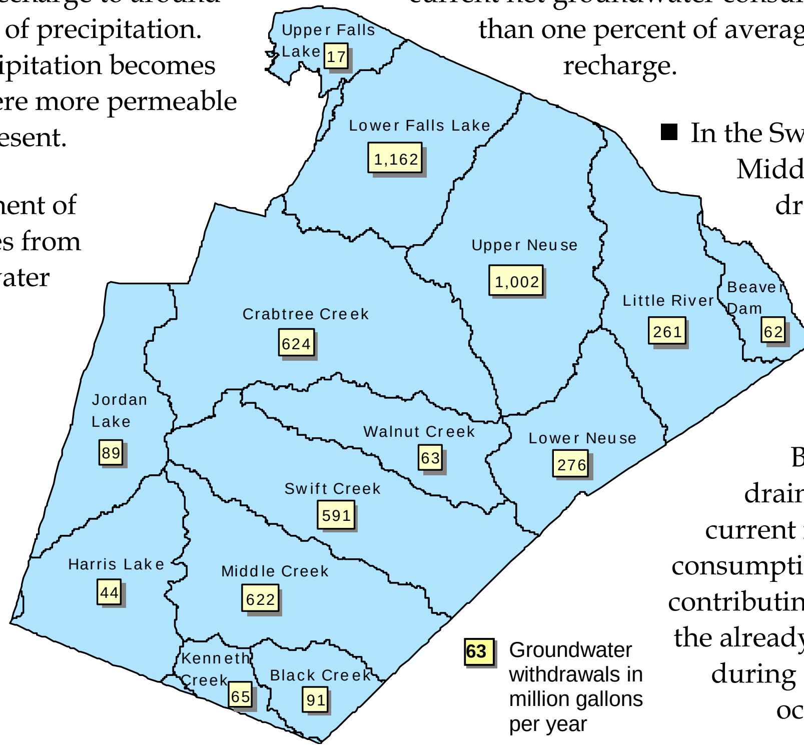


**Figure ES-1**. Present day groundwater withdrawals in the 14 HUC-11 drainage basins range from a low of 17 to a high of 1,162 million gallons per year. Since the drainage basins vary significantly in size, an assessment of the relative impacts of these withdrawals is also important.

- In the Swift Creek and Middle Creek drainage basins, and to a lesser extent in the Crabtree Creek, Kenneth Creek, and Beaver Dam drainage basins, current net groundwater consumption is contributing to the loss of the already low baseflow during dry periods that occur relatively infrequently and for short durations. In the Upper Falls Lake, Jordan Lake, Harris Lake, and Black Creek drainage basins, net groundwater consumption, although low, is probably extending the period during which streams are already dry.

- The regolith – the part of the groundwater system where most of the water is stored – is relatively thin in the area of the County underlain by the Triassic basin in the west and the Rolesville granite in the northeast. These two areas are more susceptible to reduced well yields and dry wells during droughts than are other areas of the County.

- Groundwater availability is also a function of how much water can actually be extracted from the ground. In the Triassic basin low yielding wells naturally limit the use of the resource. Maximum well yields are typically no greater than 25 gallons per minute (gpm) in this area, and average well yields are typically well below 10 gpm. In other areas, including the southeastern part of the County, where Coastal Plain sediments overlie bedrock, well yields are more favorable to larger groundwater withdrawals. Maximum well yields above 100 gpm have been reported.

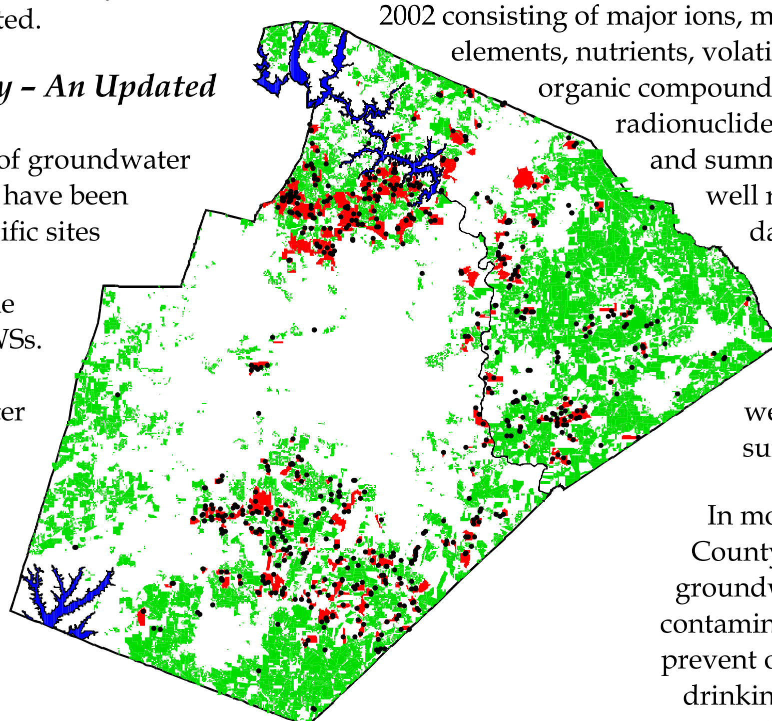

**Figure ES-2**. Areas in red represent developments served by CWSs. Green areas represent parcels where a domestic well is located, or in a few instances receive water from a CWS well. CWS wells are shown in black.

### *Groundwater Quality – An Updated Perspective*

Previous investigations of groundwater quality in Wake County have been mostly restricted to specific sites with known pollution sources, or to support the development of new CWSs. Few investigations have summarized groundwater quality countywide.

Data characterizing the quality of the groundwater provided by the CWSs in Wake County are abundant. The North Carolina Rules Governing Public Water Systems require routine sampling and analysis from CWSs to ensure that the water is safe to drink. Much less data are available, however, characterizing the quality of groundwater obtained from domestic wells, which serving individual residences. CWS wells in Wake County are located primarily bordering municipal limits. The majority of CWS wells are located in the Lower Falls Lake, Middle Creek, and Swift Creek drainage basins. Domestic wells are also numerous in these basins; however, they occur in areas served by few or no CWSs. These include the Upper Falls Lake, Jordan Lake, Kenneth Creek, Harris Lake Beaver Dam, and Black Creek drainage basins. Because routine sampling and analysis of water from domestic wells is not required, less data are available to characterize the groundwater quality in these areas.

As part of this investigation, current and historical water quality data from 275 CWSs and over 600 domestic wells were obtained and reviewed. Water quality records from CWSs from 1979 to 2002 consisting of major ions, metals and trace elements, nutrients, volatile and synthetic organic compounds, and radionuclides were reviewed and summarized. Domestic well records containing data for inorganic and organic constituents (pesticides) from 1998 to 2002 were reviewed and summarized.

In most areas of Wake County served by CWSs, groundwater is void of contaminants that would prevent or restrict its use as drinking water. Disinfection, pH adjustment, and sequestration to remove iron and manganese are the only treatment methods used in the majority of the systems. Infrequently, additional treatment methods are used to bring the water in compliance with drinking water standards. Several CWSs in Wake County treat groundwater to reduce the level of nitrates, radionuclides, and/or organic compounds to below drinking water standards.

Arsenic was detected above drinking water standards in one percent of recent samples from

CWS and domestic wells. Occurrences of arsenic in Wake County groundwater may result from natural sources, including minerals dissolved from rocks or from man-made sources including fumigants formerly used in tobacco farming and treated lumber.

Nutrients (i.e., nitrate) are generally not found in groundwater or are found only at levels below drinking water standards.

Chlorinated solvents and petroleum products most often associated with leaking underground storage tanks were detected in less than one percent of recent samples from CWSs. These compounds are more likely to occur in groundwater in the urban areas where CWSs are generally absent. These compounds were not analyzed in samples from domestic wells that were reviewed in this investigation.

Ethylene dibromide (EDB) and 1,2-dichloropropane, two compounds formerly used as soil fumigants in tobacco farming, continue to be detected in a small percentage of samples from CWSs. The presence of EDB has, in the past, resulted in the abandonment of CWS wells. Historical detections of these compounds in CWS wells have generally been limited to the eastern parts of Wake County.

Radionuclide concentrations in groundwater are highest in the northeast portion of the County and generally coincide with the Rolesville granite geologic unit. Limited data are available to characterize radon in groundwater in Wake County. Testing for radon is not yet required under the rules of the Safe Drinking Water Act. The limited available data suggest that radon in groundwater is likely to exceed the proposed drinking water standard of 300 picoCuries per liter (pCi/L) and the proposed alternate standard of 4,000 pCi/L in the northeastern part of the County, and may exceed the proposed drinking water standards in other areas of the County.

### *What Does the Future Hold?*

The future trend in the development of groundwater resources in Wake County remains unclear. Water supply plans prepared by the municipalities of Wake County suggest that fewer residents will rely on groundwater as their water supply in 2020. Yet, over the last several years the number of people connected to a CWS, plus the number of people served by a new domestic well has increased by approximately 4,000 per year. The rate at which municipalities extend public water (and sewer) to areas formerly served by groundwater will play a significant role in determining the direction of this trend.

Recharge rates in the Upper Falls Lake, Lower Falls Lake, Little River, and Swift Creek NUA/WSWs are sufficient to sustain additional water supply withdrawals, as development continues at current allowable residential zoning densities. However, increased groundwater consumption in these areas may result in a decrease in stream baseflow in periods of average precipitation and cause some streams to go dry during extended periods of low precipitation.

Accompanying the continued population growth in Wake County will be increasing pressures from development that may degrade groundwater quality. Contaminants common to urban environments include nitrates (in unsewered areas or where fertilizers are used), petroleum products (from leaking underground storage tanks), metals and nutrients (from recharge of stormwater) or volatile organic compounds (from spills or improper disposal), to name a few.

### *What Are the Next Steps?*

The investigation has found that the County's groundwater resources are of sufficient quantity and quality to sustain present and anticipated future water demand. However, in certain areas, impacts such as reduced streamflow will continue to occur, and become more pronounced especially during periods of drought.

In response to these and other findings of this investigation, recommendations to address identified data gaps or areas of additional study have been developed. The recommendations are aimed at furthering the understanding of significant aspects related to groundwater quantity and quality.

***Recommendation No. 1*** - The local governments and citizens of Wake County have demonstrated a commitment to protecting, preserving and restoring the quality and quantity of the County's water resources through their support of recent environmental initiatives, which include the Comprehensive Watershed Management Plan, the Consolidated Open Space Plan, Growth Management Strategies, and the Comprehensive Groundwater Investigation. Based on the findings and recommendations of these environmental initiatives it is recommended that Wake County take a leadership role in planning and developing an Environmental Monitoring Program for Wake County. The Environmental Monitoring Program would be used by the local governments and citizens of Wake County to closely monitor trends in the health and condition of water resources in Wake County, and establish benchmarks and performance metrics to monitor the effectiveness of strategies recommended in the various environmental initiatives for protecting, preserving and restoring the quality and quality of water resources in Wake County. It is further recommended that the Environmental Monitoring be implemented, managed and funded as a multi-jurisdictional project, involving local, state and federal governments, departments and agencies, respectively.

***Recommendation No. 2*** – Specific to groundwater resources, it is recommended that the Environmental Monitoring Program include a Long-Term Monitoring Well Network, which would include the installation of monitoring wells and stream gaging stations throughout Wake County. The Long-Term Monitoring Well Network will focus specifically on monitoring groundwater resource conditions (quality and quantity) in Wake County on a long-term basis.

***Recommendation No. 3*** – The purpose of the Comprehensive Groundwater Investigation was to conduct a thorough assessment of current groundwater conditions in Wake County with regard to quality and quantity, and to also conduct an assessment of future groundwater conditions under currently adopted growth and development policies and regulations. To develop recommendations as to "how" groundwater resources should be used and managed in the future, it is recommended that the County implement a community-based process to develop principles and policies for groundwater resource sustainability. As an initial step in this process, groundwater resource sustainability should be defined as it pertains specifically to Wake County. Once the principles and policies for groundwater resource sustainability have been developed, then Wake County can initiate efforts to prepare strategies that can be implemented to ensure that the agreed upon definition of groundwater resource sustainability can be met.

***Recommendation No. 4*** – The results of the water budget suggest that at the HUC-11 drainage basin scale, the groundwater system is not stressed at current residential densities. However, insufficient data exist to quantify potential impacts from development projects at a smaller, more localized scale. Therefore, it is recommended that Wake County work with the NCDENR DWQ Groundwater Section to assess the water quantity and quality impacts to both surface and groundwater resources from development projects. The NCDENR DWQ Groundwater Section has proposed such a study to Wake County as part of the Piedmont and Mountains Resource Evaluation Program (PMREP).

***Recommendation No. 5*** – As part of Wake County's Environmental Stewardship Agenda, it is recommended that Wake County launch a public education campaign to provide basic information about groundwater, wells, and the risks and responsibilities of well ownership. The campaign should be implemented to accomplish the following goals:

a. Provide information that will assist citizens in performing appropriate due diligence when considering housing choices that rely upon private wells or community wells;

b. Educate well owners as to the importance of proper groundwater well maintenance and wellhead protection; and

c. Encourage groundwater well owners to conduct periodic water quality testing.

***Recommendation No. 6*** – While there appears to be sufficient data to characterize the quality of community water supply wells in the County, there is an acknowledged lack of groundwater quality data for domestic wells. Therefore, it is not possible to characterize the quality of domestic wells in Wake County. To address this data gap in water quality, it is recommended that Wake County undertake the following activities:

a. Conduct a domestic well testing program. Recognizing that only a small fraction of the approximately 37,000 domestic wells can be feasibly and economically tested, the program should identify and target priority areas including eastern parts of the County where constituents formerly used in soil fumigants (e.g., EDB, 1,2-dichloropropane, and arsenic) have been detected in CWS wells. A thorough review of historical aerial photographs to identify former locations of tobacco farming should be performed to assist in identifying priority areas for sampling related to these constituents. Other priority areas should include those where domestic wells are located in urban areas. As a component of the testing program, a domestic well water quality database should be created.

b. Implement a process to collect water quality data associated with new construction. Wake County's current well regulations require testing for coliform bacteria. Under this recommendation, the list of potential water quality parameters would be expanded to include inorganics and nutrients, and in certain areas, organic compounds, radon, and radionuclides. All water quality data from new wells should be incorporated into the domestic well water quality database.

***Recommendation No. 7*** – It is recommended that Wake County conduct a countywide groundwater quality assessment focused on radon and radionuclides. Groundwater sampling and analysis should be from existing domestic wells, especially in the areas not served by CWSs. Radon in indoor air should also be investigated, since the majority of health concerns associated with radon are from inhalation of radon gas.

***Recommendation No. 8*** – It is recommended that Wake County implement a process that would require well drillers to report to the Wake County Department of Environmental Services the location and depth of attempted new wells that do not yield sufficient water. The data would be used by Wake County staff to identify additional areas that may be unfavorable for groundwater development.

# Contents

# Figures

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# Acronyms and Abbreviations

| | |
|---|---|
| AMCL | Alternate Maximum Contaminant Level |
| APRSA | Appalachian Valley- Piedmont Regional Aquifer System |
| BF | Baseflow |
| BTEX | Benzene, Toluene, Ethylene, and Xylene |
| $CaCO_3$ | Calcium Carbonate |
| $Ca^{2+}$ | Calcium Ion |
| $CO_3^{2-}$ | Carbonate Ion |
| CWS | Community Water System |
| DBP | Disinfection By-Product |
| DRP | Division of Radiation Protection |
| DWQ | Division of Water Quality |
| DWR | Division of Water Resources |
| EDB | Ethylene Dibromide |
| EDR | Estimated Domestic Recharge |
| EDW | Estimated Domestic Withdrawal |
| EPA | Environmental Protection Agency |
| ET | Evapotranspiration |
| ETJ | Extra-Territorial Jurisdiction |
| $Fe^{2+}$ | Iron |
| GAC | Granular Activated Carbon |
| GIS | Geographic Information System |
| GSAC | Groundwater Study Advisory Committee |
| GNF | Gneiss, Felsic |
| gpd | gallons per day |
| GWW | Groundwater Withdrawal |
| $HCO^{3-}$ | Bicarbonate Ion |
| HUC-11 | 11-Digit Hydrologic Unit |
| HUI | Heater Utilities, Inc. |
| IFI | Igneous, Felsic intrusive |
| LWSP | Local Water Supply Plan |
| MCL | Maximum Contaminant Level |

| | |
|---|---|
| MCLG | Maximum Contaminant Level Goal |
| MDL | Method Detection Limit |
| $Mg^{2+}$ | Magnesium Ion |
| mgd | million gallons per day |
| mg/l | milligrams per liter |
| MIF | Metaigneous Felsic |
| MMM | Multimedia Mitigation |
| MVF | Metavolcanic, felsic |
| MVM | Metavolcanic, mafic |
| Mn2+ | Manganese Ion |
| NCCGIA | North Carolina Center for Geographic Information and Analysis |
| NCDENR | North Carolina Department of Environment and Natural Resources |
| NCDHHS | North Carolina Department of Health and Human Services |
| NC ECONet | North Carolina Environment and Climate Observing Network |
| NCGS | North Carolina Geological Survey |
| NCWS | Non-Community Water System |
| NPDES | National Pollutant Discharge Elimination System |
| NRCS | Natural Resources Conservation Service |
| NRWWTP | Neuse River Wastewater Treatment Plant |
| NTNCWS | Non-Transient Non-Community Water System |
| NUA/WSW | Non-Urban Area/ Water Supply Watershed |
| NURE | National Uranium Resource Evaluation |
| $OH^-$ | Hydroxide Ion |
| P | Precipitation |
| pCi/L | Pico curies per liter |
| PWS | Public Water Supply Section |
| RO | Runoff |
| Rn-222 | Radon-222 |
| RU | Residential Unit |
| SCH | Schist |
| SDWA | Safe Drinking Water Act |
| SFR | Single Family Residence |

| | |
|---|---|
| SOC | Synthetic Organic Compound |
| $Sr^{2+}$ | Strontium Ion |
| SWAP | Source Water Assessment Program |
| SW Disch | Surface Water Discharge |
| SWW | Surface Water Withdrawal |
| TM | Technical Memorandum |
| TNCWS | Transient Non-Community Water System |
| TRI | Triassic Sedimentary Rocks |
| mg/l | Micrograms per Liter |
| UNC | University of North Carolina |
| USDA | United States Department of Agriculture |
| USGS | United States Geological Survey |
| UST | Underground Storage Tank |
| VOC | Volatile Organic Compound |
| WDES | Wake County Department of Environmental Services |
| WSW | Water Supply Watershed |
| WTP | Water Treatment Plant |
| WW/Ind Rech | Wastewater and Industrial Recharge |
| WWTP | Wastewater Treatment Plant |
| 30Q2 | Lowest monthly average streamflow with a recurrence interval of every two years |
| 7Q10 | Lowest seven consecutive day average streamflow with a recurrence interval of ten years |

# Acknowledgments

Wake County and CDM would like to thank the following individuals for their participation as members of the Groundwater Study Advisory Committee:

| | |
|---|---|
| Allen Hardy | NCDENR Public Water Supply Section |
| Melinda Chapman | United States Geological Survey |
| Tyler Clark | North Carolina Geological Survey |
| Jeri Gray | Water Resources Research Institute |
| Sherry Johnson | Watershed Protection Council, Capital Group Sierra Club, and Neuse River Foundation |
| Harry Letchworth | N.W. Poole Well and Pump Company |
| Tara Lightner | Raleigh Realtors Association |
| Sara Robertson | Robertson Farms |
| Jill Strickler | Heater Utilities, Inc. |
| Terry Stephens | Home Builders Association |
| Dr. Skip Stoddard | North Carolina State University |
| Stephanie Sudano | Town of Holly Springs |
| Nat Wilson | NCDENR Division of Water Resources Groundwater Branch |
| Jay Zimmerman | NCDENR Division of Water Quality Groundwater Section |

Wake County and CDM would also like to thank Rick Bolich (NCDENR Division of Water Quality Groundwater Section) for his role in the Technical Advisory Committee and Dr. Charles Welby, Professor Emeritus, North Carolina State University, for his contributions as a technical advisor.

# Section 1
# Introduction

## 1.1 Background

Between 1990 and 2000, the population of Wake County grew by 201,535, a rise of over 47 percent. Accompanying this growth have been increased pressures to the County's water resources. Surface water has long been recognized as the County's most valuable water resource. Two major reservoirs, Jordan Lake and Falls Lake, serve nearly all of the residents who live within the boundaries of the twelve municipalities of Wake County. However, much of the growth in the past decade has occurred outside of municipal boundaries, in areas where water and sewer service are not provided. In these areas development of the County's groundwater resources has occurred to the point where the number of residents using groundwater for water supply is the among the highest of all North Carolina counties (USGS, 1995).

Building on a recommendation in the *Comprehensive Water/Sewer Plan* (CH2M HILL, 1998) and as an extension of the *Comprehensive Watershed Management Plan* (CH2M HILL, 2003), the Wake County Board of Commissioners approved an effort to perform a countywide groundwater investigation in June of 2002. The overriding purpose of this investigation was to determine the sustainability of the County's groundwater resources. In other words, the investigation was meant to include the collection and analysis of information pertinent to determining if current and future groundwater use can be sustained.

## 1.2 Groundwater Resource Sustainability

Groundwater resource sustainability is not a term that can be easily or universally defined. In the United States Geological Survey (USGS) report titled *Sustainability of Ground-Water Resources* (1999), it is defined as "the development and use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences." While this definition may generally apply in most instances, the definition of "unacceptable consequences" may vary significantly. For example, in an area where limited water resources are strained by a population that requires almost all available water merely to survive, groundwater withdrawals that significantly impact stream flow and lake levels may be deemed acceptable. This is the case occurring in portions of the world such as the West Bank in the Middle East. In other instances protection of stream flow and lake levels may be of equal priority with withdrawals for human or other uses, and a more balanced approach is required.

To further illustrate this point, consider Nassau and Suffolk counties, located on Long Island New York. Both counties rely solely on groundwater for their water supply. Nassau County, with a population of 1.3 million withdraws approximately 180 million gallons per day, or just over 50 percent of the natural recharge to the aquifers (CDM, 1998). Recent studies have determined that this amount of groundwater use is sustainable from a water supply standpoint; however, significant impacts to the nature of Nassau County's streams have occurred. Before development, stormwater represented only 13 percent of streamflow. Presently, stormwater is nearly 50 percent of total flow. The total flowing length of most of the County's south-shore streams has been reduced by over half, and many ponds that used to be filled year-round are now full only after storm events. Nassau County has deemed these impacts acceptable and has developed a definition of sustainability that allows for these impacts. In contrast, neighboring Suffolk County has made it a priority to protect its surface water resources and has defined a level of sustainable groundwater withdrawal that is much lower than in Nassau County.

This investigation was performed to determine, based on available data, if current and future levels of groundwater use in Wake County can be maintained once an agreed upon definition of sustainability has been developed. It is important that Wake County and its stakeholders begin developing definitions for unacceptable consequences and sustainability so that the effective management of the resource can occur.

## 1.3 Stakeholder Involvement

Groundwater is an important resource to many people in Wake County. Recognizing this, the Wake County Department of Environmental Services, at the beginning of this investigation, invited representatives from some of the many groups that regulate, investigate, protect, or use the County's groundwater resources. These included representatives from the USGS, North Carolina Department of Environment and Natural Resources (NCDENR), the Wake County Home Builders Association, Raleigh Realtors Association, the Town of Holly Springs, the North Carolina Geological Survey (NCGS), the Water Resources Research Institute (WRRI), North Carolina State University, Heater Utilities, Inc. (HUI), N.W. Poole Well and Pump, Robertson Farms, and the Watershed Protection Council. Throughout the yearlong investigation, the group, called the Groundwater Study Advisory Committee (GSAC), met each month with members of Wake County and the project team to review and discuss interim findings.

## 1.4 Investigation Objectives

Wake County and its stakeholders, at the beginning of the investigation, identified a number of objectives. Through the objectives, Wake County and its stakeholders tasked the project team to:

- Estimate current total groundwater consumption.
- Estimate future groundwater consumption for various planning horizons.
- Evaluate future conditions based on estimated future groundwater consumption, with current programs and policies in place.
- Estimate groundwater recharge rates countywide.
- Establish a relationship between groundwater and stream baseflow.
- Develop and provide a useful database of information and GIS coverages to assist in future groundwater resource planning.
- Develop a database of well yields and evaluate well yield patterns.
- Assess the groundwater quality countywide, and within each hydrogeologic unit.
- Identify areas where groundwater quality may affect groundwater use.
- Identify where most of the wells are located within the County.
- Provide information to support zoning based on groundwater availability.
- Provide a further understanding of the localized areas where water quality is degraded due to elevated levels of arsenic, radon, pesticides, iron and manganese.
- Prepare and provide public information regarding septic tank and private well operation and maintenance.
- Integrate the interim and final findings of this and other water resource studies, programs, and initiatives.
- Assess the potential increase or decrease of recharge to groundwater due to sanitary sewers (i.e., inflow/infiltration and loss of recharge

from septic tanks in sewered areas) and water distribution piping (leakage).

- Determine the number and location of stream gages needed to support validation/refinement of current assessments and future management of groundwater resources.

- Evaluate the risk to groundwater quality as it relates to various land-use types.

The remainder of this report presents the results of this investigation in light of these objectives. The report is organized as follows: Section 2 discusses the hydrogeologic setting; Section 3 presents the results of water budgets prepared for the County's 14 major hydrologic units; Section 4 presents a summary of existing information characterizing groundwater quality; Section 5 presents an analysis of water supply trends and an assessment of future conditions; and Section 6 contains conclusions and recommendations for further study. Interim Technical Memoranda, meeting agendas and minutes, and other pertinent and supporting information are included in the Appendices.

# Section 2
# Hydrogeologic Setting

## 2.1 Hydrogeologic Units

Wake County lies primarily within the Piedmont Physiographic Province of North Carolina (**Figure 2-1**). The province is characterized by crystalline bedrock overlain by varying thickness of unconsolidated material, called regolith. In the southeast a small portion of the County lies within the Coastal Plain Province, where sandy sediments ranging up to 80 feet or more in thickness overlie the crystalline rock. The physical characteristics of the bedrock and regolith largely determine the water supply potential and quality of the groundwater system in Wake County.

Hundreds of unique rock units have been identified, delineated, and named in Wake County. The NCGS has recently completed a draft update to the *Geologic Map of North Carolina* (1985) for the area covered by the Raleigh 1:100,000-scale Quadrangle. The updated draft version of the geologic map is shown in **Figure 2-2**. Rock unit codes and descriptions can be found in TM No. 1 (Appendix A).

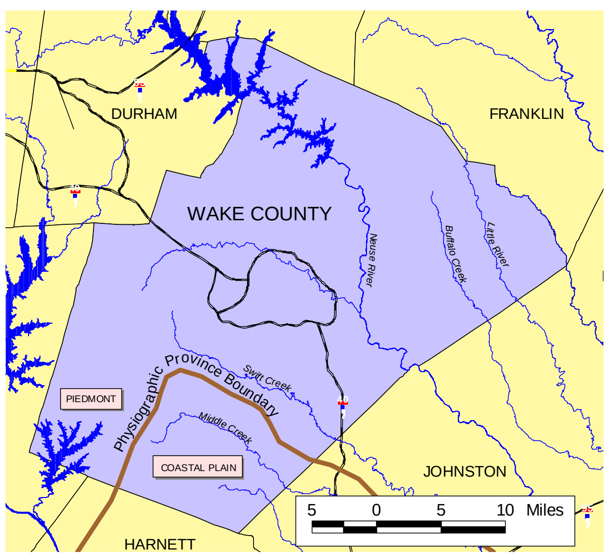



**Figure 2-1**
**Location of the Piedmont and Coastal Plain Provinces in Wake County**

The geologic map delineates rock units based on their geological characteristics without consideration for water-bearing potential. For the benefit of this investigation, the NCGS grouped the geologic units into distinct hydrogeologic units, according to the nomenclature and classification scheme used in the *Hydrogeologic Unit Map of the Piedmont and Blue Ridge Provinces of North Carolina* (Daniel and Payne, 1990). The hydrogeologic units are based on the water-bearing and water-yielding potential of the several rock types. As presented by Daniel and Payne, the underlying assumption with this classification is that the origin, composition, and texture are linked not only to the primary porosity of the rock but also the susceptibility of the rock to develop secondary porosity through fractures and solution openings. Rock composition and texture are likely to also influence the rate and depth of weathering and the water-bearing properties of the resulting regolith.

**Figure 2-3** shows the location and extent of the hydrogeologic units in Wake County (the hydrogeologic unit map is also a draft version.) **Table 2-1** provides a listing, description, and analysis of the areal distribution of each unit. The hydrogeologic units delineated by the NCGS represent basement rock only. The Coastal Plain sediments are not considered as an additional, unique hydrogeologic unit. Although the presence of the sandy Coastal Plain sediments in the southeastern part of the County influence the water supply potential and groundwater quality characteristics, most wells drilled for water supply purposes in this area tap into the bedrock portion of the aquifer.

Three major units, the igneous, felsic intrusive (IFI) in the northeast; the gneiss, felsic (GNF) in a band

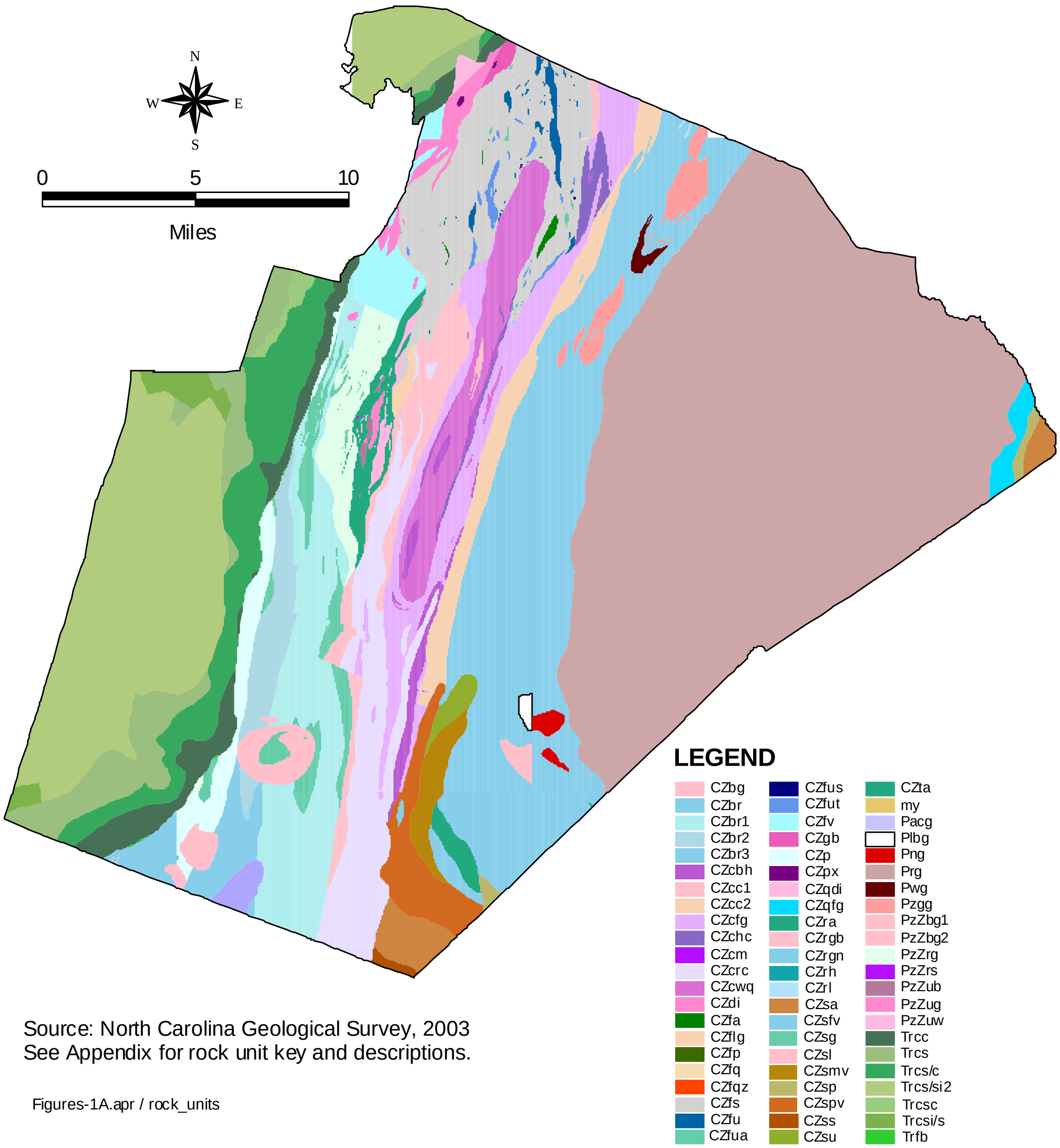
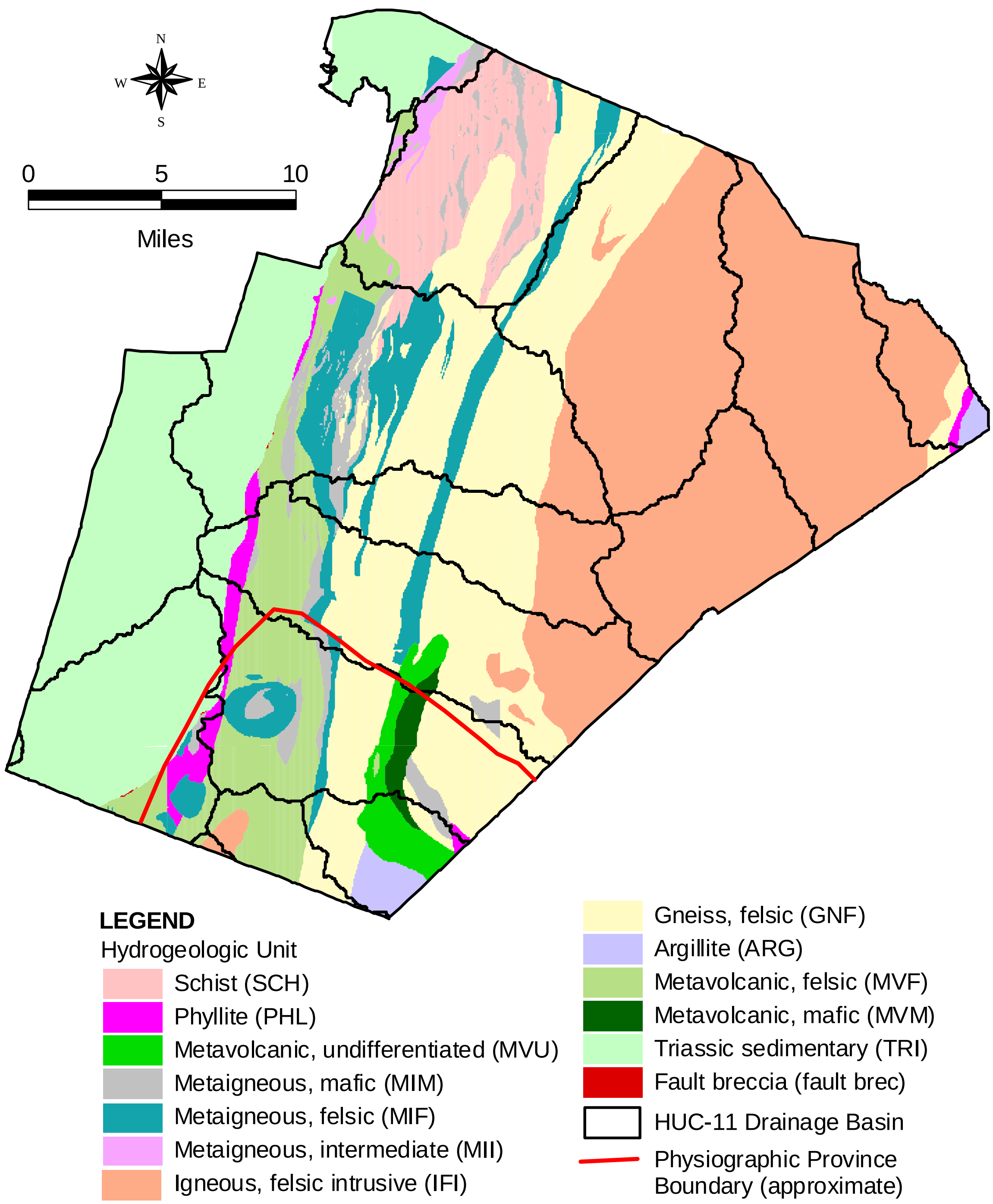



**Figure 2-2**
**Rock Units of Wake County**

running north-south through the center of the County; and Triassic sedimentary rocks (TRI) in a band running north-south in the west cover nearly 75 percent of Wake County. The remaining units occur as bands of varying size running north-south in between the three major units.

The water-bearing and water-transmitting properties of these units, where they occur in Wake County, are examined through an analysis of well yields in Section 3.4.1 of this report.




figures-1a / hydro_units

**Figure 2-3**
**Hydrogeologic Units of Wake County**

**Table 2-1**
**Hydrogeologic Units of Wake County**

| Hydrogeologic Unit Code | Hydrogeologic Unit Name | Lithologic Description | Area of Wake County (square miles) | Percentage of Wake County by Area |
|---|---|---|---|---|
| IFI | Igneous, felsic intrusive | Light-colored, mostly granitic rocks, fine- to coarse-grained, some porphyritic, usually massive, locally foliated; includes granite, granodiorite, quartz diorite, quartz monzonite, alaskites. | 260.7 | 30.4% |
| GNF | Gneiss, felsic | Mainly granitic gneiss; light-colored to gray, fine- to coarse-grained rocks, usually with distinct layering and foliation, often interlayered with mafic gneiss and schist. | 204.9 | 23.9% |
| TRI | Triassic sedimentary rocks | Mainly redbeds composed of shale, sandstone, arkose, and conglomerate (fanglomerate near basin margins). | 161.8 | 18.8% |
| MVF | Metavolcanic, felsic | Chiefly dense, fine-grained, light-colored to greenish-gray felsic tuffs and felsic crystal tuffs, includes interbedded felsic flows. Felsic lithic tuffs, tuff breccias, and some epiclastic rocks; recrystallized fine-grained groundmass contains feldspar, sericite, chlorite and quartz. Often with well-developed cleavage, may be locally sheared; phyllitic zones are common. | 67.0 | 7.8% |
| MIF | Metaigneous, felsic | Light colored, massive to foliated metamorphosed bodies of varying assemblages of felsic intrusive rock types; local shearing and jointing are common. | 53.5 | 6.2% |
| SCH | Schist | Schistose rocks containing primarily the micas muscovite or biotite or both, occasional sericite and chlorite schists; locally interlayed with hornblende gneiss and schist, commonly with distinct layering and foliation. | 41.9 | 4.9% |
| MIM | Metaigneous, mafic | Massive and schistose greenstone, amphibolite, metagabbro and metadiabase; may be strongly sheared and recrystallized; metamorphosed ultramafic bodies are often strongly foliated, altered to serpentinite, talc chlorite-tremolite schist and gneiss. | 26.5 | 3.1% |
| MVU | Metavolcanic, undifferentiated | Volcanic rocks of all origins (extrusive and eruptive) and compositions (felsic to mafic) interbedded in such a complex assemblage that mapping of individual units is not practical. | 13.1 | 1.5% |
| PHL | Phyllite | Light-gray to greenish-gray to white, fined grained rock having well-developed cleavage; composed primarily of sericite but may contain chlorite. | 11.3 | 1.3% |
| ARG | Argillite | Fine-grained, thinly laminated rock having prominent bedding planes and axial plane cleavage; locally includes mudstone, shale, thinly laminated siltstone, conglomerate, and felsic volcanic rock. | 7.6 | <1.0% |
| MVM | Metavolcanic, mafic | Grayish-green to dark-green, fine- to medium-grained andesitic to basaltic tuffs, crystal tuffs, crystal-lithic tuffs, tuff breccias and flows. | 5.2 | <1.0% |
| MII | Metaigneous, intermediate | Gray to greenish-gray, medium- to coarse-grained, massive to foliated, well-joined, metamorphosed bodies of dioritic composition. | 5.1 | <1.0% |
| fault brec | Breccia Faults | Fragmental rock formed by crushing or grinding along faults. | 0.1 | <1.0% |

[1]Hydrogeolgoic unit descriptions from Daniel and Payne, 1990. Hydrogeologic unit identification and mapping from NCGS, 2003.

## 2.2 The Regolith-Fractured Crystalline Rock Aquifer System

The following paragraphs describe the general composition and nature of the regolith-fractured crystalline rock aquifer system that is characteristic of the Piedmont. The information contained herein comes from Daniel (2001), Daniel and Dahlen (2002), and Heath, (1980), which have provided the best description of the system.

In Wake County, the crystalline rocks are overlain by regolith of thickness ranging from zero (where it is absent) to more than 200 feet. Regolith can be composed of saprolite, alluvium, and soil. Saprolite is the clay-rich, residual material resulting from the in-place weathering of bedrock. It is typically the most dominant component of the regolith. Alluvium refers to sediments that have been recently deposited in riverbeds, floodplains, and lakes. Soil is generally restricted to a thin layer on top of saprolite and alluvial deposits. An idealized drawing of the regolith-fractured crystalline rock aquifer system is shown in **Figure 2-4**.

A transition zone composed of partially weathered rock and lesser amounts of saprolite occurs as unconsolidated material grades into bedrock. The thickness and texture of this zone depend largely on the texture and composition of the parent rock.

Water is stored in the regolith in pore spaces between the fragmental material of varying size. Porosities of the Piedmont regolith range from 35 to 55 percent (Heath, 1980), accounting for the bulk of the groundwater storage. Porosity in the regolith tends to decrease with depth, as the degree of weathering decreases. In bedrock water is stored in fractures of varying size and dimension formed within otherwise solid rock. Porosities of Piedmont bedrock are generally an order of magnitude smaller than the regolith (ranging from 1 to 3 percent). The abundance and size of fractures generally decrease with depth. Wells drilled in Wake County beyond 600 feet may serve more as underground storage tanks for water than conduits to tap deep fractures in bedrock.

Most new water supply wells are cased through the regolith and finished with open holes in bedrock. Well regulations require the well casing to extend at least one foot into consolidated rock. Because of its higher porosity the regolith serves as a storage reservoir, feeding the fractures in the bedrock. The fractures serve as an interconnected network of pipes that transmit water to wells, springs, lakes, wetlands, and other water features.

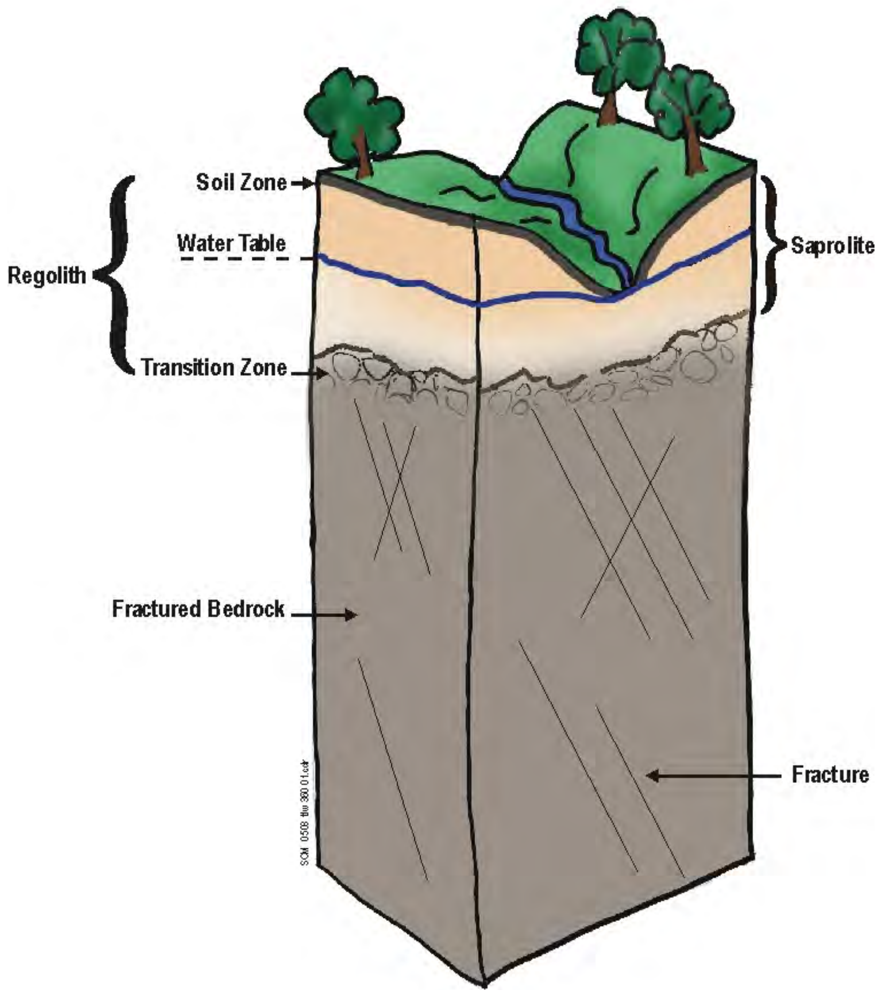



**Figure 2-4**
**Major Components of the Regolith-Fractured Crystalline Rock Aquifer System (adapted from Daniel and Dahlen, 2002)**

# Section 3
# Groundwater Quantity

## 3.1 Previous Investigations

Although a number of studies have examined various aspects relating to groundwater resources in the Piedmont Province of North Carolina, relatively few have dealt specifically with the availability and use of groundwater resources in Wake County. May and Thomas (1968) provided one of the first countywide assessments of groundwater resources through an analysis of well yields from 268 wells. Well yields were correlated with rock types and loosely correlated with topographic location (hills, flats, slopes, and draws). Average yields per rock type and topographic location were developed. Godfrey (1978) provided a summary of the challenges and limitations facing homeowners and developers attempting to obtain adequate supplies of groundwater in the Triassic basin of western Wake County. The report included a general description of the geologic and hydrogeologic conditions within the basin with an emphasis on the recognition of geologic clues to improve the probability of locating successful wells.

In the early 1980s, two studies were undertaken in an attempt to provide an improved understanding of the occurrence of groundwater in the crystalline rocks of Wake County and to provide an improved understanding of the quantity of groundwater that might be withdrawn from those rocks without overdrafting the resource. The first study, by Welby and Wilson (1982), described the relationship between certain geological factors including bedrock type and the yields of wells drilled into the bedrock. This report was followed in 1983 by an unpublished report to the Wake County Planning Department (Welby, 1983), which discussed what were termed "Risk Levels" for groundwater use. Both reports were written with the purpose of providing, from limited data, some guidelines for use of groundwater as an element in land-use planning for Wake County. Both reports focused on the County as a whole and did not address groundwater occurrence and inventory in individual drainage basins. Neither report addressed the recognized limitations on groundwater use in the Triassic basin area of the County, west of the Jonesboro Fault.

The first report by Welby and Wilson addressed groundwater in terms of the rock types distributed through the County, and examined several other factors that were traditionally thought to control groundwater occurrence in crystalline rocks. Stream flow information was assessed to provide insight into the volume of groundwater that might be considered recharge. The values for recharge obtained from this approach were found to agree with estimates of recharge using the Thornthwaite and Mather (1957) approach to the water balance.

Available well yield data from CWSs was also assessed to provide additional information relating to groundwater occurrence and availability. Evaluation of these records showed that upwards of 25% of the wells initially drilled to supply the CWS eventually failed. It was also noted that in Wake County, topographic setting seems less important as a factor associated with well yield than rock type.

The report draws a number of conclusions with respect to the understanding and management of Wake County's groundwater resources.

- Well yields alone should not be considered in land-use planning decisions but rather the actual amount of water that reaches the saturated zone should be considered on some areal basis.

- Based on a per capita use of 100 gal per person per day, and an average of two to three people per household, the east central portion of Wake County will, on the long-term, support a population density of about one acre per residential unit during annual drought conditions. Eastward and westward, the "safe density" decreases to approximately two to three acres per residential unit.

- Local water supply problems may arise as local recharge areas are developed and decreases of groundwater recharge occur due to increased impervious surface.

- In general, groundwater may begin to be mined if withdrawals exceed 300 to 400 gallons per acre per day, although local population centers may exceed that amount and not unduly affect the regional groundwater budget if a certain amount of open space suitable for groundwater recharge is maintained around them. For example, as long as the consumptive water use for a 100-acre tract does not exceed 30,000 to 40,000 gallons per day, the water usage will not exceed that amount recharged during a normal year.

With respect to the above conclusions, the report also emphasizes the point that groundwater recharge to crystalline rocks is concentrated in local, small drainage basins. Interception of recharging groundwater by any given fracture system does not necessarily follow a region-wide systematic approach.

It should be noted that the conclusions drawn by the report make several assumptions when determining the "safe density" of development. The term "safe density", like sustainability, is partly subjective, and has yet to be fully defined in Wake County.

The second report on groundwater availability in Wake County is unpublished (Welby, 1983) and was submitted to the Wake County Planning Department. The intent of this report was to provide the County with information about the distribution of favorable and unfavorable groundwater availability and to assess the potential intensity of groundwater use that could be tolerated without over-drafting the resource. Five classes of relative favorability for groundwater withdrawal were established based upon the data from the Welby and Wilson (1983) report, including geology, rock porosity, and permeability as determined by fracture coefficients, stream low flow data, apparent recharge, and well yields from pumping tests as well as additional well data obtained subsequent to the completion of that report. The five classes were termed "Risk Levels". Residential density based upon the potential availability of groundwater, and the estimated use of groundwater per residential unit, were used to define the "Risk Levels". Their distribution is shown in **Figure 3-1**. The report concludes that based on the available data, the densest development in the County should be limited to the equivalent of one residential unit per acre (Risk Level I). In those areas where the rocks tend not to yield large volumes of water and recharge volumes are relatively small, the concentration of residential units should be no more than one unit per four acres (Risk Level V). For each Risk Level a safe yield volume was presented based on an estimated total annual recharge rate. The safe yield volumes in gallons per acre per day (gal/ac/day) are listed in **Figure 3-1**.

## 3.2 Water Budget Approach

Previous investigations of groundwater resources in Wake County have suggested that the most important factors to be considered in evaluating the groundwater resources of Wake County were (1) the amount of recharge from precipitation; (2) the inventory of the groundwater already in the ground; and (3) the withdrawal rate. These studies have emphasized the importance of considering groundwater availability and use in land-use planning.

Building on these previous investigations and considering the objectives identified by Wake County and its stakeholders, a water budget approach was selected as the mechanism to provide the best current assessment of the County's groundwater resources from a quantity standpoint. A water budget is simply an accounting of water movement within the hydrologic cycle, both natural and artificial. Water budgets can be completed at a basin or subbasin level, although

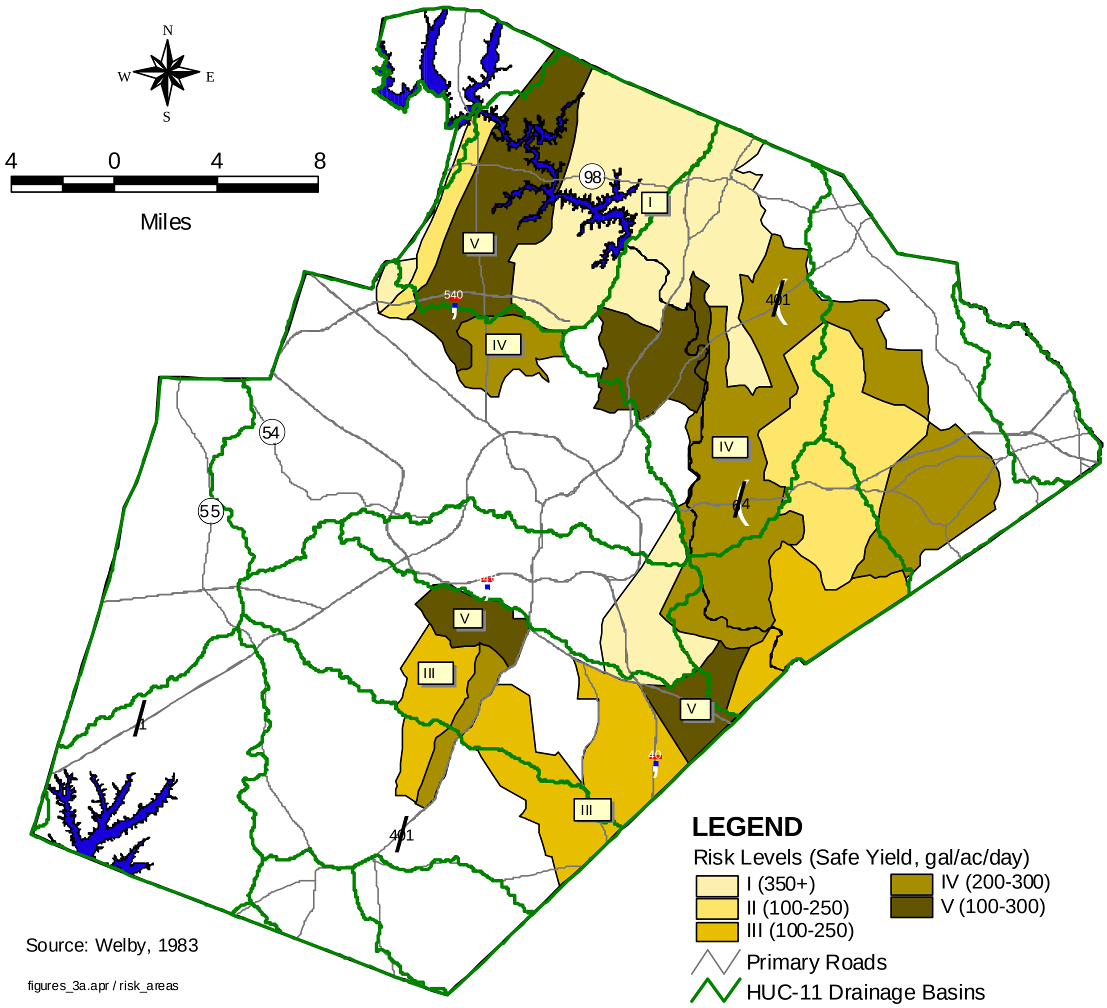



**Figure 3-1**
**Areas of Favorable and Unfavorable Groundwater Availability (Welby, 1983).**

each approach may have unique limitations based the quantity and quality of data available to provide an assessment of the system.

The water budgets serve as a useful tool for a number of reasons. In the context of this investigation the process of collecting, compiling and analyzing the data necessary to develop the water budgets was proved critical for estimating groundwater withdrawal rates, estimating recharge, identifying the relationship between streamflow and baseflow, identifying the areas served by domestic wells and onsite wastewater systems, and developing a better understanding of the impacts that sanitary sewers have on groundwater recharge.

There are a number of commonly recognized uses for preparing water budgets, the most important of which are:

- Developing an understanding of the movement and use of water within each drainage basin.
- Developing a concise means of comparing drainage basins with each other in terms of water consumption, baseflow, and runoff.

- Identifying drainage basins that have a relatively high level of water consumption.
- Comparing the natural versus man-made components of the hydrologic cycle.
- Identifying subbasins where large exports or imports of water are occurring.
- Providing a basis to assess sustainability of the water resource.
- Identifying where management decisions will result in the most impact and allowing the resource managers and planners to focus management efforts on the most pressing issues.

### 3.2.1 Water Budget Unit of Measure

It is an underlying assumption that groundwater and surface water basins generally coincide throughout the County; thus groundwater data can be referenced spatially to the watersheds and subbasins. This assumption is useful since analysis of stream flow data can be used to estimate recharge to the aquifers (see Section 3.2.3.10) and will serve as a critical component of the water budgets calculated for each unit. For a long period of record it is assumed that groundwater discharge equals groundwater recharge minus total withdrawal from wells.

Various levels of hydrologic (surface watershed) basins have been delineated in Wake County. These include the 8-, 11- and 14-digit hydrologic units as designated by the USDA Natural Resources Conservation Service (NRCS). The 8-, 11- and 14-digit hydrogeologic units divide the County into five, 14, and 45 basins respectively (note: basins for which only a very small portion occur in Wake County are not included in these totals). In the *Wake County Watershed Management Plan* (CH2M HILL, 2003), the County was divided into 81 basins primarily based on the location of available data and basin characteristics such as water quality ratings, land use, and location of potential pollution sources.

The 81 basins delineated in the *Watershed Management Plan*, and the 45 basins of the 14-digit hydrologic unit were deemed too discrete for the purposes of the water quantity assessment, primarily because sufficient streamflow data were not available to characterize uniquely each of the basins. The availability of streamflow information is described in **Figure 3-2**, which shows the location of current and former stream gages within the County. Stream gages include those currently maintained by the USGS and former stations identified and used by Welby and Wilson (1982). Ten current stream gages include daily average flow data. An additional three gages (not shown on **Figure 3-2**) produce only stream stage data.

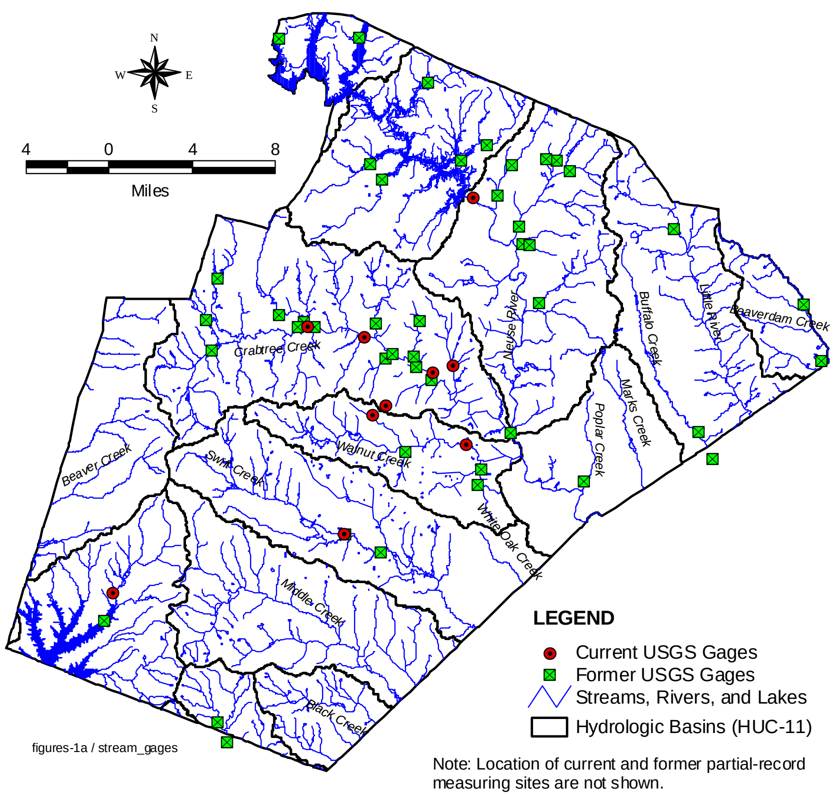



**Figure 3-2**
**Location of Current and Former Stream Gaging Stations**

The 11-digit hydrologic units (HUC-11) which divide the County into 14 drainage basins were chosen as the most appropriate level of study based on basin size and availability of streamflow data. The extent and location of the NUA/WSWs were also considered when selecting the appropriate hydrologic unit size for the water quantity assessment. Because public water and sewer service will not extend into the NUA/WSWs, they have been identified as priority areas with regard to understanding groundwater resource sustainability. **Figure 3-3** shows the location of the 14 HUC-11 drainage basins, and the extent of the WSW areas.

Further division of the hydrologic basins was considered with respect to the hydrogeologic units. Although there are statistical differences in the water yielding properties of some of the hydrogeologic units in the County, the decision was made not to further sub-divide the 14 basins into additional hydrogeologic units. This decision was based primarily on the location of stream gages and the availability of streamflow data. In most instances, stream gages are not spatially located to differentiate baseflow associated with different hydrogeologic units within individual basins. Further evidence to support this decision comes from Welby (1982) who found that although

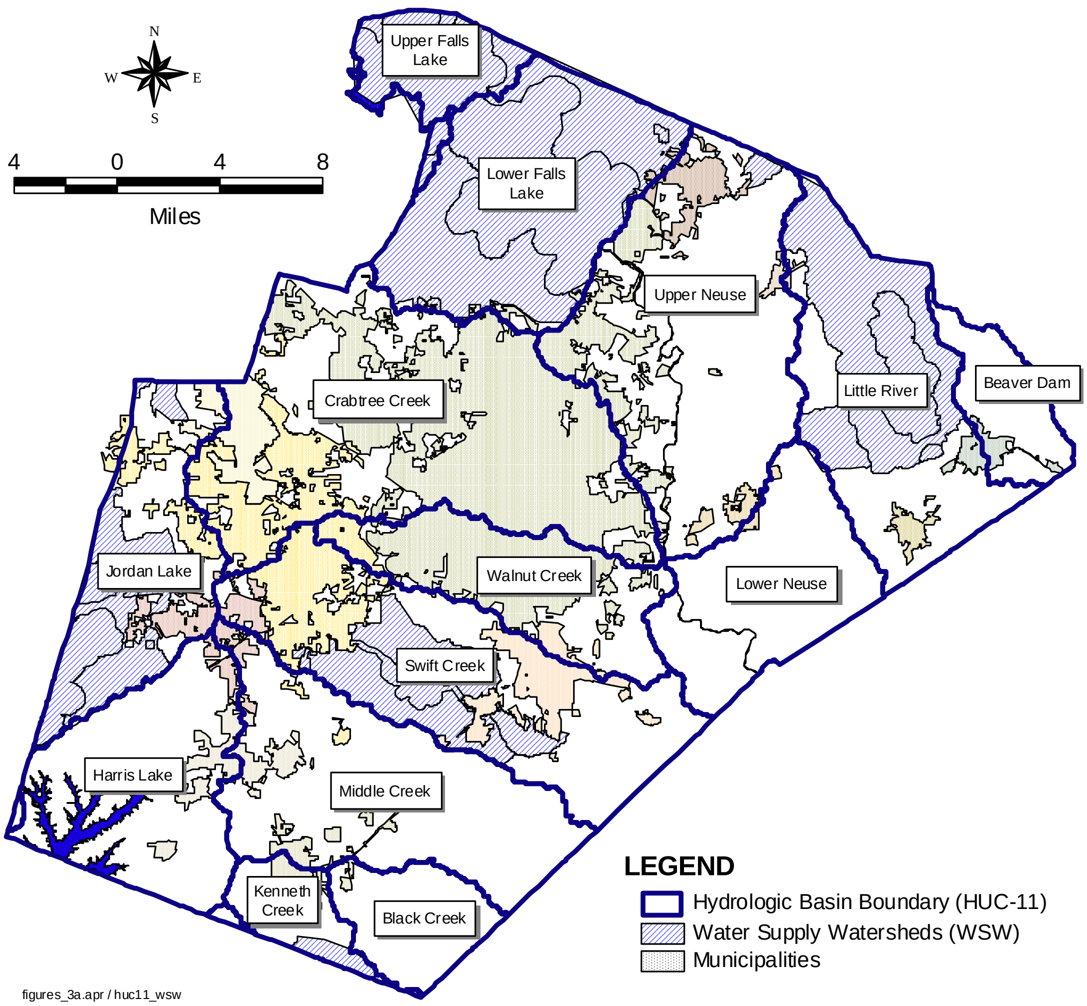



**Figure 3-3**
**HUC-11 Drainage Basins**

lithology is a significant factor in determining well yield (and water bearing potential), it does not explain all of the variations. Welby (1983) further argued that although rock types provide an important guide to groundwater availability, there is enough variation within broad groupings of rocks so that rock type cannot be used to define groundwater availability alone.

## 3.2.2 Water Budget Equation

The full water budget accounts for both the natural and artificial movement of water within the hydrologic cycle. The equation used in the assessment has been arranged so the left side of the equation generally reflects water "into" the system and the right side of the equation reflects water "out" of the system. The full water budget equation is shown in **Figure 3-4.**

## 3.2.3 Methodology

Technical Memorandum (TM) No. 2 described the data sources used to prepare the water budgets for each drainage basin and summarized the collected data with respect to applicability, quality, completeness, format, and potential use. The discussion below details how the data were used to arrive at estimates of each component of the water budget equation. Supporting data tables are included as appropriate.

### 3.2.3.1 Precipitation

An examination of precipitation from six stations located within Wake County with periods of record greater than 43 years indicated that precipitation is not equal in all parts of the County. The greatest apparent difference has been observed at the precipitation gaging station located at the RDU Airport. Precipitation measured at this station has typically been on the order of 1 to 3 inches per year less than other stations in the County. As such, a unique annual average precipitation value for each basin was assigned based on data compiled by the DWQ Groundwater Section and covering the 30-year period from 1967 to 1996. **Table 3-1** lists the precipitation rate in inches per year used for each basin in the water budget equation.

### 3.2.3.2 Wastewater and Industrial Recharge

Wastewater and industrial recharge in Wake County occurs at sites where wastewater is land applied in the form of spray or drip irrigation. To arrive at an estimate of WW/Ind Rech within each drainage basin, a database from the NCDENR Non-Discharge Permitting Unit was obtained. The database contains a list of 73 facilities with permits to apply wastewater to the land surface. The majority of the facilities are listed as single-family

**Figure 3-4**
**Water Budget Equation**

***P + WW/Ind Rech + EDR + SW Disch = ET + RO + SWW + GWW + EDW + BF***

where:

**P** is average annual precipitation.
**WW/Ind Rech** is wastewater and industrial discharge back to groundwater.
**EDR** is Estimated Domestic Recharge to groundwater through onsite wastewater systems.
**SW Disch** is the sum of all public wastewater system or industrial discharges to streams.
**ET** is evapotranspiration in inches.
**RO** is runoff.
**SWW** is the sum of all surface water withdrawals for public water supply or industry.
**GWW** is the sum of all groundwater withdrawals by public, commercial and industrial wells.
**EDW** is the estimated domestic withdrawals from private wells.
**BF** is mean annual baseflow of streams.

**Table 3-1**
**Average Annual Precipitation by Drainage Basin**

| Drainage Basin | Avg. Annual Precipitation (inches/year) | Drainage Basin | Avg. Annual Precipitation (inches/year) |
|---|---|---|---|
| Upper Falls Lake | 45.64 | Middle Creek | 45.75 |
| Lower Falls Lake | 44.73 | Black River | 46.31 |
| Upper Neuse | 45.08 | Little River | 45.45 |
| Crabtree Creek | 43.87 | Beaver Dam | 45.64 |
| Walnut Creek | 45.22 | Jordan Lake | 44.85 |
| Lower Neuse | 45.17 | Harris Lake | 45.73 |
| Swift Creek | 45.33 | Kenneth Creek | 46.33 |

residences (SFRs) with drip irrigation systems. Only four facilities were determined to spray irrigate in sufficient quantity to impact the water budget when considered at the drainage basin level. These facilities included the Neuse River WWTP, the Wrenn Road (Garner) WWTP, the Sandling Beach State Recreation Area, and the Falls Lake State Recreation Area. Amounts that were spray irrigated at each facility in 2000 are shown in **Table 3-2**. Since in each instance the facilities spray irrigate over vegetated areas, a significant component of the amount, which is land-applied is expected to be lost to evapotranspiration; therefore, the assumption was made that only 25 percent of amount reported for year 2000 was returned as recharge to the groundwater system.

### 3.2.3.3 Estimated Domestic Recharge

The first step in estimating domestic recharge for each basin was to determine the number of parcels in each drainage basin that were likely to be served by onsite wastewater treatment systems. Geographical information system (GIS) data layers of sewer service areas from each municipality were used to determine all areas within the County served by municipal sewer systems. Parcels within these areas were removed from the database. Several subdivisions served by Heater Utilities Inc.

**Table 3-2**
**Wastewater and Industrial Discharges to Groundwater (Spray Irrigation)**

| Drainage Basin | Facility Name | Reported or Permitted Discharge Rate | | Total at Assumed Recharge Rate of 25% |
|---|---|---|---|---|
| | | (gpd) | (mgd) | (mgd) |
| Upper Falls Lake | NC DENR/P&R-Sandling Beach and NC DENR/P&R-Falls Lake Recreation | 23,300 | 0.023 | 0.006 |
| Swift Creek | Wrenn Road WWTP Spray Irrigation Facility (Garner) | 800,672 | 0.801 | 0.200 |
| Lower Neuse | City of Raleigh Neuse River WWTP - PUD Reuse | 62,316 | 0.062 | 0.016 |

(HUI) which operate their own sewer and wastewater treatment systems and which discharge to streams were also identified, and the associated parcels were removed from the database. All remaining parcels classified as residential, agri-farm, apartments, manufactured homes, and mobile home parks not within the limits of these two areas, were assumed to be served by onsite wastewater treatment systems, as shown in **Figure 3-5**. Year 2000 census tract data were then used to estimate the number of people per household in these areas.

The second step was to determine the estimated domestic recharge rate. The amount of wastewater being returned through onsite wastewater treatment systems on a per person basis was estimated through analysis of year 2000 and 2001 billing records provided by HUI. HUI operates CWSs (served solely by groundwater) in 11 of the

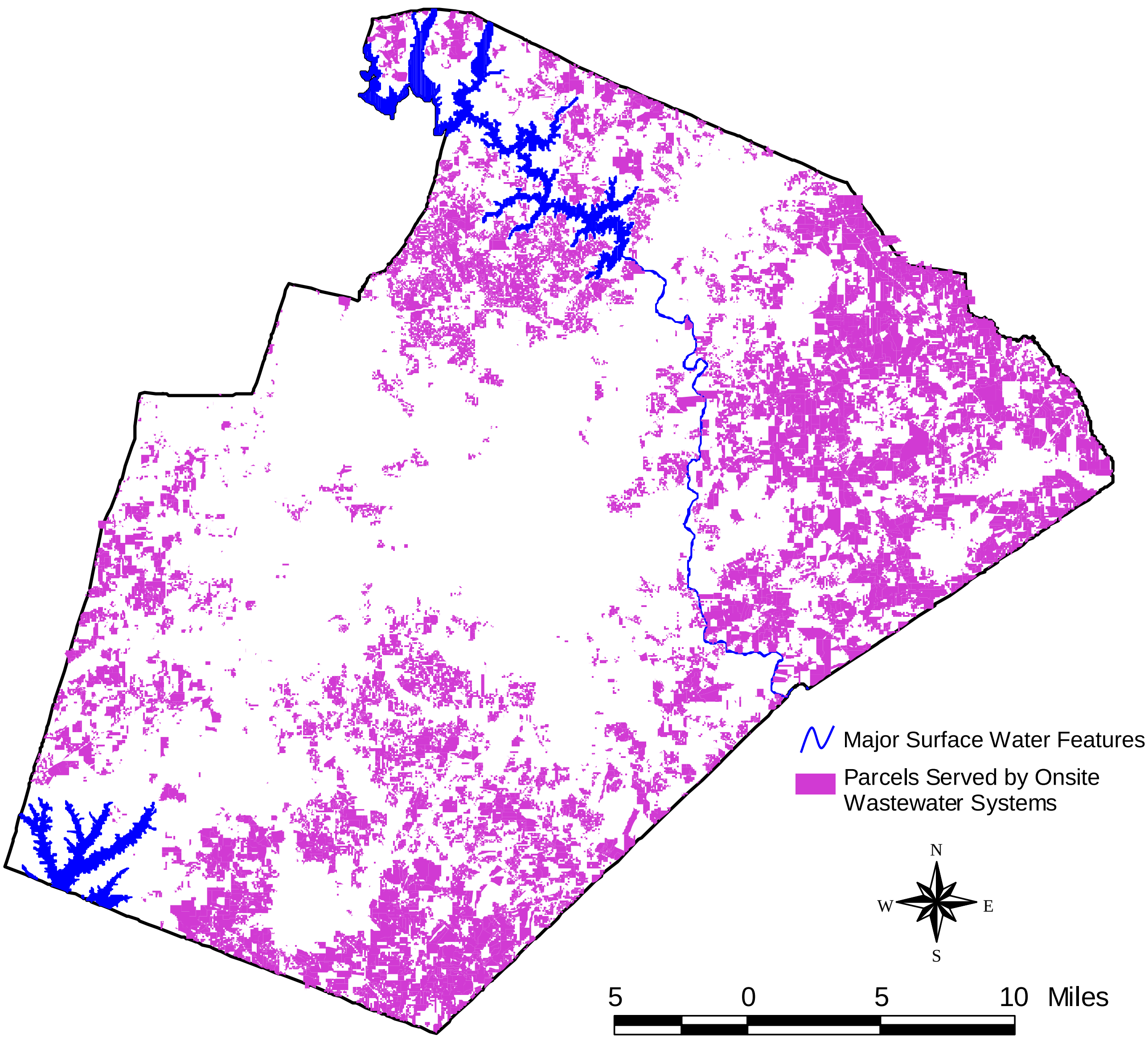



**Figure 3-5**
**Parcels Served by Onsite Wastewater Treatment Systems**

14 drainage basins, and these systems serve approximately 45,000 residents. The billing information was used to develop estimates of water withdrawals on a per person basis for the non-growing season months. Water use estimates of the non-growing season were used since monthly analysis of the data showed a significant increase in water use during the summer months, which was mostly attributed to irrigation demand. Water used for irrigation is expected to be almost completely lost to evapotranspiration (ET) and is not a component to be considered in domestic recharge through onsite wastewater treatment systems.

In the absence of published data to the contrary, it was assumed that 90 percent of the non-growing season water use for each drainage basin is returned as recharge through onsite wastewater treatment systems[1]. This accounts for losses of 10 percent due to ET and the small portion that is estimated to be lost to consumptive use during the winter. On an average annual basis, it is estimated that approximately 60 to 80 percent of domestic water is returned as recharge (Amoozegar, 2002). For the water budget equation, a value of 68 percent was used, which accounts for a leaching field ET loss of 22 percent and a consumptive use loss of 10 percent.

**Table 3-3** presents the estimated population served by onsite wastewater treatment systems, the estimated return rate per person, and the estimated domestic recharge rate per drainage basin.

#### 3.2.3.4 Surface Water Discharges

Surface water discharges were calculated from year 2000 NPDES permit information provided by the NCDENR DWQ. A total of 71 discharges in Wake County were identified, as shown in **Table 3-4**.

**Table 3-3**
**Estimated Domestic Recharge (EDR)**

| HUC-11 Drainage Basin | Residents Served by Onsite Wastewater Systems | Non-growing Season Per Capita Use[1] (gpd/person) | Estimated Return Rate (90%) (gpd/person) | EDR (gpd) | Area (sq. ft) | EDR | |
|---|---|---|---|---|---|---|---|
| | | | | | | (cu. ft/yr) | (in/yr) |
| Beaver Dam | 2,503 | 60 | 54 | 102,603 | 556,382,374 | 5,006,713 | 0.108 |
| Black Creek | 4,067 | 54 | 49 | 150,494 | 639,319,372 | 7,343,633 | 0.138 |
| Crabtree Creek | 9,076 | 64 | 58 | 399,328 | 3,700,201,979 | 19,485,933 | 0.063 |
| Harris Lake | 2,202 | 49 | 44 | 72,669 | 1,710,227,037 | 3,546,013 | 0.025 |
| Jordan Lake | 4,455 | 49 | 44 | 147,031 | 1,515,324,323 | 7,174,617 | 0.057 |
| Kenneth Creek | 2,859 | 54 | 49 | 105,792 | 402,508,446 | 5,162,322 | 0.154 |
| Little River | 9,851 | 60 | 54 | 403,893 | 2,166,506,282 | 19,708,665 | 0.109 |
| Lower Falls Lake | 26,919 | 68 | 61 | 1,238,263 | 2,171,377,588 | 60,423,282 | 0.334 |
| Lower Neuse | 9,472 | 58 | 52 | 369,406 | 1,407,114,020 | 18,025,811 | 0.154 |
| Middle Creek | 24,447 | 56 | 50 | 928,994 | 2,223,030,421 | 45,331,944 | 0.245 |
| Swift Creek | 19,893 | 51 | 46 | 696,262 | 2,533,033,896 | 33,975,369 | 0.161 |
| Upper Falls Lake | 825 | 49 | 44 | 27,216 | 571,669,339 | 1,328,074 | 0.028 |
| Upper Neuse | 22,777 | 66 | 59 | 1,024,952 | 2,944,778,184 | 50,014,389 | 0.204 |
| Walnut Creek | 3,479 | 55 | 50 | 128,722 | 1,290,360,787 | 6,281,197 | 0.058 |
| COUNTY TOTAL | 142,825 | -- | -- | 5,795,626 | 23,831,834,048 | 282,807,961 | 0.142 |

Table Notes:
[1] Per capita usage estimates taken from year 2000/2001 billing records provided by Heater Utilities, Inc.

[1] A similar estimate was made for a watershed in Colorado underlain by crystalline rocks (Dano et al, 2002).

**Table 3-4**
**Surface Water Discharges**

| Drainage Basin | Permit Number | Facility Name | Expiry Date | Permitted Flow (gpd) | Permitted Flow (mgd) | Actual Discharge (gpd) | Actual Discharge (gpd) min | Actual Discharge (gpd) max | Actual Discharge (mgd) min | Actual Discharge (mgd) max | Average Actual Discharge (mgd) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Falls Lake | NC0082376 | City of Raleigh - Johnson WTP | 2/28/03 | not limited | - | 2932000-7539000 | 2932000 | 7539000 | 2.93 | 7.539 | 5.23 |
| Lower Falls Lake | NC0063614 | Heater Utilities - Wildwood Green | 1/31/03 | 100000 | 0.10 | 44800-55800 | 44800 | 55800 | 0.04 | 0.056 | 0.05 |
| Lower Falls Lake | NC0049662 | Heater Utilities - Hawthorne Subdivision | 3/31/03 | 161000 | 0.16 | 88400-118000 | 88400 | 118000 | 0.09 | 0.118 | 0.10 |
| Lower Falls Lake | NC0085863 | Heater Utilities - Waterfall | 1/31/03 | not limited | - | 1700-5800 | 1700 | 5800 | 0 | 0.006 | 0.00 |
| Upper Neuse | NC0030759 | Town of Wake Forest - WWTP | 2/28/03 | 2400000 | 2.40 | 1237100-1543700 | 1237100 | 1543700 | 1.24 | 1.544 | 1.39 |
| Upper Neuse | NC0001376 | Riverplace II; LLC | 1/31/99 | 5000000 | 5.00 | 57000-77000 | 57000 | 77000 | 0.06 | 0.077 | 0.07 |
| Upper Neuse | NC0040606 | Heater Utilities - Barclay Downs | 3/31/03 | 35000 | 0.04 | 13300-23300 | 13300 | 23300 | 0.01 | 0.023 | 0.02 |
| Upper Neuse | NC0060577 | Heater Utilities - Beachwood | 3/31/03 | 100000 | 0.10 | 18500-22800 | 18500 | 22800 | 0.02 | 0.023 | 0.02 |
| Upper Neuse | NC0039292 | Uniprop; INC. / Riverwalk MHP | 2/28/03 | 51000 | 0.05 | 21600-40400 | 21600 | 40400 | 0.02 | 0.04 | 0.03 |
| Upper Neuse | NC0058505 | Heater Utilities - Mallard Crossing | 3/31/03 | 100000 | 0.10 | 30200-37800 | 30200 | 37800 | 0.03 | 0.038 | 0.03 |
| Upper Neuse | NC0065714 | Tradewinds Homeowners Association.INC | 2/28/03 | 50000 | 0.05 | 15200-18400 | 15200 | 18400 | 0.015 | 0.018 | 0.02 |
| Upper Neuse | NC0064408 | Neuse Crossing Utilities Corporation | 2/28/03 | 150000 | 0.15 | 110000-140000 | 110000 | 140000 | 0.11 | 0.14 | 0.13 |
| Upper Neuse | NC0064149 | Jones Dairy Farm Utilities | 2/28/03 | 160000 | 0.16 | 57000-68000 | 57000 | 68000 | 0.06 | 0.068 | 0.06 |
| Upper Neuse | NC0082376 | City of Raleigh - Johnson WTP | 2/28/03 | not limited | - | 2932000-7539000 | 2932000 | 7539000 | 2.93 | 7.539 | 5.23 |
| Upper Neuse | NC0063746 | Ira D. Lee - Deerchase | 2/28/03 | 50000 | 0.05 | 21500-29100 | 21500 | 29100 | 0.02 | 0.029 | 0.02 |
| Upper Neuse | NC0073318 | Ira D. Lee - Whippoorwill Valley | 2/28/03 | 50000 | 0.05 | 19300-23900 | 19300 | 23900 | 0.02 | 0.024 | 0.02 |
| Upper Neuse | NC0056278 | River Mill Homeowner Association; INC | 2/28/03 | 20000 | 0.02 | 1500-2200 | 1500 | 2200 | 0.002 | 0.002 | 0.00 |
| Upper Neuse | NC0007528 | Town of Wake Forest - WTP | 5/31/03 | not limited | - | 26000-242000 | 26000 | 242000 | 0.03 | 0.242 | 0.14 |
| Crabtree Creek | NC0048879 | Town of Cary - North WWTP | 2/28/03 | 12000000 | 12.00 | 5472600-6504100 | 5472600 | 6504100 | 5.47 | 6.504 | 5.99 |
| Crabtree Creek | NC0084310 | A.T. Williams Oil CO. *** | - | - | - | - | - | - | - | - | - |
| Crabtree Creek | NC0086126 | Alcatel Network Systems; INC. | 12/31/02 | 80000 | 0.08 | 50000-60000 | 50000 | 60000 | 0.05 | 0.06 | 0.06 |
| Crabtree Creek | NC0081469 | Colonial Pipeline - RDU Delivery | 2/28/03 | not limited | - | 200-8600 | 200 | 8600 | 0 | 0.009 | 0.00 |
| Crabtree Creek | NC0081469 | Colonial Pipeline - RDU Delivery | 2/28/03 | not limited | - | 200-8600 | 200 | 8600 | 0 | 0.009 | 0.00 |
| Crabtree Creek [b] | NC0084514 | RDU International Airport - WWTP | 2/28/03 | 14400 | 0.01 | no data available | - | - | - | - | 0.01 |
| Crabtree Creek [b] | NC0084514 | RDU International Airport - WWTP | 2/28/03 | 14400 | 0.01 | no data available | - | - | - | - | 0.01 |
| Crabtree Creek [b] | NC0084514 | RDU International Airport - WWTP | 2/28/03 | 14400 | 0.01 | no data available | - | - | - | - | 0.01 |
| Crabtree Creek [b] | NC0084514 | RDU International Airport - WWTP | 2/28/03 | 14400 | 0.01 | no data available | - | - | - | - | 0.01 |
| Crabtree Creek [b] | NC0084514 | RDU International Airport - WWTP | 2/28/03 | 14400 | 0.01 | no data available | - | - | - | - | 0.01 |
| Crabtree Creek [b] | NC0084514 | RDU International Airport - WWTP | 2/28/03 | 14400 | 0.01 | no data available | - | - | - | - | 0.01 |
| Crabtree Creek [b] | NC0084514 | RDU International Airport - WWTP | 2/28/03 | 14400 | 0.01 | no data available | - | - | - | - | 0.01 |
| Crabtree Creek [b] | NC0084514 | RDU International Airport - WWTP | 2/28/03 | 14400 | 0.01 | no data available | - | - | - | - | 0.01 |
| Crabtree Creek | NC0045608 | Ward Transformer Company | 2/28/03 | 50000 | 0.05 | 15700-41000 | 15700 | 41000 | 0.02 | 0.041 | 0.03 |
| Lower Neuse | NC0029033 | City of Raleigh - Neuse River WWTP | 2/28/03 | 60000000 | 60.00 | 33328300-40538600 | 3332830 | 40538600 | 3.33 | 40.54 | 21.93 |
| Lower Neuse | NC0064378 | CWS - Willowbrook Subdivision | 3/31/03 | 30000 | 0.03 | 12000-18000 | 12000 | 18000 | 0.01 | 0.018 | 0.01 |
| Lower Neuse | NC0062219 | CWS - Kings Grant Subdivision | 3/31/03 | 70000 | 0.07 | 19000-25000 | 19000 | 25000 | 0.02 | 0.025 | 0.02 |
| Lower Neuse | NC0051322 | CWS - Ashley Hill Subdivision | 3/31/03 | 125000 | 0.13 | 58600-108000 | 58600 | 108000 | 0.06 | 0.108 | 0.08 |
| Lower Neuse | NC0056391 | Cross Creek Mobile Estates | 2/28/03 | 50000 | 0.05 | 22000-40200 | 22000 | 40200 | 0.02 | 0.04 | 0.03 |
| Lower Neuse | NC0038784 | Riverview Mobile Home Park | 2/28/03 | 35000 | 0.04 | 24000-42000 | 24000 | 42000 | 0.02 | 0.042 | 0.03 |
| Lower Neuse | NC0040266 | Knightdale Estates MHP | 2/28/03 | 25000 | 0.03 | 18000-36000 | 18000 | 36000 | 0.02 | 0.036 | 0.03 |
| Lower Neuse | NC0065706 | Crosby Utilities/Cottonwood | 2/28/03 | 57500 | 0.06 | 37000-46000 | 37000 | 46000 | 0.04 | 0.046 | 0.04 |
| Lower Neuse | NC0081540 | Square D Compan y | 7/31/02 | 43200 | 0.04 | 8300-15400 | 8300 | 15400 | 0.01 | 0.015 | 0.01 |
| Swift Creek | NC0049034 | Mount Auburn Training Center | 2/28/03 | 2400 | 0.00 | 400-3400 | 400 | 3400 | 0 | 0.003 | 0.00 |
| Swift Creek | NC0060526 | Pope Industrial Parl II; LTD | 2/28/03 | 8000 | 0.01 | 2600-3600 | 2600 | 3600 | 0 | 0.004 | 0.00 |



CDM

**Table 3-4 (continued)**
**Surface Water Discharges**

| Drainage Basin | Permit Number | Facility Name | Expiry Date | Permitted Flow (gpd) | Permitted Flow (mgd) | Actual Discharge (gpd) | Actual Discharge (gpd) min | Actual Discharge (gpd) max | Actual Discharge (mgd) min | Actual Discharge (mgd) max | Average Actual Discharge (mgd) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Middle Creek | NC0083747 | Dutchman Creek; INC./Twin Lake | 4/30/03 | not limited | - | no data available | - | - | - | - | - |
| Middle Creek | NC0073679 | Heater Utilities - Oak Hollow WTP | 4/30/03 | not limited | - | 2600-2700 | 2600 | 2700 | 0 | 0.003 | 0.00 |
| Middle Creek | NC0066516 | Town of Fuquay Varina - WWTP | 4/30/03 | 500000 | 0.50 | 131000-284000 | 131000 | 284000 | 0.13 | 0.284 | 0.21 |
| Middle Creek | NC0035181 | N.C. Center for Mature Adults | 4/30/03 | 6500 | 0.01 | 1800-3200 | 1800 | 3200 | 0 | 0.003 | 0.00 |
| Middle Creek [c] | NC0066150 | Brookfield Prop - Brighton Forest WWTP | 4/30/03 | 117000 | 0.12 | not constructed | - | - | - | - | -- |
| Middle Creek | NC0062715 | Heater Utilities/Crooked Creek | 4/30/03 | 40000 | 0.04 | 7000-19300 | 7000 | 19300 | 0.01 | 0.019 | 0.01 |
| Middle Creek | NC0061638 | Nero Utility - Amherst WWTP | 4/30/03 | 46000 | 0.05 | 10700-15900 | 10700 | 15900 | 0.01 | 0.016 | 0.01 |
| Middle Creek | NC0082996 | Heater Utilities - Hollybrook | 4/30/03 | not limited | - | 600-1500 | 600 | 1500 | 0 | 0.002 | 0.00 |
| Middle Creek | NC0062740 | Heater Utilities/Briarwood Farms | 2/28/03 | 40000 | 0.04 | 8300-10400 | 8300 | 10400 | 0.01 | 0.01 | 0.01 |
| Middle Creek | NC0022217 | Motiva Enterprises - Apex Term. | 4/30/03 | not limited | - | 42000-250000 | 42000 | 250000 | 0.04 | 0.25 | 0.15 |
| Little River | NC0086266 | CWS - Woodtrace Well #1 WTP | 4/30/03 | not limited | - | 3000 | 3000 | 3000 | 0.003 | 0.003 | 0.003 |
| Little River | NC0049042 | Riley Hill Baptist Church INC. | 12/31/01 | 1200 | 0.00 | 100 | 100 | 100 | 0 | 1E-04 | 0.00 |
| Beaver Dam | NC0079316 | Town of Zebulon - Little Creek WWTP | 5/31/03 | 1850000 | 1.85 | 636200-1141800 | 636200 | 1141800 | 0.64 | 1.142 | 0.89 |
| Jordan Lake [a] | NC0028118 | Town of Cary and Apex WTP | 4/30/06 | not limited | - | 420000-790000 | 420000 | 790000 | 0.42 | 0.79 | 0.61 |
| Harris Lake [a] | NC0063096 | CP&L Shearon Harris Nuclear | 7/31/06 | multiple outfalls | - | multiple flows | - | - | - | - | - |
| Harris Lake [a] | NC0063096 | CP&L Shearon Harris Nuclear | 7/31/06 | multiple outfalls | - | multiple flows | - | - | - | - | - |
| Harris Lake [a] | NC0063096 | CP&L Shearon Harris Nuclear | 7/31/06 | multiple outfalls | - | multiple flows | - | - | - | - | - |
| Harris Lake [a] | NC0063096 | CP&L Shearon Harris Nuclear | 7/31/06 | multiple outfalls | - | multiple flows | - | - | - | - | - |
| Harris Lake [a] | NC0063096 | CP&L Shearon Harris Nuclear | 7/31/06 | multiple outfalls | - | multiple flows | - | - | - | - | - |
| Harris Lake [a] | NC0063096 | CP&L Shearon Harris Nuclear | 7/31/06 | multiple outfalls | - | multiple flows | - | - | - | - | - |
| Harris Lake [a] | NC0063096 | CP&L Shearon Harris Nuclear [c] | 7/31/06 | multiple outfalls | - | multiple flows | - | - | - | - | 3.96 |
| Harris Lake [a] | NC0055051 | Country Lake Estates Association | 7/31/06 | 90000 | 0.09 | 13600-26000 | 13600 | 26000 | 0.01 | 0.03 | 0.02 |
| Harris Lake [a] | NC0039586 | Town of Holly Springs - WWTP | 7/31/06 | 1500000 | 1.50 | 623300-767400 | 623300 | 767400 | 0.62 | 0.77 | 0.70 |
| Kenneth Cree k [a] | NC0081591 | Fuquay Varina/Kenneth Creek WWTP | 7/31/06 | 1200000 | 1.20 | 717200-1290300 | 717200 | 290300 | 0.72 | 0.29 | 0.51 |

Notes:
Source: NCDENR DWQ NPDES Discharge Database for the Neuse and Cape Fear Basins (Wake County only).
[a] Permit numbers presented in the NCBasinPro database did not match those in the NC DWQ database.
[b] Actual flows were not available, so permitted flows were used as actual flows.
[c] 3.963 mgd was average daily discharge for 1999, from DWR web-site (water withdrawal and discharge summary)

Since a minimum and maximum discharge was provided, an average discharge was calculated from the minimum and maximum reported values for use in the water budget equation.

### 3.2.3.5 Evapotranspiration

ET is difficult to directly measure, especially at the drainage basin level. Several studies within Wake County and the Piedmont have estimated both monthly and average annual ET. Welby and Wilson (1982), using the Thornthwaite and Mather (1957) approach to the water balance, estimated average annual ET at 30.5 inches per year for the Raleigh-Durham area. Hardy and Hardy (1975) estimated average annual ET at 33.8 inches/year for the North Carolina Piedmont. Baseflow and total streamflow data for 15 drainage basins located in Orange County (Daniel, 1996) were used to back calculate an estimate of ET, under the assumption that the drainage basins in Orange County were primarily undeveloped, and therefore not heavily influenced by groundwater withdrawals or other factors. Using this method, and assuming average annual precipitation was 45 inches per year, ET was estimated to range between 31.5 and 34.1 inches per year, with an average of 32.7 inches per year. These studies suggest that on an average annual basis, ET is in the range of 32 inches per year. Since no data exists to differentiate the ET rate applied to each of the 14 Wake County drainage basins, 32 inches per year was assigned equally to each basin in this analysis.

### 3.2.3.6 Runoff

Runoff was calculated for each drainage basin for both impervious and pervious surfaces. For pervious surfaces, runoff was estimated by calculating the percent area of each drainage basin composed of the hydrologic soil groups A, B, C, and D (Musgrave, 1964). The Soil Conservation Service has prepared soil maps for Wake County that identify these four soil groups. Group A soils have the highest infiltration rate (greater than 0.3 inches per hour) and consist primarily of well drained sands and gravels. Group B soils have moderate infiltration rates (0.15 to 0.3 inches per hour). Groups C and D soils have progressively lower infiltration rates, ranging from 0.05 to .15 inches per hour and 0 to 0.05 inches per hour, respectively. Runoff factors for each soil group developed and applied in previous studies in the Piedmont (NVPDC, 1979) were used to approximate runoff from each soil type, and a weighted average was used to arrive at a pervious surface runoff estimate for the each basin, based on the percentage of each soil type.

The amount of impervious surface in each basin was estimated using GIS data developed by Wake County GIS Department. At a sub-basin level, impervious surfaces had been estimated by totaling rooftops, streets, sidewalks, and parking lots based on existing GIS data layers. Orthoimagery files were used to determine general widths of pavement and sidewalk for various types of roads, and a weighted average was developed. Parking lot sizes were estimated based on general trends observed in the orthoimagery files. Parking lots of commercial parcels were estimated to account for between 25 and 75 percent of the total parcel area, based on the size of the parcel. Parking lots of industrial, institutional, and other parcels were estimated to account for between 30 and 60 percent of the total parcel area based on use type (e.g., schools, apartments, condominiums, industrial). The amount of impervious surface was then aggregated to the HUC-11 level to match the 14 drainage basins used in this study. A runoff factor of .95 (i.e., 95 percent of the rainfall runs off impervious surface) was used to calculate impervious area runoff in each basin, and this amount was added to the pervious area runoff estimate to arrive at a total runoff estimate.

As a check runoff estimates developed using the methods described above were compared to the runoff value calculated by baseflow separation method (described in Section 3.2.2.10) for the Middle Creek, Swift Creek, Walnut Creek, and Crabtree Creek drainage basins. **Table 3-5** shows the area of each basin with respect to hydrologic soil groups, the percent of imperviousness, and the estimated runoff volume. In each instance, runoff estimated by the method presented above was

**Table 3-5**
**Runoff Estimates by Drainage Basin**

| Drainage Basin | Percentage of Hydrologic Soil Group by Area (Pervious Surfaces) | | | | | Estimated Amount of Impervious Surface (Percent) | Pervious Surface Runoff (in/yr) | Impervious Surface Runoff (in/yr) | Total Runoff (in/yr) |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | Water | | | | |
| Upper Falls Lake | 0% | 19% | 43% | 37% | 1% | 0.8% | 5.59 | 0.30 | 5.89 |
| Lower Falls Lake | 0% | 83% | 13% | 3% | 1% | 4.9% | 4.04 | 1.88 | 5.92 |
| Upper Neuse | 1% | 74% | 10% | 13% | 2% | 7.8% | 4.22 | 3.01 | 7.23 |
| Crabtree Creek | 0% | 70% | 20% | 9% | 1% | 17.6% | 4.22 | 6.59 | 10.81 |
| Walnut Creek | 0% | 84% | 7% | 8% | 1% | 17.4% | 4.06 | 6.77 | 10.83 |
| Lower Neuse | 2% | 81% | 8% | 8% | 1% | 3.6% | 4.01 | 1.40 | 5.41 |
| Swift Creek | 1% | 80% | 9% | 8% | 2% | 11.0% | 4.05 | 4.29 | 8.34 |
| Middle Creek | 14% | 66% | 7% | 12% | 1% | 6.5% | 3.85 | 2.57 | 6.42 |
| Black Creek | 35% | 45% | 4% | 14% | 2% | 3.7% | 3.33 | 1.50 | 4.83 |
| Little River | 0% | 74% | 9% | 16% | 2% | 3.9% | 4.31 | 1.51 | 5.82 |
| Beaver Dam | 0% | 76% | 5% | 18% | 1% | 4.9% | 4.32 | 1.92 | 6.24 |
| Jordan Lake | 0% | 13% | 46% | 40% | 1% | 5.1% | 5.61 | 1.89 | 7.50 |
| Harris Lake | 3% | 43% | 34% | 19% | 1% | 2.0% | 4.87 | 0.77 | 5.64 |
| Kenneth Creek | 43% | 41% | 3% | 11% | 2% | 7.6% | 3.07 | 3.11 | 6.18 |

within 15 percent of the runoff calculated by the baseflow separation method, indicating that at least for these four drainage basins, the method used to calculate runoff produced reasonable estimates.

### 3.2.3.7 Surface Water Withdrawals

Surface water withdrawals were estimated from information provided in the 1997 Local Water Supply Plans for each of the Wake County municipalities. Additional surface water withdrawals were incorporated from information provided on the NCDENR Division of Water Resources (DWR) Water Withdrawal Registration website. Surface water withdrawals that occur outside of Wake County, but are used to supply water to Wake County residents, were not considered in this evaluation. Surface water withdrawals from ponds or streams that were less than 100,000 gpd (the DWR reporting limit) were not considered in this evaluation. **Table 3-6** lists the surface water withdrawals by basin.

### 3.2.3.8 Groundwater Withdrawals

Groundwater withdrawals (GWW) for public supply purposes were estimated based on year 2000 billing records provided by HUI and Carolina Water Service. HUI and Carolina Water Service operate 190 of the 275 public water supply systems that use groundwater in Wake County, and the only systems with reported withdrawals greater than 100,000 gallons per day. Since no single source of data was available listing year 2000 withdrawals from all other CWSs, the smaller systems not run by HUI or Carolina Water Service were estimated based on population, and included in the EDW term, described later in this section. Groundwater withdrawal totals are shown in **Table 3-7**. Based on year 2000 billing records, the approximately 48,000 people served by HUI and Carolina Water Service systems used 4.6 million gallons of water per day (mgd), resulting in an average water use of just over 80 gallons per person per day. Variations in water use between basins on a per person, per day basis were noted and were used to develop the estimated domestic withdrawal (EDW) term, discussed later in this section. The variations are primarily attributed to differences in irrigation use between subdivisions within each basin.

HUI estimates of system losses indicate that between two and three percent of water is unaccounted for between the well and final delivery point. For the purposes of this analysis, this water was assumed to be lost through delivery systems leaks and returned to the groundwater system, resulting in no net loss since the totals presented above were based on data from meters at delivery points.

Commercial and industrial withdrawals were also accounted for in the GWW term. Commercial and industrial withdrawals were estimated by using the GIS parcel coverage to total the commercial and

**Table 3-6**
**Surface Water Withdrawals**

| Drainage Basin | Name of Water System or Registered Withdrawer | Average Daily Withdrawal Rate (mgd) |
|---|---|---|
| Lower Falls Lake | Raleigh | 48.61 |
| Upper Neuse | Wake Forest | 0.59 |
| Little River | Zebulon | 0.33 |
| Middle Creek | Devils Ridge Golf Club | 0.41 |
| Harris Lake | Shearon Harris Nuclear Plant | 37.44 |
| Swift Creek | Lake Wheeler Road Field Lab | 0.18 |

Source: 1997 Local Water Supply Plans and DWR Water Withdrawal Registration website.

**Table 3-7**
**Community Water System Ground Water Withdrawals**

| Drainage Basin | 2000 Withdrawals/Basin[1] Heater (gallons) | Carolina Water Service (gallons) | Year 2000 Ground Water Withdrawals (gallons) | Area in Wake County (sq. ft) | Year 2000 Ground Water Withdrawals (in/yr) |
|---|---|---|---|---|---|
| Beaver Dam | 2,566,320 | 0 | 2,566,320 | 556,382,374 | 0.01 |
| Black Creek | 2,129,583 | 0 | 2,129,583 | 639,319,372 | 0.01 |
| Crabtree Creek | 87,722,801 | 0 | 87,722,801 | 3,700,201,979 | 0.04 |
| Harris Lake | 849,039 | 0 | 849,039 | 1,710,227,037 | 0.00 |
| Jordan Lake | 0 | 0 | 0 | 1,515,324,323 | 0.00 |
| Kenneth Creek | 0 | 0 | 0 | 402,508,446 | 0.00 |
| Little River | 32,431,856 | 3,445,456 | 35,877,312 | 2,166,506,282 | 0.03 |
| Lower Falls Lake | 641,325,991 | 0 | 641,325,991 | 2,171,377,588 | 0.47 |
| Lower Neuse | 43,554,594 | 66,176,390 | 109,730,984 | 1,407,114,020 | 0.13 |
| Middle Creek | 239,817,354 | 2,492,460 | 242,309,814 | 2,223,030,421 | 0.17 |
| Swift Creek | 150,588,292 | 5,960,012 | 156,548,304 | 2,533,033,896 | 0.10 |
| Upper Falls Lake | 0 | 0 | 0 | 571,669,339 | 0.00 |
| Upper Neuse | 117,817,116 | 10,866,900 | 128,684,016 | 2,944,778,184 | 0.07 |
| Walnut Creek | 4,990,936 | 0 | 4,990,936 | 1,290,360,787 | 0.01 |

Note:
[1] 2001 reported withdrawals for HUI systems in Crabtree Creek basin were used due to anamolous 2000 data.

industrial parcels in each basin, which occur outside of municipal limits and are not within an area served by public water supply. An assumed withdrawal rate of 850 gpd was used based on estimates derived from an analysis of commercial water use in the Orange Water and Sewer Authority (CH2M HILL, 1998) service area. Since no similar "average" industrial rate was available, water use for industrial parcels was assumed to be 1,000 gpd. Only 56 industrial parcels were identified, compared to 584 commercial parcels; therefore, any significant over or under estimate of industrial water use will not result in a measurable impact to the overall GWW estimate. Groundwater use estimates for commercial and industrial parcels are presented in **Table 3-8**.

The other groundwater withdrawals that were deemed potentially significant to the water budget included those from quarries and golf courses. The DWR Water Withdrawal Registration database reports nine quarries in Wake County that withdrew a total of 1.9 mgd in 1999 (**Table 3-9**). Over 90 percent of these withdrawals occurred in the Crabtree Creek and Upper Neuse drainage basins. Based on the fact that no Wake County golf courses have registered groundwater withdrawals greater than 100,000 gpd, it is assumed that irrigation use of groundwater at golf courses was only a minor term at best in the overall water budget. As a rough check seven golf courses were contacted and questioned with regard to their irrigation practices and source of water. Of the seven, one golf course reported an estimated average annual groundwater use of 0.3 mgd. (Note: this golf course was not listed in DWR Water Withdrawal Registration Database.) Based on these data, and other anecdotal evidence, a total groundwater withdrawal rate of 0.3 mgd for golf course irrigation use was applied to the Crabtree Creek, Upper Neuse, and Swift Creek basins in the water budget. These basins were identified as having the largest concentration of golf courses through analysis of GIS parcel information. The assignment of a 0.3 mgd withdrawal to each of these basins was based on the assumption that one golf course within each basin used groundwater for irrigation purposes.

Nurseries and agriculture were also investigated as potential major users of groundwater. Of the 12 largest nurseries in Wake County, less than half reported use of groundwater for irrigation purposes. Only one nursery offered an estimate of withdrawal rates, which totaled about 50,000 gallons per month, for four months of the year. According to The Farm Services Agency (Youngblood, pers. comm.), very few wells in Wake County are used for direct irrigation of cropland, or to fill ponds that may be used to irrigate cropland. Based on this evidence, groundwater withdrawals for agricultural and horticultural use were considered to be only a very minor component of the overall water budget.

#### 3.2.3.9 Estimated Domestic Withdrawals

Domestic withdrawals were estimated using a similar approach to that used to estimate the EDR term. GIS data layers of water service areas from each municipality were used to determine all areas within the County served by publicly supplied surface water. Parcels within these areas were removed from the database. Subdivisions served by HUI and Carolina Water Service were also identified, and the associated parcels were removed from the database. All parcels classified as residential, agri-farm, apartments, manufactured homes, and mobile home parks not within the limits of these two areas were assumed to be served by domestic wells or small CWSs (non-HUI or Carolina Water Service systems). These parcels are shown in **Figure 3-6**. Year 2000 census tract data were then used to estimate the number of people per household in these areas.

Households in areas where public water service was recently extended but have declined the service and have remained on well water were not considered in the water budget. Although anecdotal information indicates that this does occur to a limited extent, the number of households that fall into this category is expected to be insignificant in terms of the overall water budget. Some

**Table 3-8**
**Groundwater Use Estimate for Commercial and Industrial Parcels**

| | Wells Serving… | | | | | Onsite Wastwater Systems Serving… | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Drainage Basin** | **Number of Commercial Parcels[1]** | **Assumed Commercial Withdrawal (mgd)** | **Number of Industrial Parcels[1]** | **Assumed Industrial Withdrawal (mgd)** | | **Number of Commercial Parcels[1]** | **Assumed Commercial Return (mgd)** | **Number of Industrial Parcels[1]** | **Assumed Industrial Return (mgd)** |
| Upper Falls Lake | 5 | **0.004** | 0 | **0.000** | | 5 | **0.002** | 0 | **0.000** |
| Lower Falls Lake | 31 | **0.026** | 2 | **0.002** | | 32 | **0.014** | 2 | **0.001** |
| Upper Neuse | 84 | **0.071** | 15 | **0.015** | | 97 | **0.041** | 15 | **0.008** |
| Crabtree Creek | 85 | **0.072** | 15 | **0.015** | | 87 | **0.037** | 15 | **0.008** |
| Walnut Creek | 20 | **0.017** | 1 | **0.001** | | 22 | **0.009** | 1 | **0.001** |
| Lower Neuse | 27 | **0.023** | 2 | **0.002** | | 28 | **0.012** | 2 | **0.001** |
| Swift Creek | 112 | **0.095** | 11 | **0.011** | | 119 | **0.051** | 11 | **0.006** |
| Middle Creek | 92 | **0.078** | 1 | **0.001** | | 93 | **0.040** | 1 | **0.001** |
| Black Creek | 9 | **0.008** | 0 | **0.000** | | 9 | **0.004** | 0 | **0.000** |
| Little River | 60 | **0.051** | 6 | **0.006** | | 65 | **0.028** | 7 | **0.004** |
| Beaver Dam | 9 | **0.008** | 0 | **0.000** | | 9 | **0.004** | 0 | **0.000** |
| Jordan Lake | 27 | **0.023** | 2 | **0.002** | | 27 | **0.011** | 2 | **0.001** |
| Harris Lake | 13 | **0.011** | 1 | **0.001** | | 13 | **0.006** | 1 | **0.001** |
| Kenneth Creek | 10 | **0.009** | 0 | **0.000** | | 10 | **0.004** | 0 | **0.000** |

| | | |
|---|---|---|
| Assumed annual withdrawal rate for Commercial parcels[2]: | 850 | gpd |
| Assumed annual withdrawal rate for Industrial parcels[3]: | 1,000 | gpd |
| Assumed wastewater return percentage for Commercial parcels: | 50% | |
| Assumed wastewater return percentage for Industrial parcels: | 50% | |
| Assumed wastewater return rate for Commercial parcels: | 425 | gpd |
| Assumed wastewater return rate for Industrial parcels: | 500 | gpd |

[1] Number of parcels estimated for areas not served by publicly supplied water.
[2] Estimate derived from 1998 commercial water use reported in OWASA Master Plan (CH2M HILL, 2001)
[3] Esimate based on reasonable judgement.

**Table 3-9**
**Quarries with Registered Withdrawals**

| Drainage Basin | Quarry (Owner) | Reported 1999 Withdrawal (mgd) |
|---|---|---|
| Harris Lake | Hanson Aggregates Carolina, Inc. | 0.000 |
| Harris Lake | Martin Marietta Materials, Inc. | 0.002 |
| Crabtree Creek | Martin Marietta Materials, Inc.. | 0.005 |
| Crabtree Creek | Hanson Aggregates Carolina, Inc. | 0.500 |
| Crabtree Creek | Wake Stone Corporation | 0.268 |
| Walnut Creek | Martin Marietta Materials, Inc. | 0.040 |
| Upper Neuse | Hanson Aggregates Carolina, Inc. | 0.550 |
| Upper Neuse | Burlington Industries | 0.001 |
| Upper Neuse | Wake Stone Corporation | 0.510 |

| | | |
|---|---|---|
| **Withdrawal per Basin (mgd):** | Harris Lake | 0.002 |
| | Crabtree Creek | 0.773 |
| | Walnut Creek | 0.040 |
| | Upper Neuse | 1.061 |
| | County Total (mgd): | 1.876 |

Source: DWR Water Withdrawal Registration website

municipalities (e.g., Holly Springs) generally do not allow residents to keep wells if extended public water unless certain strict criteria are met to prevent potential cross connections.

The second step was to determine the estimated domestic withdrawal rate. The amount of water withdrawn on a per person basis was approximated through analysis of year 2000 and 2001 billing records provided by HUI. The billing information was used to develop an average annual estimate of water withdrawals on a per person basis. Since HUI does not operate any systems in the Kenneth Creek, Jordan Lake, or Upper Falls Lake basins, the withdrawal rate calculated for Harris Lake (52 gallon per person per day) was used for Jordan Lake and Upper Falls Lake, since all three contain predominantly Triassic Basin sediments. The usage rate calculated for Black Creek (59 gallons per person per day) was used for neighboring Kenneth Creek. Also, since the usage rate calculated for Beaver Dam was based only on a system serving 44 people and appeared to be exceptionally high, the usage rate

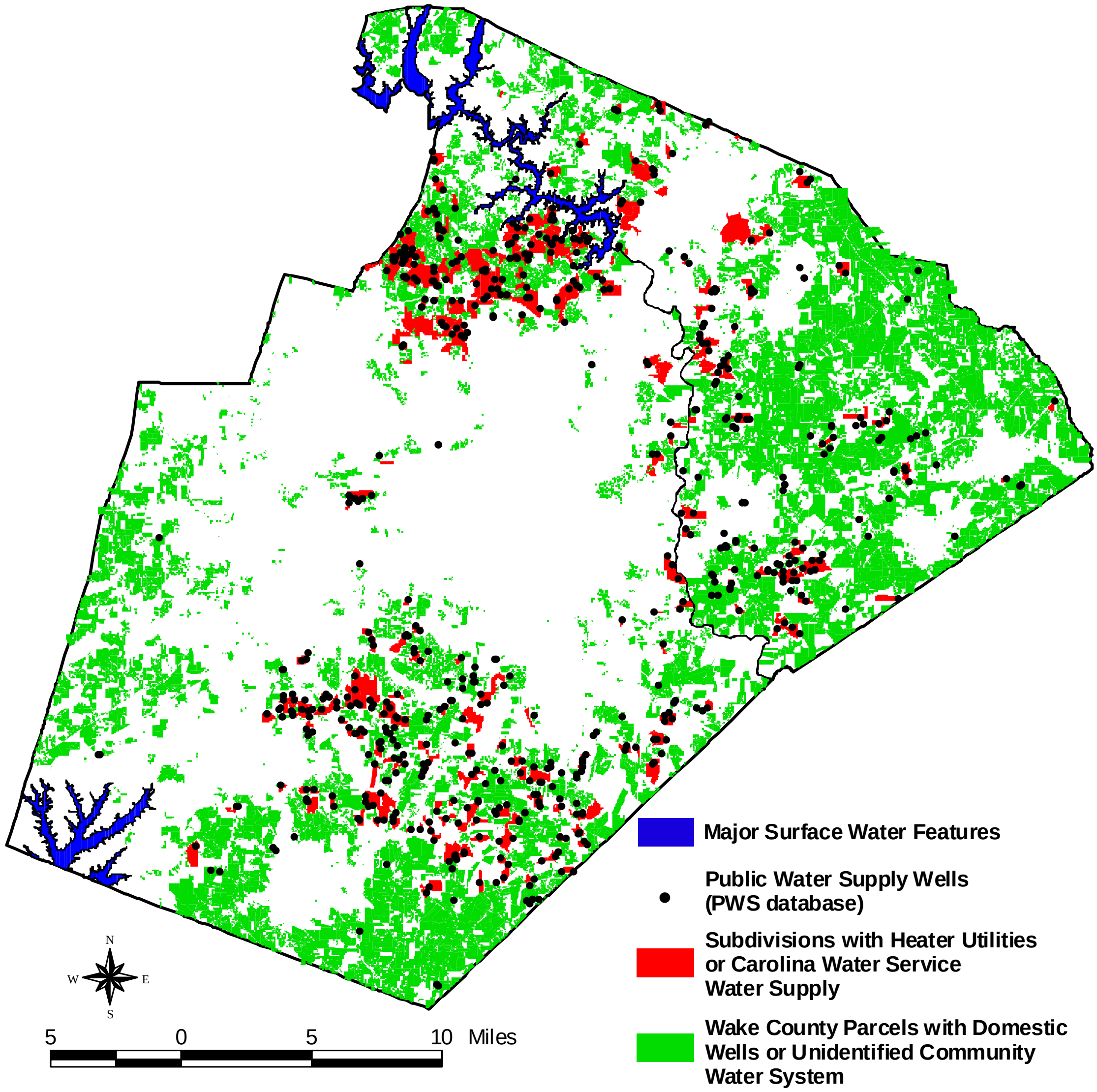



**Figure 3-6**
**Areas Served by Domestic Wells and Community Water System Wells**

for neighboring Little River (64 gallons per person per day) was used.

**Table 3-10** presents the estimated population served by domestic wells or small CWSs, the estimated usage per person, and the estimated domestic withdrawal rate per drainage basin.

### 3.2.3.10 Baseflow

Baseflow was estimated by performing stream hydrograph separations, which are mathematical procedures to differentiate stream baseflow and overland flow (runoff). Several different techniques for performing stream hydrograph separations are available. Three of the most common methods include the fixed interval, the sliding interval, and the local minima. The sliding interval method was chosen for this investigation because it has been shown to provide average estimates of baseflow compared to the other two methods. The sliding interval method calculates baseflow by finding the lowest discharge for a

**Table 3-10**
**Estimated Domestic Withdrawal (EDW)**

| Drainage Basin | Population not on Major CWS or Municipal Water[1] | Average Annual Per Capita Use[2] (gpd/person) | EDW (gpd) | Area (sq. ft) | EDW (cu. ft/yr) | EDW (in/yr) |
|---|---|---|---|---|---|---|
| Beaver Dam | 2,428 | 64 | 155,412 | 556,382,374 | 7,583,630 | 0.164 |
| Black Creek | 3,976 | 59 | 234,581 | 639,319,372 | 11,446,803 | 0.215 |
| Crabtree Creek | 4,159 | 75 | 311,927 | 3,700,201,979 | 15,221,049 | 0.049 |
| Harris Lake | 1,994 | 52 | 103,706 | 1,710,227,037 | 5,060,504 | 0.036 |
| Jordan Lake | 4,209 | 52 | 218,869 | 1,515,324,323 | 10,680,107 | 0.085 |
| Kenneth Creek | 2,859 | 59 | 168,696 | 402,508,446 | 8,231,811 | 0.245 |
| Little River | 8,757 | 64 | 560,462 | 2,166,506,282 | 27,348,751 | 0.151 |
| Lower Falls Lake | 13,973 | 100 | 1,397,315 | 2,171,377,588 | 68,184,489 | 0.377 |
| Lower Neuse | 6,712 | 64 | 429,596 | 1,407,114,020 | 20,962,883 | 0.179 |
| Middle Creek | 14,798 | 65 | 961,894 | 2,223,030,421 | 46,937,343 | 0.253 |
| Swift Creek | 13,526 | 58 | 784,505 | 2,533,033,896 | 38,281,303 | 0.181 |
| Upper Falls Lake | 825 | 52 | 42,886 | 571,669,339 | 2,092,723 | 0.044 |
| Upper Neuse | 12,775 | 74 | 945,354 | 2,944,778,184 | 46,130,263 | 0.188 |
| Walnut Creek | 1,858 | 55 | 102,164 | 1,290,360,787 | 4,985,256 | 0.046 |
| TOTAL | 92,850 | 69 | 6,417,367 | 23,831,834,048 | 313,146,916 | 0.158 |

Notes:
[1] "Major" CWS defined here as Heater Utilities, Inc. or Carolina Water Service.
[2] Per capita usage estimates based on year 2000 and 2001 billing records provided by Heater Utilities, Inc.

certain interval of days as determined by the size of the drainage basin. The process is repeated by sliding the interval to the next day until a discharge has been assigned to each day. The assigned daily values are then averaged to arrive at an estimate of baseflow over a given period of time.

Of the ten continuous USGS streamflow gages in, or immediately outside the County, only four were determined to have either a long enough period of record (i.e., greater than 5 years) or drainage basin of sufficient size (i.e., greater than 10 square miles) to serve as representative gages for their respective basin, as shown in **Table 3-11**.

To estimate baseflow in the remaining 10 drainage basins, an analytical model termed the "Modified Landscape Model" was used. The model was recently developed by the NCDENR DWQ Groundwater Section (Mew et al, 2002) as a tool to estimate average annual recharge in the Piedmont and Coastal Plain provinces of North Carolina. To develop the model, county soil maps were used to delineate landscape units having similar recharge characteristics. Landscape units were assigned recharge values according to geologic origin, texture, and slope. Baseflow was estimated by hydrograph separation for six drainage basins in the Coastal Plain and seven drainage basins in the Piedmont. These baseflow estimates were compared to the Modified Landscape Model estimates of recharge, and the recharge values for each landscape unit were iteratively adjusted during a calibration procedure until reasonable match of baseflow was achieved. This comparison is made since the baseflow component of streamflow is considered to be equal to groundwater recharge, assuming there are no long-term changes in groundwater storage.

A comparison of the baseflow and recharge estimates developed through hydrograph separation (this investigation), and the Modified Landscape Model, is presented in **Table 3-12**. In general, the two methods provide similar estimates of recharge for the four basins that can be compared. One notable exception is Swift Creek, which has an estimated mean stream baseflow of 4.80 inches per year, compared to the recharge model's estimate of 7.14 inches per year.

To complete the water budget equation, the hydrograph separation derived estimated baseflows were used for basins with sufficient data to support reasonable baseflow estimates. For the remaining ten basins, the estimated recharge rates calculated by the modified landscape model were used.

### 3.2.4 Water Budget Observations

The water budgets for current day average conditions for the 14 drainage basins of Wake County are shown in **Table 3-13**. All values are shown in inches per year to facilitate a comparison between drainage basins. The rate "inches per year" is calculated by dividing the total amount of water for the year (in $ft^3$ per year) by the drainage basin area (in $ft^2$). In this way, the size of the basin will not affect the numbers in the columns, and each basin can be compared directly with all the other basins.

A few general comments should be made first about the water budgets.

- The water budget is designed to present an overview of average conditions, and does not necessarily represent the budget for any particular year. Year-by-year variations are expected and can be quite significant primarily due to variations in rainfall, ET, runoff, and baseflow. These components of the water budget are all driven by rainfall, but will not necessarily increase or decrease proportionally to rainfall for any given year.

- Likewise, significant variation in terms such as ET, baseflow, and groundwater withdrawals can occur seasonally. The water budget does not attempt to represent the seasonal variations but rather to present an average annual assessment.

- The accuracy of the values in each column is difficult to assess but varies as well. Each number may have a significant, but unknown range within which the true estimate can be

**Table 3-11**
**Baseflow, Runoff, and Average Total Flow Data for USGS Continuous Record Gaging Stations**

| Drainage Basin | Station Name | Drainage Area (sq. miles) | Years of Record | Usability* | Mean Baseflow (inches/year) | Mean Runoff (inches/year) | Mean Total Flow (inches/year) |
|---|---|---|---|---|---|---|---|
| Upper Neuse Lake | Neuse River near Falls Lake | 771.0 | 31 | No; Dam controlled | 6.5 | 6.4 | 12.9 |
| Crabtree Creek | Crabtree Creek at Ebenezer Church Rd. | 76.0 | 8 | OK, but can use station at US 1 at Raleigh | 7.1 | 7.8 | 14.9 |
| Crabtree Creek | Crabtree Creek at Hwy 70 at Raleigh | 97.6 | 9 | OK, but can use station at US 1 at Raleigh | 7.1 | 7.0 | 14.1 |
| Crabtree Creek | Crabtree Creek at US 1 at Raleigh** | 121.0 | 9 | OK | 8.5 | 9.4 | 17.9 |
| Crabtree Creek | Marsh Creek near New Hope | 6.8 | 17 | No; Drainage size too small | 9.8 | 9.4 | 19.2 |
| Walnut Creek | Rocky Branch below Pullen Dr. at Raleigh | 1.2 | 5 | No; Drainage size too small | 7.5 | 22.2 | 29.7 |
| Walnut Creek | Walnut Creek at Sunnybrook Drive** | 29.0 | 5 | OK | 8.4 | 11.2 | 19.6 |
| Swift Creek | Swift Creek near McCullars Crossroads** | 35.8 | 14 | OK (spillway at Lake Wheeler) | 4.8 | 9.5 | 14.3 |
| Harris Lake | White Oak Creek at Green Level | 7.0 | 2 | No; Short period of record | 10.4 | 11.0 | 21.4 |
| Middle Creek | Middle Creek near Clayton** | 83.5 | 63 | OK | 8.2 | 6.8 | 14.8 |

* Usability refers to the adequacy of the gage location and amount of associated data in developing defensible baseflow estimates.
** Stations where data were used to develop baseflow estimates in the water budget equation.

**Table 3-12**
**Comparison of Hydrograph Separation Derived Baseflows and the Modified Landscape Model Recharge Estimates**

| Drainage Basin | Dranage Basin Area (sq. feet) | Modified Landscape Model Recharge Estimate[1] Recharge (cubic feet/year) | Modified Landscape Model Recharge Estimate[1] Recharge (in/yr) | Hydrograph Separation Baseflow Estimate[2] (in/yr) |
|---|---|---|---|---|
| Upper Falls Lake | 570,856,480 | 179,907,391 | 3.78 | -- |
| Lower Falls Lake | 2,170,589,343 | 1,286,816,777 | 7.11 | -- |
| Upper Neuse | 2,938,111,624 | 1,823,045,661 | 7.45 | -- |
| Crabtree Creek | 3,694,966,334 | 1,788,291,997 | **5.81** | **7.52** |
| Walnut Creek | 1,290,360,787 | 790,418,192 | **7.35** | **8.40** |
| Lower Neuse | 1,406,482,019 | 927,305,458 | 7.91 | -- |
| Swift Creek | 2,530,865,601 | 1,506,855,419 | **7.14** | **4.80** |
| Middle Creek | 2,222,911,306 | 1,393,607,340 | **7.52** | **6.38** |
| Black Creek | 638,866,837 | 423,903,646 | 7.96 | -- |
| Little River | 2,159,320,205 | 1,498,111,251 | 8.33 | -- |
| Beaver Dam | 556,202,230 | 360,031,395 | 7.77 | -- |
| Jordan Lake | 1,511,626,613 | 344,003,298 | 2.73 | -- |
| Harris Lake | 1,706,190,448 | 519,853,671 | 3.66 | -- |
| Kenneth Creek | 402,195,485 | 248,645,541 | 7.42 | -- |
| County | 23,799,545,312 | 13,090,797,037 | 6.60 | |

1 - NCDENR Division of Water Quality Groundwater Section recharge estimate using the modified landscape model (Mew et al, 2002)
2 - Baseflow calculated using the sliding interval technique, and adjusted to account for major NPDES discharges.

**Table 3-13**
**Water Budget Summary**

| Drainage Basin | Water In (inches/year) | | | | | Water Out (inches/year) | | | | | | TOTALS (inches/year) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | WW/IND Rech | EDR | SW Disch | = | ET | RO | SWW | GWW | EDW | BF | IN | OUT | Difference |
| Upper Falls Lake | 45.64 | 0.01 | 0.04 | 0.00 | = | 32.00 | 5.89 | 0.00 | 0.00 | 0.04 | 3.78 | 45.69 | 41.72 | 3.97 |
| Lower Falls Lake | 44.73 | 0.00 | 0.44 | 1.45 | = | 32.00 | 5.92 | 13.11 | 0.48 | 0.38 | 7.11 | 46.63 | 59.00 | -12.37 |
| Upper Neuse | 45.08 | 0.01 | 0.27 | 1.43 | = | 32.00 | 7.23 | 0.12 | 0.36 | 0.19 | 7.45 | 46.79 | 47.34 | -0.55 |
| Crabtree Creek | 43.87 | 0.01 | 0.08 | 0.98 | = | 32.00 | 10.81 | 0.00 | 0.22 | 0.05 | 7.52 | 44.94 | 50.60 | -5.66 |
| Walnut Creek | 45.22 | 0.00 | 0.08 | 0.00 | = | 32.00 | 10.83 | 0.00 | 0.03 | 0.05 | 8.40 | 45.30 | 51.31 | -6.01 |
| Lower Neuse | 45.17 | 0.01 | 0.20 | 9.24 | = | 32.00 | 5.41 | 0.00 | 0.14 | 0.18 | 7.91 | 54.63 | 45.64 | 8.99 |
| Swift Creek | 45.33 | 0.06 | 0.21 | 0.01 | = | 32.00 | 8.34 | 0.00 | 0.19 | 0.18 | 4.80 | 45.61 | 45.51 | 0.10 |
| Middle Creek | 45.75 | 0.01 | 0.32 | 2.07 | = | 32.00 | 6.42 | 0.11 | 0.20 | 0.25 | 6.38 | 48.16 | 45.36 | 2.80 |
| Black Creek | 46.31 | 0.00 | 0.18 | 0.00 | = | 32.00 | 4.83 | 0.00 | 0.01 | 0.22 | 7.96 | 46.50 | 45.02 | 1.48 |
| Little River | 45.45 | 0.01 | 0.14 | 0.00 | = | 32.00 | 5.82 | 0.09 | 0.04 | 0.15 | 8.33 | 45.60 | 46.43 | -0.82 |
| Beaver Dam | 45.64 | 0.00 | 0.14 | 0.94 | = | 32.00 | 6.24 | 0.00 | 0.02 | 0.16 | 7.77 | 46.72 | 46.19 | 0.54 |
| Jordan Lake | 44.85 | 0.00 | 0.08 | 0.23 | = | 32.00 | 7.50 | 0.00 | 0.01 | 0.09 | 2.73 | 45.16 | 42.33 | 2.84 |
| Harris Lake | 45.73 | 0.00 | 0.03 | 1.60 | = | 32.00 | 5.64 | 12.82 | 0.01 | 0.04 | 3.66 | 47.37 | 54.16 | -6.79 |
| Kenneth Creek | 46.33 | 0.01 | 0.20 | 0.73 | = | 32.00 | 6.18 | 0.00 | 0.01 | 0.25 | 7.42 | 47.27 | 45.86 | 1.42 |

***P*** = Precipitation
***WW/IND Rech*** = Spray irrigation and return through commercial and industrial onsite wastewater systems
***EDR*** = Estimated domestic recharge
***SW Disch*** = Surface water discharge
***ET*** = Evapotranspiration
***RO*** = Runoff
***SWW*** = Surface water withdrawals
***GWW*** = Groundwater withdrawals from Community Water Systems operated by Heater Utilities and Carolina Water Service plus estimated commercial and industrial groundwater withdrawals.
***EDW*** = Estimated domestic withdrawals plus estimated withdrawals from small Community Water Systems
***BF*** = Baseflow

Note: It is important to understand that the water budgets represent present day conditions. The water budgets are expected to change in the future (see Section 5) as a result of increased amount of impervious surface and increases or decreases in groundwater and surface water withdrawals and discharges.

found. Please refer to TM No. 3, for a discussion of the expected accuracy of the values.

- The budget should be considered with regard to the information it supplies about the relative amounts of water associated with each element of the budget. Small differences should be ignored, but large differences are probably meaningful.

The natural components of the water cycle are clearly dominant. On the inflow side, precipitation accounts for about 97 percent of the flow, with surface water discharges accounting for about three percent. On the outflow side, the natural components of ET, baseflow, and runoff from pervious surfaces account for almost 90 percent of the flows. Surface water withdrawals account for about four percent, with the rest primarily attributed to runoff from impervious surfaces.

From an examination of the table a number of observations can be drawn about each component of the water budget. These are listed below for each column, along with a rough estimate of the expected accuracy of the values in the water budget column. The accuracy estimates are not statistically determined and only represent reasonable professional judgment.

As previously mentioned, the development of the water budgets also helped to meet the specific objectives identified by Wake County and its stakeholders (e.g. estimating recharge rates and total groundwater consumption). Where applicable, observations or insight pertaining to the objectives listed in Section 1 of this report are also presented below.

#### 3.2.4.1 Precipitation

Precipitation is based on existing gage data. There is some variation in rainfall across Wake County. The difference between the highest and lowest average annual rainfall for a drainage basin is almost 2.5 inches. When compared to the levels of groundwater withdrawals, this is a fairly substantial difference.

#### 3.2.4.2 Wastewater and Industrial Recharge

With the exception of Swift Creek, recharge of wastewater is not significant. The Wrenn Road WWTP in the Swift Creek basin contributes 0.6 inches per year of groundwater recharge from spray irrigation to that basin.

#### 3.2.4.3 Estimated Domestic Recharge

The highest estimated EDR, 0.44 inches per year for Lower Falls Lake is less than seven percent of the estimated recharge of the groundwater as represented by baseflow. Since this is less than the estimated accuracy of the precipitation values, it is not having a significant effect on the overall water budget.

#### 3.2.4.4 Surface Water Discharges

Surface water discharges represent a significant component in the water budget. For Wake County the average is about 1.3 inches per year. For those drainage basins with large surface water discharges, this usually represents a significant increase in streamflow even during dry periods, and also generally indicates a transfer of water from sources outside of the drainage basin. The drainage basins can be roughly grouped into three categories: (1) Significant Impact (more than 1 inch/year) occurs in the Lower Neuse, Middle Creek, Harris Lake, Lower Falls Lake, and Upper Neuse drainage basins; (2) Moderate Impact (between 0.1 and 1 inch per year) occurs in Crabtree Creek, Beaver Dam, Kenneth Creek, and Jordan Lake drainage basins.; and (3) Insignificant Impact occurring in Swift Creek, Little River, Black Creek, Walnut Creek, and Upper Falls Lake drainage basins.

#### 3.2.4.5 Evapotranspiration

The ET value used is the same for all drainage basins and represents a reasonable estimate based on several studies done in the Piedmont. However, it does not account for the variation that occurs due to rainfall variation between basins, nor does it account for the effects of varying vegetation and land use between basins.

ET is the single largest component of water leaving the system, accounting for about 67 percent of the outflow. It is primarily a natural phenomenon that is difficult to influence through management measures, but it can be affected by changes in land use and vegetation. Increased development will generally result in reduced transpiration because of the loss of vegetation. Depending on the method of stormwater management, evaporation may increase or decrease. If runoff is detained in detention ponds or other structures, evaporation may increase.

**3.2.4.6 Runoff**

Runoff is a significant component of the water budget, accounting for about 15 percent of the outflow. It is primarily a concern for stream management. However, increased runoff usually is paired with decreased groundwater recharge and decreased stream baseflow. Walnut Creek and Crabtree Creek have the highest runoff values, and are also the most developed drainage basins. The other drainage basins all fall within the expected ranges of runoff for less developed conditions.

**3.2.4.7 Surface Water Withdrawals**

Surface water withdrawals represent only a very small component of the water budget (less than 0.2 percent) with two exceptions, Lower Falls Lake and Harris Lake. For each of these drainage basins surface water withdrawals represent an increase of over 25 percent of the outflow that probably occurred prior to the construction of Falls Lake and Harris Lake. The City of Raleigh's water treatment plant accounts for the withdrawal in the Lower Falls Lake drainage basin, and the Shearon Harris power facility accounts for the withdrawal in the Harris Lake drainage basin. These withdrawals are important in the overall water budget, but do not have a large impact on the groundwater portion of the flow.

**3.2.4.8 Groundwater Withdrawals**

Lower Falls Lake, Upper Neuse, Crabtree Creek, Middle Creek, Swift Creek, and Lower Neuse drainage basins all have groundwater withdrawals in the range of 0.1 to 0.5 inches per year. These rates of withdrawal represent the largest volumes of groundwater withdrawals in the County. The other drainage basins have a much lower use of groundwater.

**3.2.4.9 Estimated Domestic Withdrawals**

The drainage basins all show relatively low rates of domestic withdrawal in comparison with the overall hydrologic cycle. The average EDW among the basins is about 0.16 inches per year, or only about 0.4 percent of the total water in the system. Higher intensity domestic withdrawals (more than 0.2 inches per year) are found in Lower Falls Lake, Middle Creek, Kenneth Creek, and Black Creek drainage basins. Moderate intensity domestic withdrawals (between 0.1 and 0.2 inches per year) are found in Upper Neuse, Swift Creek, Lower Neuse, Beaver Dam, and Little River drainage basins. Jordan Lake, Crabtree Creek, Walnut Creek, Upper Falls Lake, and Harris Lake have relatively low EDW estimates of less than 0.1 inch per year.

Total groundwater use in Wake County, which is defined as the sum of all groundwater withdrawals (GWW + EDW) is approximately 13.6 mgd (0.33 inches per year). Total net groundwater consumption, which is defined as the amount of groundwater withdrawn less the amount that is returned through onsite wastewater systems, and wastewater and industrial discharge (GWW + EDW – EDR – WW/Ind Rech) is approximately 5.5 mgd (0.14 inches per year). The difference, about 8.1 mgd (0.19 inches per year) accounts for water that is returned to the groundwater system primarily through domestic onsite wastewater treatment systems.

**3.2.4.10 Baseflow**

Baseflow is one of the major components of the water budget, representing on the average between 5 to 20 percent of the outflow. If one assumes there are no long-term changes in groundwater storage, then the baseflow component of streamflow can be considered to be equal to groundwater recharge.

Baseflow varies greatly from year to year and may disappear entirely during periods of drought or for portions of each summer. Most of the estimates for Wake County fall within the 6 to 8 inches per year range. However, Upper Falls Lake, Harris Lake, and Jordan Lake have significantly lower values. All three basins are underlain primarily by Triassic sediments, which are poorly infiltrated by recharge and are low yielding. The estimated value of baseflow for Swift Creek is comparatively low. For the most part the Swift Creek drainage basin is not underlain by Triassic basin sediments, and it has a small percentage of impervious surface compared to Walnut Creek and Crabtree Creek.

As shown in **Table 3-14**, baseflow (or recharge) as a percentage of precipitation, ranges from 6 to 19 percent on a HUC-11 drainage basin level for an average year. Recharge rates within a drainage basin may vary widely due to the different soil types, slope, and other factors. Another estimate of recharge in terms of its spatial variation across Wake County is presented in **Figure 3-7**. The figure was prepared using recharge estimates (inches per year) derived solely from the NCDENR modified landscape model. The figure provides a better indication of how recharge rates vary across the County compared to those developed at the drainage basin level.

Data from the four drainage basins where baseflow separations were performed, suggests that baseflow accounts for between 34 and 55 percent of total streamflow in Wake County. On an average annual basis, baseflow accounts for 34, 43, 47, and 55 percent of total streamflow in Swift Creek, Walnut Creek, Crabtree Creek, and Middle Creek, respectively. The range of values may be attributed to such factors as the nature of the hydrogeologic units through which the streams pass and the amount of imperviousness within the drainage basins. Baseflow as a percentage of total streamflow is expected to be lower in the very western part of Wake County (i.e., the Triassic Basin) compared to elsewhere in the County.

#### 3.2.4.11 Difference in Inflow and Outflow

The column in **Table 3-13** labeled "difference" is simply the difference between the estimated amount flowing into the drainage basin and the

**Table 3-14**
**Recharge as a Percentage of Precipitation by Drainage Basin**

| Drainage Basin | Recharge as a Percentage of Precipitation | Drainage Basin | Recharge as a Percentage of Precipitation |
|---|---|---|---|
| Upper Falls Lake | 8% | Middle Creek | 14% |
| Lower Falls Lake | 16% | Black River | 17% |
| Upper Neuse | 17% | Little River | 18% |
| Crabtree Creek | 17% | Beaver Dam | 17% |
| Walnut Creek | 19% | Jordan Lake | 6% |
| Lower Neuse | 18% | Harris Lake | 8% |
| Swift Creek | 11% | Kenneth Creek | 16% |

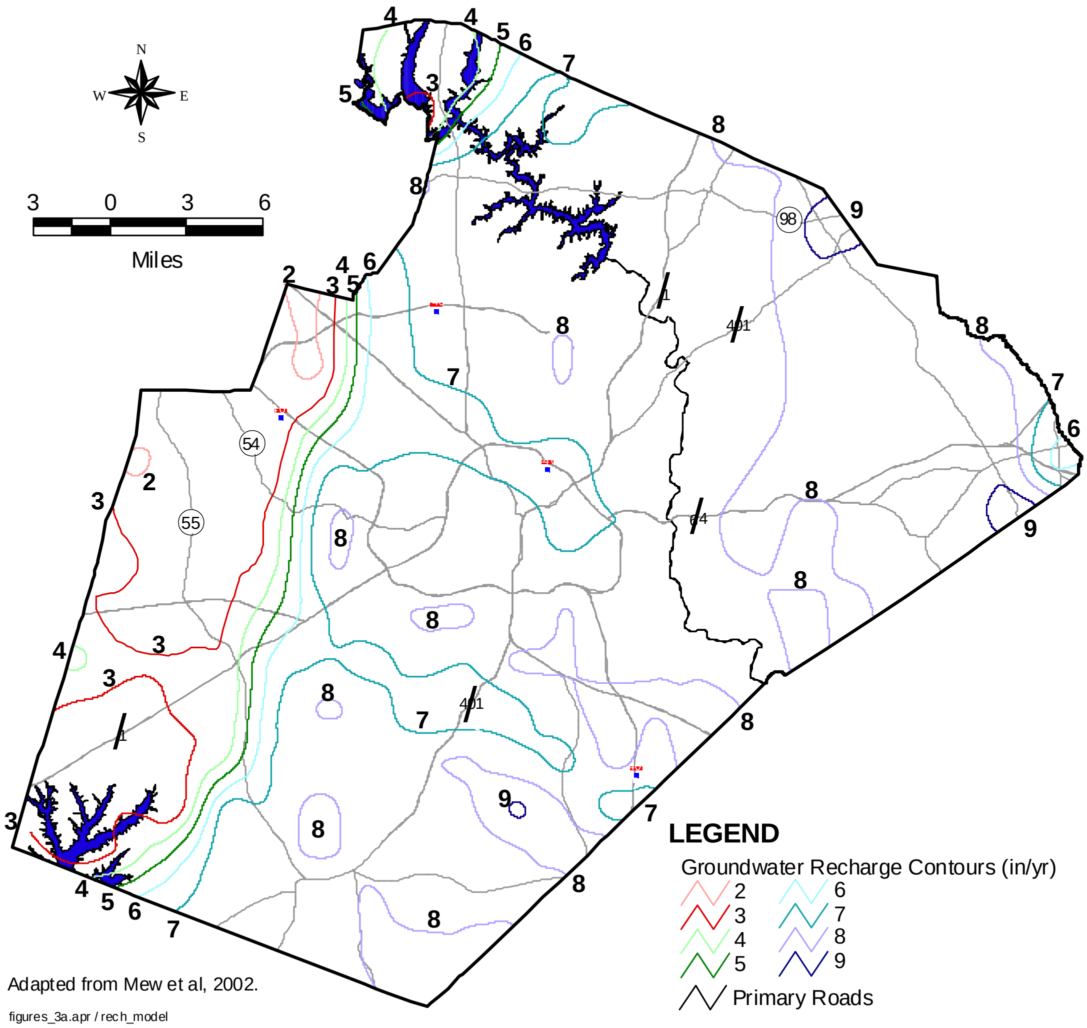



**Figure 3-7**
**Groundwater Recharge Rates (inches/year)**

amount flowing out. The value is a combination of the various errors of estimation of each of the components, along with an indication of a significant amount of water exported from or imported into the drainage basin.

The Lower Neuse, Middle Creek, and Upper Neuse drainage basins are receiving a significant amount of water from outside the drainage basin. To a lesser extent, Kenneth Creek and Beaver Dam drainage basins show this same pattern. These drainage basins are impacted by the large wastewater discharges (City of Raleigh Neuse River WWTP, Fuquay-Varina WWTP, City of Raleigh Water Treatment Plant, and the Wake Forest WWTP).

Upper Falls Lake, Jordan Lake, and Black Creek have significant positive differences. There is no apparent cause of this imbalance which can probably be attributed to underestimating some combination of baseflow, runoff, and ET.

Harris Lake and Lower Falls Lake show “deficits” with outflow larger than inflow. This is attributed to large surface water withdrawals (Neuse River WTP and Shearon Harris power facility) with the export of water out of the drainage basin.

Crabtree Creek and Walnut Creek also show "deficits". They can probably be attributed to overestimating baseflow, runoff, and/or ET.

Beaver Dam, Swift Creek, and Little River results show reasonably low differences between inflow and outflow, potentially indicating that no significant import or export of water is occurring and that the estimates provided are reasonable.

## 3.3 Groundwater Resource Sustainability

Water budgets provide insight into the overall movement and use of water within a drainage basin. However, the question of sustainable yield of the aquifer is not directly answered by the results. In a USGS report titled "Sustainability of Ground-Water Resources" (Alley et al, 1999), issues of sustainable yield are approached from a variety of perspectives. The report points out that resource sustainability has proven to be an elusive concept to define. They define it as "development and use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences". They further point out that groundwater sustainability must be defined within the context of the complete hydrologic system of which groundwater is a part.

In order to define groundwater resource sustainability in Wake County, three primary questions must be addressed:

- Is current and projected water consumption significant when compared to the natural flows within the groundwater portion of the aquifer system?
- Is current and projected water consumption having a significant impact on stream baseflow during periods of drought?
- What amount of water can actually be extracted from the aquifers (i.e., well yield)?

In the case of Wake County the water budget results indicate that current groundwater consumption represents a relatively small percentage of the water budget, which is still dominated by the natural components of precipitation, ET, runoff, and baseflow.

Comparing current net groundwater consumption to average annual baseflow further reinforces this fact. The reason this comparison is made is that average annual baseflow is a reasonable estimate of total recharge to the groundwater system, as discussed previously. **Table 3-15** compares net groundwater consumption (water withdrawn and not returned to the groundwater aquifer) with various estimates of stream baseflow. The table shows that groundwater consumption as a percentage of annual average baseflow ranges from a low of -0.1 percent for Walnut Creek to a high of 5.8 percent for Lower Falls Lake. These are relatively low numbers and suggest that at the (HUC-11) drainage basin scale, current consumption is not depleting the groundwater system on a long-term basis.

The negative net groundwater consumption value for Walnut Creek indicates that more water is being returned to the aquifer in that drainage basin than is withdrawn. This appears to be a result of the fact that a larger number of households are served by public water and have onsite wastewater systems, compared to the number of households served by domestic wells or community wells which have onsite wastewater systems. Approximately 3,500 residents are served by onsite wastewater systems compared to just over 2,100 that use a domestic well or are served by a CWS. Therefore, approximately 1,400 residents (or approximately 560 households) have public water service but not public sewer service.

Before addressing the second question, one must understand that the groundwater which is withdrawn from the aquifer must be balanced in some way. The three possible "balancing mechanisms" are 1) more water entering the aquifer (i.e., increased recharge), 2) less water leaving the aquifer (i.e., decreased discharge to

**Table 3-15**
**Net Groundwater Consumption Compared to Baseflow and Low Flows**

| ***Drainage Basin*** | ***Net Groundwater Consumption (in/yr)*** | ***Average Baseflow (in/yr)*** | ***Net Groundwater Consumption as a Percentage of Average Baseflow*** | ***7Q10* (in/yr)*** | ***Net Groundwater Consumption as a Percentage of 7Q10*** | ***30Q2** (in/yr)*** | ***Net Groundwater Consumption as a Percentage of 30Q2*** |
|---|---|---|---|---|---|---|---|
| Upper Falls Lake | 0.003 | 3.78 | 0.1% | 0.000 | 7Q10 is 0 | 0.338 | 1% |
| Lower Falls Lake | 0.412 | 7.11 | 5.8% | 1.483 | 28% | 3.728 | 11% |
| Upper Neuse | 0.269 | 7.45 | 3.6% | 1.018 | 26% | 4.116 | 7% |
| Crabtree Creek | 0.180 | 7.52 | 2.4% | 0.255 | 71% | 1.073 | 17% |
| Walnut Creek | -0.005 | 8.40 | -0.1% | 0.264 | -2% | 3.163 | 0% |
| Lower Neuse | 0.097 | 7.91 | 1.2% | 1.384 | 7% | 4.919 | 2% |
| Swift Creek | 0.103 | 4.80 | 2.2% | 0.032 | 320% | 1.002 | 10% |
| Middle Creek | 0.116 | 6.38 | 1.8% | 0.046 | 254% | 1.386 | 8% |
| Black Creek | 0.041 | 7.96 | 0.5% | 0.000 | 7Q10 is 0 | 0.175 | 24% |
| Little River | 0.041 | 8.33 | 0.5% | 0.168 | 24% | 1.343 | 3% |
| Beaver Dam | 0.033 | 7.77 | 0.4% | 0.041 | 81% | 1.184 | 3% |
| Jordan Lake | 0.014 | 2.73 | 0.5% | 0.000 | 7Q10 is 0 | NA | NA |
| Harris Lake | 0.006 | 3.66 | 0.2% | 0.000 | 7Q10 is 0 | 0.042 | 15% |
| Kenneth Creek | 0.047 | 7.42 | 0.6% | 0.078 | 61% | 1.454 | 3% |

*Net Groundwater Consumption = GWW + EDW - EDR - WW/Ind Rech*

** 7Q10 is defined as the lowest seven consecutive day average streamflow with a recurrence interval of ten years.*

*** 30Q2 is defined as the lowest 30 consecutive day average streamflow with a recurrence interval of two years.*

streams), or 3) removal of water stored in the aquifer. Since groundwater withdrawals and replenishment by recharge vary both seasonally and annually, minor temporary withdrawals of water stored in the aquifer may be balanced by intervening additions to storage. If withdrawals are minor compared to recharge, then there is likely to be little impact on groundwater storage. The withdrawals will likely be balanced by similar reductions in stream baseflow.

**Table 3-15** also shows two measures of low flow:

- 30Q2: the lowest monthly average streamflow with a recurrence interval of two years.
- 7Q10: the lowest seven consecutive day average streamflow with a recurrence interval of ten years.

The 30Q2 and 7Q10 low flow estimates at the HUC-11 drainage basin level were developed from measurements and estimates taken from numerous continuous and partial record stations within each drainage basin as documented by Weaver, 1998 and Weaver and Pope, 2001. In 7 of the 14 drainage basins, low flow estimates were only available from one or two record stations, limiting the useability when extrapolating to the basin level. **Table 3-16** presents the complete list of the low flow data used to develop the drainage basin-level estimates.

The less extreme low flow condition is the 30Q2 flow. The table indicates that estimated groundwater consumption does not exceed the 30Q2 for any of the drainage basins. The highest consumptive use when compared to the 30Q2 flow is 49 percent for Black Creek, ranging down to one percent for Upper Falls Lake (not considering Walnut Creek which has a negative net groundwater consumption). That means that reduced recharge from precipitation, not current consumption, is the primary cause of long periods of dry streambeds during periods of drought that occur every couple of years.

For the more extreme low flow condition, the 7Q10, several of the drainage basins indicate a net groundwater consumption that is higher than the 7Q10 flow, if indeed the 7Q10 is actually greater than zero. These include Upper Falls Lake, Swift Creek, Middle Creek, Black Creek, Jordan Lake, and Harris Lake. This suggests that these drainage basins will occasionally experience a complete lack of baseflow during dry periods. It also suggests that current net groundwater consumption is contributing to the loss of the already low baseflow during dry periods that occur relatively infrequently and for short durations. Current net groundwater consumption also is probably extending the period during which streams are dry in several of the drainage basins. Unfortunately, the low streamflow statistics shown in **Table 3-15** are very rough estimates because there are few long-term gages to provide better estimates.

## 3.4 Well Yield

An examination of available well yield information provides insight into the third question, “What amount of water can actually be extracted from the aquifers?” Well yield information from primarily domestic wells installed in Wake County between 1997 and August of 2002 was obtained from the Wake County Department of Environmental Services (WDES). WDES maintains an electronic database to support and facilitate the permitting and approval of wells and onsite wastewater systems in Wake County. Well yields were placed on GIS coverages to examine the distribution of well yields in the County.

**Figure 3-8** shows the distribution of maximum domestic well yields, contoured into zones of similar yield. Driller-reported yields from 2,710 wells were used in this analysis. To arrive at the maximum yield for a particular area, a 5,000-foot by 5,000-foot grid was placed over the County map, and the maximum reported yield within each grid cell was selected. Depending on the density of wells in a particular area, grid cells may have contained between zero and 56 wells with a reported yield value. A contour map was then

**Table 3-16**
**Low Flow Characteristics of Wake County Streams**

| Station No. | Station Name | Basin | Drainage Area (sq mi) | 7Q10 (cfs) | 30Q2 (cfs) | Area (sq ft) | 7Q10 (in/yr) | 30Q2 (in/yr) | Flow | Continuous or Periodic |
|---|---|---|---|---|---|---|---|---|---|---|
| 121 | Beaverdam Creek near Creedmoor | Upper Falls | 44.2 | 0 | 1.1 | 1,232,225,280 | 0.00 | 0.34 | | P |
| 124 | New Light Creek near Purnell | Lower Falls | 19.2 | 1.6 | 3.8 | 535,265,280 | 1.131 | 2.687 | | P |
| 125 | Upper Barton Creek near Bayleaf | Lower Falls | 12.4 | 0.5 | 3.1 | 345,692,160 | 0.547 | 3.394 | | P |
| 127 | Lower Barton Creek near Bayleaf | Lower Falls | 13.1 | 1.5 | 3.3 | 365,207,040 | 1.554 | 3.420 | | P |
| 131 | Horse Creek near Wake Forest | Lower Falls | 21.2 | 3.6 | 7.9 | 591,022,080 | 2.305 | 5.058 | | P |
| 135 | Neuse River near Falls | Lower Falls | 771 | 57.9 | 86.3 | 21,494,246,400 | 1.019 | 1.519 | R | C |
| 140 | Richland Creek at NC 98 at Wake Forest | Upper Neuse | 7.66 | 0.5 | 2.2 | 213,548,544 | 0.886 | 3.899 | | P |
| 141 | Richland Creek near Forestville | Upper Neuse | 10.5 | 0.8 | 2.7 | 292,723,200 | 1.034 | 3.491 | | P |
| 144 | Neuse River at US Hwy 1 | Upper Neuse | 792 | 12.6 | 51.9 | 22,079,692,800 | 0.216 | 0.890 | R | C |
| 146 | Austin Creek at Wake Forest | Upper Neuse | 3.98 | 0.1 | 1.6 | 110,956,032 | 0.341 | 5.457 | | P |
| 159 | Harris Creek near Wake Crossroads | Upper Neuse | 9.85 | 1.0 | 3.2 | 274,602,240 | 1.378 | 4.410 | | P |
| 162 | Neuse River near Raleigh | Upper Neuse | 877 | 39 | 130 | 24,449,356,800 | 0.604 | 2.012 | R | P |
| 245 | Poplar Creek near Knightdale | Lower Neuse | 8.83 | 0.9 | 3.2 | 246,166,272 | 1.384 | 4.919 | | P |
| 236 | Walnut Creek at Sunnybrook Road at Raleigh | Walnut Creek | 29.4 | 0.3 | 7.0 | 819,624,960 | 0.139 | 3.232 | | P |
| 240 | Big Branch near Garner | Walnut Creek | 11.8 | 0.5 | 2.6 | 328,965,120 | 0.575 | 2.991 | | P |
| 321 | Cedar Fork near Rolesville | Little River | 4.41 | < 0.05 | 0.5 | 122,943,744 | < 0.154 | 1.539 | | P |
| 326 | Buffalo Creek at Poole Rd near Wendell | Little River | 15.8 | 0.2 | 1.5 | 440,478,720 | 0.172 | 1.289 | | P |
| 372 | Moccasin Creek near Zebulon | Beaver Dam | 29.8 | 0.09 | 2.6 | 830,776,320 | 0.041 | 1.184 | | P |
| 164 | Crabtree Creek at SR 1615 near Cary | Crabtree Creek | 3.83 | 0 | NA | 106,774,272 | 0.000 | NA | | P |
| 169 | Licks Creek near Morrisville | Crabtree Creek | 0.3 | 0 | 0 | 8,363,520 | 0.000 | 0.000 | | P |
| 176 | Little Brier Creek near Nelson | Crabtree Creek | 8.58 | 0 | 0 | 239,196,672 | 0.000 | 0.000 | | P |
| 177 | Stirrup Iron Creek near Morrisville | Crabtree Creek | 25.4 | 0 | < 0.05 | 708,111,360 | 0.000 | < 0.027 | | P |
| 178 | Crabtree Creek near Cary | Crabtree Creek | 52.2 | 0.2 | 1.2 | 1,455,252,480 | 0.052 | 0.312 | | P |
| 188 | Crabtree Creek at SR 1649 | Crabtree Creek | 76 | 0.3 | 3.7 | 2,118,758,400 | 0.054 | 0.661 | R | C |
| 195 | Hare Snipe Creek near Millbrook | Crabtree Creek | 7.22 | 0.2 | 1.2 | 201,282,048 | 0.376 | 2.256 | | P |
| 200 | Mine Creek near Millbrook | Crabtree Creek | 8.87 | 0.8 | 3.2 | 247,281,408 | 1.224 | 4.897 | | P |
| 209 | Big Branch near Millbrook | Crabtree Creek | 3.78 | 0.7 | 1.8 | 105,380,352 | 2.514 | 6.464 | | P |
| 212 | Crabtree Creek at US 1 at Raleigh | Crabtree Creek | 121 | 2 | 13 | 3,373,286,400 | 0.224 | 1.458 | R | C |
| 220 | Marsh Creek near New Hope | Crabtree Creek | 6.84 | 0.3 | 1.5 | 190,688,256 | 0.595 | 2.977 | U | C |
| 256 | Swift Creek near Apex | Swift Creek | 21.0 | 0 | 0.4 | 585,446,400 | 0.000 | 0.259 | | P |
| 258 | Dutchmans Branch near McCullers Crossroads | Swift Creek | 5.23 | 0 | 0.1 | 145,804,032 | 0.000 | 0.260 | | P |
| 262 | Swift Creek near McCullers | Swift Creek | 55.2 | 0.1 | 4.9 | 1,538,887,680 | 0.025 | 1.205 | | P |
| 266 | Swift Creek near Drug Store | Swift Creek | 86.6 | 0.3 | 7 | 2,414,269,440 | 0.047 | 1.097 | | P |
| 274 | Middle Creek at Durham and Southern RR near Apex | Middle Creek | 0.7 | 0 | 0 | 19,514,880 | 0.000 | 0.000 | | P |
| 283 | Terrible Creek at SR 1404 at Five Points | Middle Creek | 4.92 | 0 | 0.1 | 137,161,728 | 0.000 | 0.276 | | P |
| 284 | Middle Creek near Clayton | Middle Creek | 83.5 | 0.3 | 9 | 2,327,846,400 | 0.049 | 1.463 | U | C |
| 286 | Black Creek near Willow Springs | Black Creek | 3.87 | 0 | < 0.05 | 107,889,408 | 0.00 | < 0.18 | | P |
| 225 | Kit Creek near Genlee | Jordan Lake | 8.29 | 0 | NA | 231,111,936 | 0.000 | NA | | P |
| 248 | Beaver Creek Tributary to Apex | Jordan Lake | 0.5 | 0 | NA | 13,939,200 | 0.000 | NA | | P |
| 249 | Beaver Creek at Apex | Jordan Lake | 5.65 | 0 | NA | 157,512,960 | 0.000 | NA | | P |
| 250 | Beaver Creek near New Hill | Jordan Lake | 18 | 0 | NA | 501,811,200 | 0.000 | NA | | P |
| 420 | White Oak Creek near Friendship | Harris Lake | 13.2 | 0 | NA | 367,994,880 | 0.000 | NA | | P |
| 421 | White Oak Creek near Holly Springs | Harris Lake | 22.5 | 0 | 0.07 | 627,264,000 | 0.000 | 0.042 | | P |
| 436 | Kenneth Creek near Chalybeate | Kenneth Creek | 14 | 0.08 | 1.5 | 390,297,600 | 0.078 | 1.454 | | P |

Data Sources: Weaver and Pope, 2001) and Weaver, 1998
R = Regulated; U = Unregulated; C = Continuous; P = Partial; NA - No data available



CDM

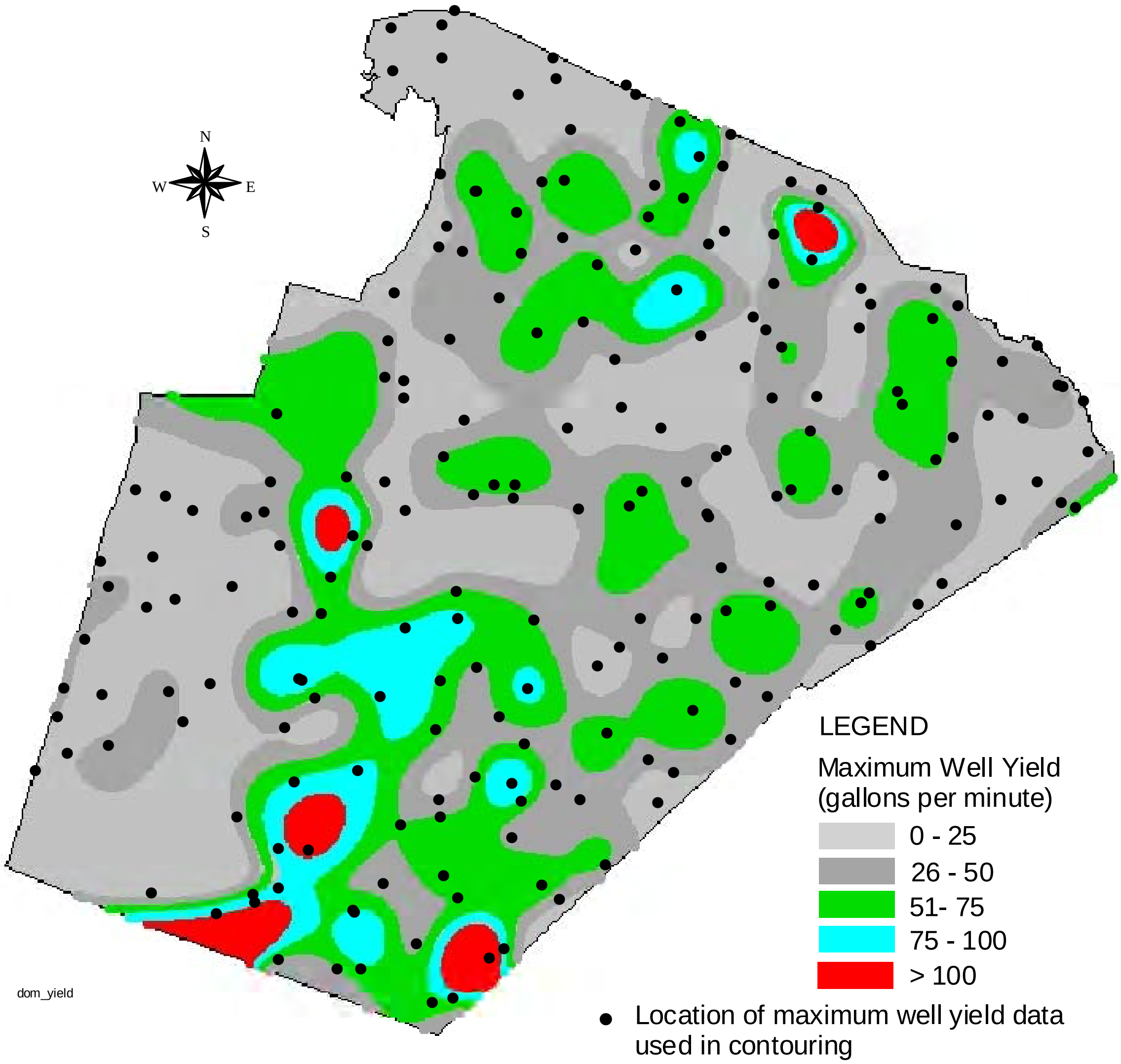



**Figure 3-8**
**Distribution of Maximum Domestic Well Yields**

generated based on the maximum reported yield within each grid cell.

The figure suggests that yields from new wells drilled in the indicated areas are likely to fall within the range of zero and the maximum reported value for the particular area. It does not indicate that the maximum well yield will be obtained.

A few generalizations can be made from the figure:

- Maximum domestic well yields are lowest in the Triassic basin and are generally below 25 gpm.
- The areas of highest maximum domestic well yields occur primarily in the Coastal Plain. Although new domestic wells in this region are typically installed into bedrock below the Coastal Plain sediments, the higher well yields may indicate that more water is available from storage in the overlying Coastal Plain sediments when compared to the saprolite found in the Piedmont.

Average yield of all 2,710 wells was just under 14 gpm, with a standard deviation of 16.5. Twenty five percent of the yields were below 4 gpm, 50 percent were below 8 gpm, and seventy five percent were below 20 gpm.

As cited by Daniel (2001), previous studies have shown that yields of wells tapping fractured crystalline rock can be positively correlated with well construction, including depth and diameter. As a result, and under the assumption most domestic wells are of a standard diameter, well yield was divided by foot of well depth, since well depth is highly variable. Well depths of the 2,710 wells ranged from 62 feet to 905 feet with a mean of 296 feet, a median of 260 feet and a standard deviation of 240. The resulting maximum yield-per-foot values are contoured in **Figure 3-9** in the same manner as the yield values.

The same general observations appear to hold true with regard to the maximum well yield per foot as were made for the maximum well yield distribution. Wells located in the Triassic basin result in yields no greater than 0.1 gpm per foot. Wells with the highest gpm per foot values most often appear in the Coastal Plain portion of the County.

The use of domestic well yield data is subject to a number of important limitations, namely:

- Since 24-hour pump tests are not required for domestic wells, drillers typically estimate yields through crude methods such as bailing or visually judging the amount of water blown up through the hole during drilling.
- The quantity of water needed for domestic consumption of a single household is relatively small, and as a result, the required yields of domestic wells do not necessarily represent the true water-bearing capacity of the aquifer.
- Well yield data for individual wells does not reflect the areas where wells were attempted but abandoned due to low yield.
- Anecdotal information suggests that lower estimates of yield (1 to 5 gallons per minute) are likely more accurate than some of the higher reported yield values since the driller was more inclined to obtain an accurate measurement of yield when it was low.
- Godfrey (1978) suggests well yields estimated by drillers are almost always high.

The well yield information from CWS wells is considered to provide a more accurate reflection of actual well yield for a particular area, since long-term pumping tests are typically performed to ensure the adequacy of the well. For this reason, well yield information for 387 active and inactive CWS wells was also obtained from the NCDENR PWS and HUI.

The CWSs are centered primarily in three basins, Lower Falls Lake, Swift Creek and Middle Creek, and to a slightly lesser extent in the Upper and Lower Neuse basins. As a result, their limited spatial distribution does not lend itself to contouring areas of maximum well yield on a county-wide basis. **Figure 3-10** shows CWS well yields differentiated by size and color. Several areas stand out that appear to generally have high yields. Yields of 75 gpm or greater tend to be most abundant in the south-central portion of the Lower Falls Lake basin (east of Creedmoor Road and North of I-540) and the eastern portion of the Middle Creek basin (north of Middle Creek). The mean well yield for all 386 wells was 50 gpm, with a standard deviation of 37. Twenty five percent of the wells had yields above 64 gpm and 25 percent of the wells had yields below 25 gpm.

Well yield is an important indicator of the ability of a well to supply enough water to those it serves. The minimum design standard acceptable to the Federal Housing Administration for a single-family dwelling is 400 gallons per day (Linaweaver et al, 1967, cited by Daniel, 1996). The most effective method to determine if a well is capable of providing enough water is by conducting a 24-hour pump test; however, for most domestic wells, pump tests of much a shorter duration are

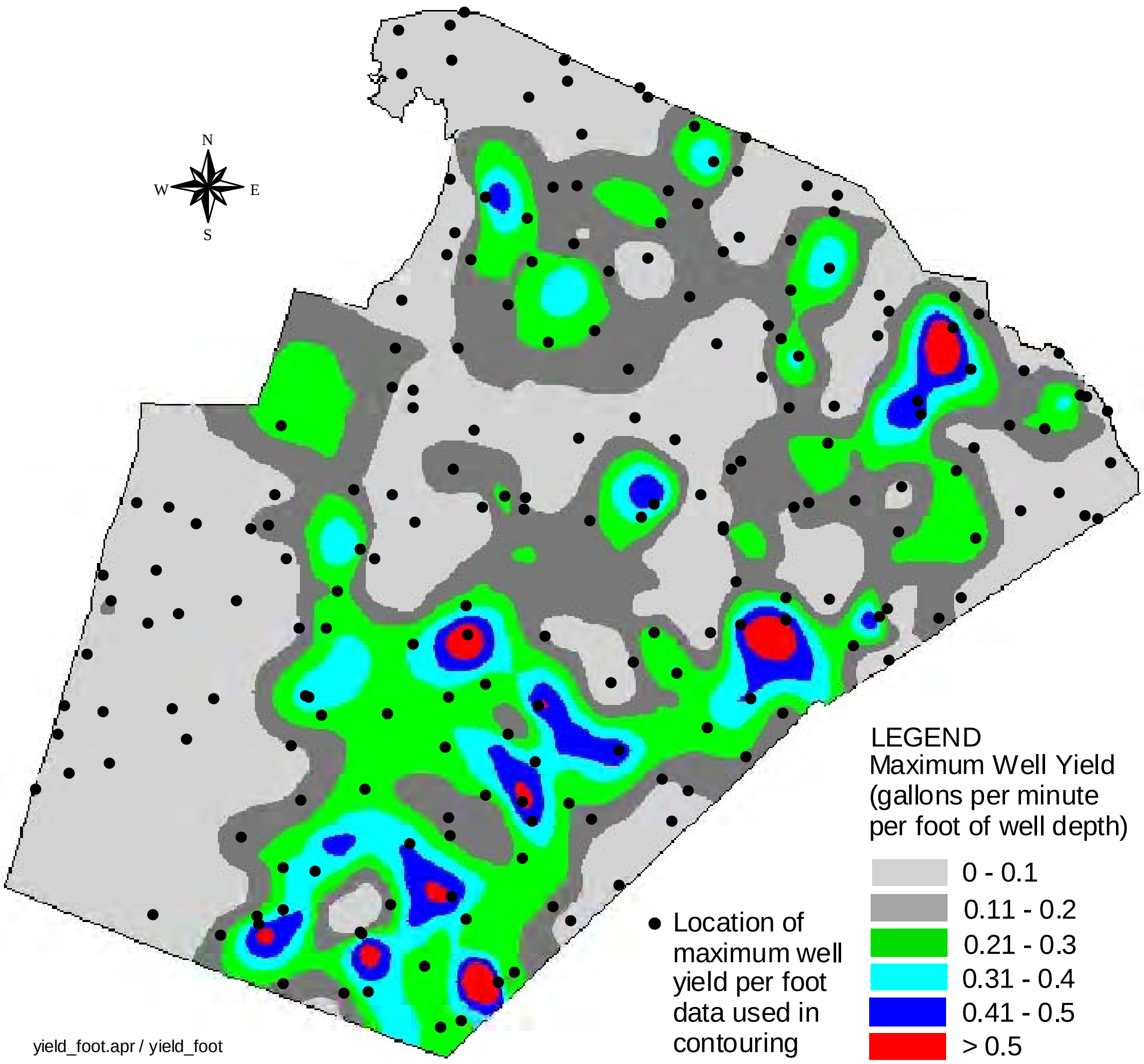



**Figure 3-9**
**Distribution of Maximum Well Yield Per Foot of Well Depth**

performed when the well is installed. Most of the well yield information presented in the preceding paragraphs is from pump tests of less than 24 hours. It is important to note that the sustained yield of a well determined over a 24-hour period may be less than that determined through a short duration pump test.

### 3.4.1 Well Yields by Hydrogeologic Unit

Well yields can also be matched with rock type to identify differences in relative yields of the different hydrogeologic units. This approach can also provide information as to which areas of the County are more and less favorable for groundwater withdrawals. **Figure 3-11** shows domestic well yield statistics for each of the seven major hydrogeologic units in Wake County. Included are the mean, median, 25th percentile and 75th percentile. The 25th percentile means that 75 percent of the domestic wells in a particular hydrogeologic unit have a reported yield above the given value. The 75th percentile means that 25 percent of the domestic wells in a particular

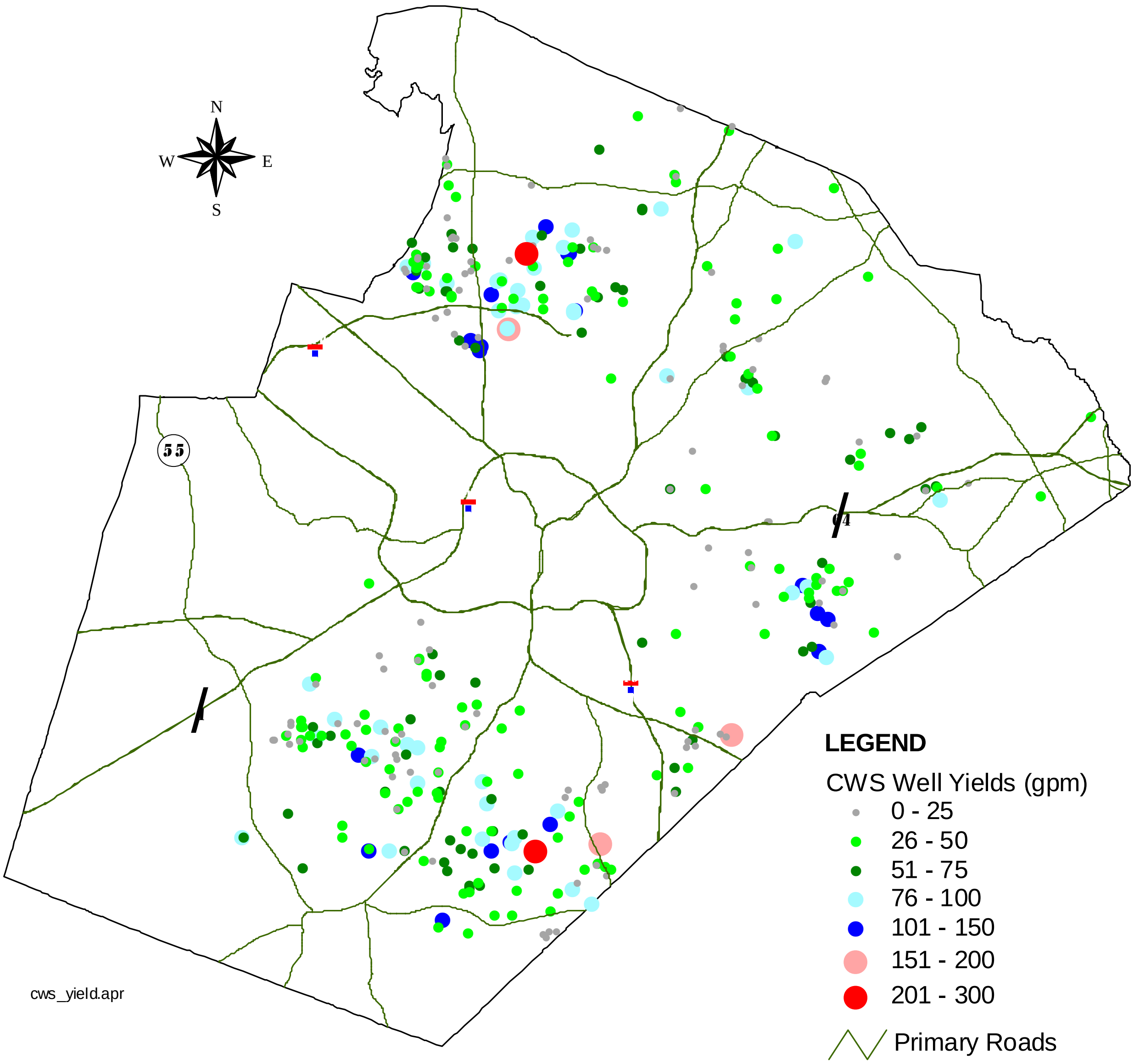



**Figure 3-10**
**Distribution of Community Water System Well Yields**

hydrogeologic unit have a reported yield above the given value.

Domestic well yields in the metaigneous felsic (MIF) unit are the highest of the major hydrogeologic units. The mean well yield in the MIF unit of 19.8 gpm is nearly identical to the mean documented by Daniel (2002) for domestic wells of the MIF unit in the Piedmont and Blue Ridge Provinces. Domestic well yields are generally lowest in the TRI and schist (SCH) units of Wake County, averaging less than half of the mean of the MIF unit. Interestingly, in the domestic wells of the Piedmont and Blue Ridge surveyed by Daniel, the highest mean well yield occurred in the SCH unit. It is unclear why domestic well yields of the SCH unit in Wake County are significantly lower than that observed by Daniel in areas west.

**Figure 3-12** shows CWS well yield statistics for each of the seven major hydrogeologic units in Wake County. Similar to domestic well yields,

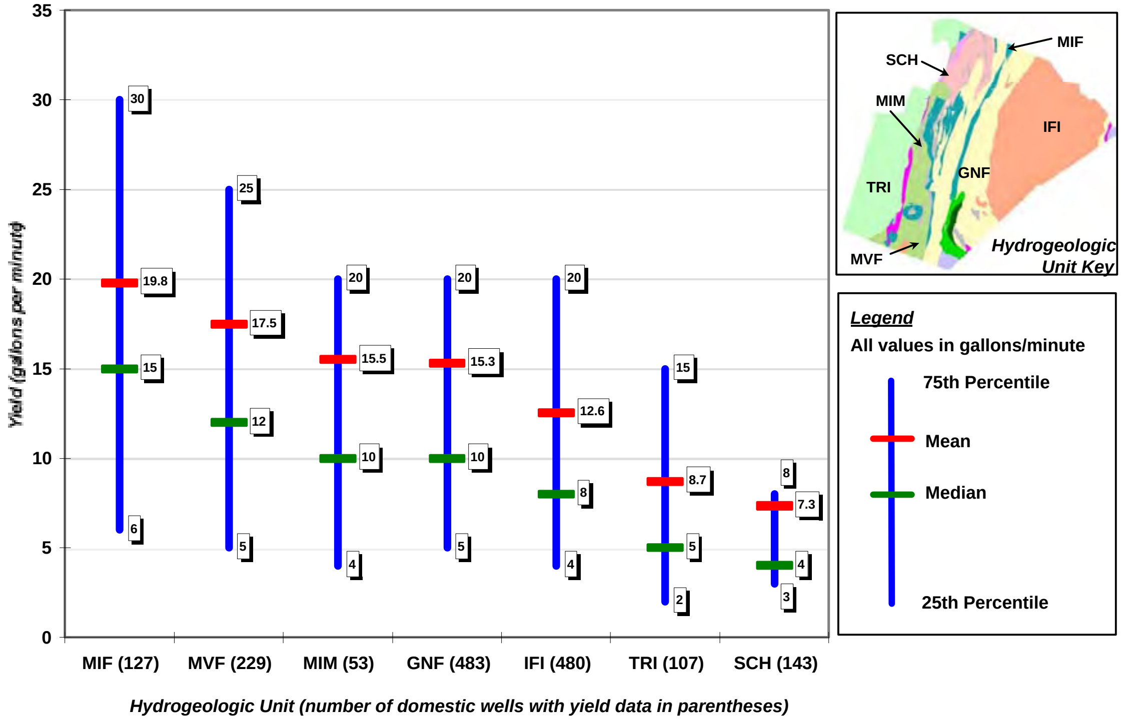



**Figure 3-11**
**Relation of Domestic Well Yields to Hydrogeologic Units in Wake County**

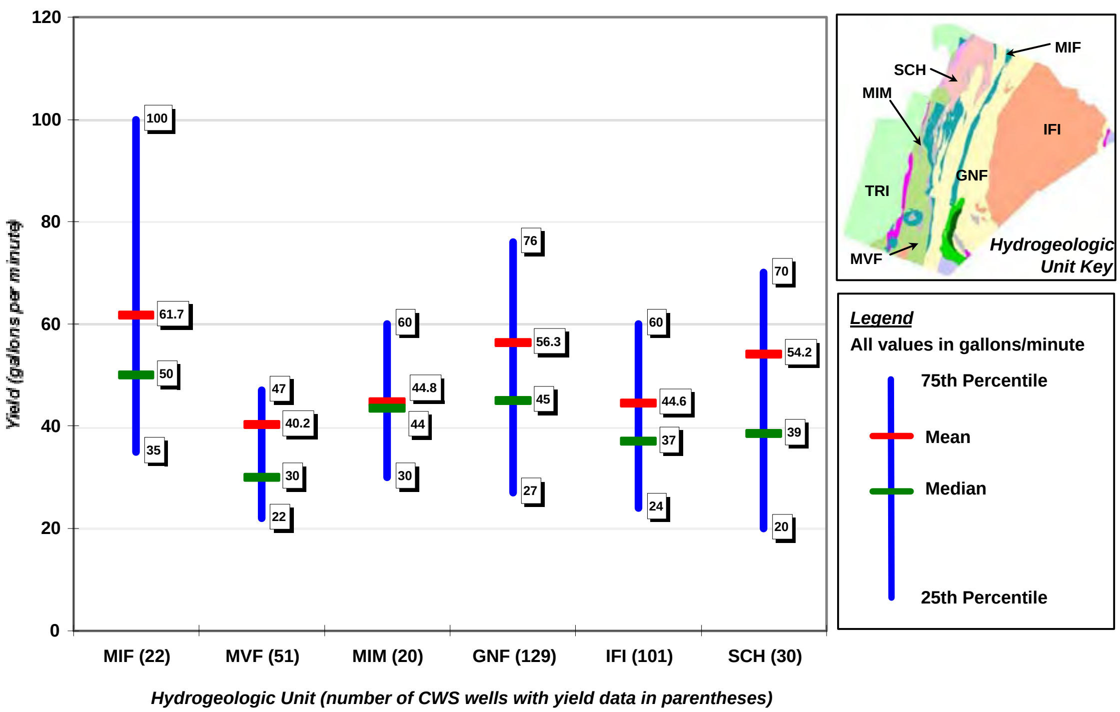



**Figure 3-12**
**Relation of CWS Well Yields to Hydrogeologic Units in Wake County**

CWS well yields are generally the highest in the MIF unit. Mean CWS well yields in the remaining major units of Wake County do not mirror those of domestic wells.

### 3.4.2 Diabase Dikes

The presence of numerous diabase dikes in Wake County is an important consideration in evaluating well yields, especially in the Triassic basin. Diabase dikes are igneous intrusions injected as molten magma into rock fractures. As the magma cools and solidifies, more fractures are commonly produced in the surrounding rocks and the hardened diabase. The associated fractures locally increase the chance accumulation of groundwater and for higher yielding wells. Diabase dikes may range in width from only a few inches to over 200 feet.

Anecdotal information has suggested that the majority of water-producing wells located in the Triassic basin are in or near diabase dikes. Knowing the location of these dikes before a well is drilled is useful information for a developer or homeowner attempting to locate an ample water supply in the Triassic basin. The NCGS has recently developed a GIS map of the observed and inferred locations of diabase dikes in Wake County, as shown in **Figure 3-13**. As evident by the map, numerous dikes have been located within the Triassic basin. It should be emphasized that diabase dikes are too numerous and many are too narrow to be shown on a map (such as **Figure 3-13**). Many others exist and only a detailed survey of a specific site can determine if a dike is present.

## 3.5 Groundwater Quantity Management

The water quantity data collected and the analyses prepared in this investigation can be used by Wake County for groundwater management planning. Since domestic water supply represents the largest category of groundwater withdrawals in Wake County, management of these withdrawals will ultimately have the most impact on the sustainability of the resource. While it is beyond the scope of this investigation to propose water resource management decisions, the following sections show how the data can be used to develop and support such decisions.

### 3.5.1 Recharge Related to Development Density

As the areas of Wake County outside of corporate limits continue to grow, the density of development should be considered carefully to prevent groundwater withdrawals that approach and/or exceed the developed condition recharge rate. Decisions on housing density, especially in the NUA/WSW areas, should consider: (1) groundwater availability; (2) the agreed upon definition of sustainability as it pertains to impacts to low flow periods in the streams; and (3) the difficulty of actually drilling wells with sufficient yield to supply water for a home or small community. As a first step toward making these decisions, an analysis of low flow statistics for each drainage basin has been carried out as they relate to per acre estimates of groundwater recharge.

**Table 3-17** presents calculations that show the average annual baseflow and the 7Q10 and 30Q2 low flow estimates for each drainage basin, translated into recharge rates per acre of land. The table indicates that recharge rates comparable to the 30Q2 flow rate range from a low of three gallons per acre per day in Harris Lake, to a high of 366 gallons per acre per day for the Lower Neuse River. For the more stringent criterion of the 7Q10 baseflow, recharge rates vary from zero gallons per acre per day to about 110 gallons per acre per day for the Lower Falls Lake drainage basin. Data from several basins suggest that the 7Q10 flow is actually zero, which means the stream is dry for more than a week upon occasion.

Conservatively assuming there are three persons per residential unit (household) and each person uses 100 gallons per day, the total groundwater withdrawal for a residential unit would be 300 gallons per day. This is considered a conservative estimate of average residential groundwater demand since per capita use in Wake County is closer to 70 gallons per person per day. By

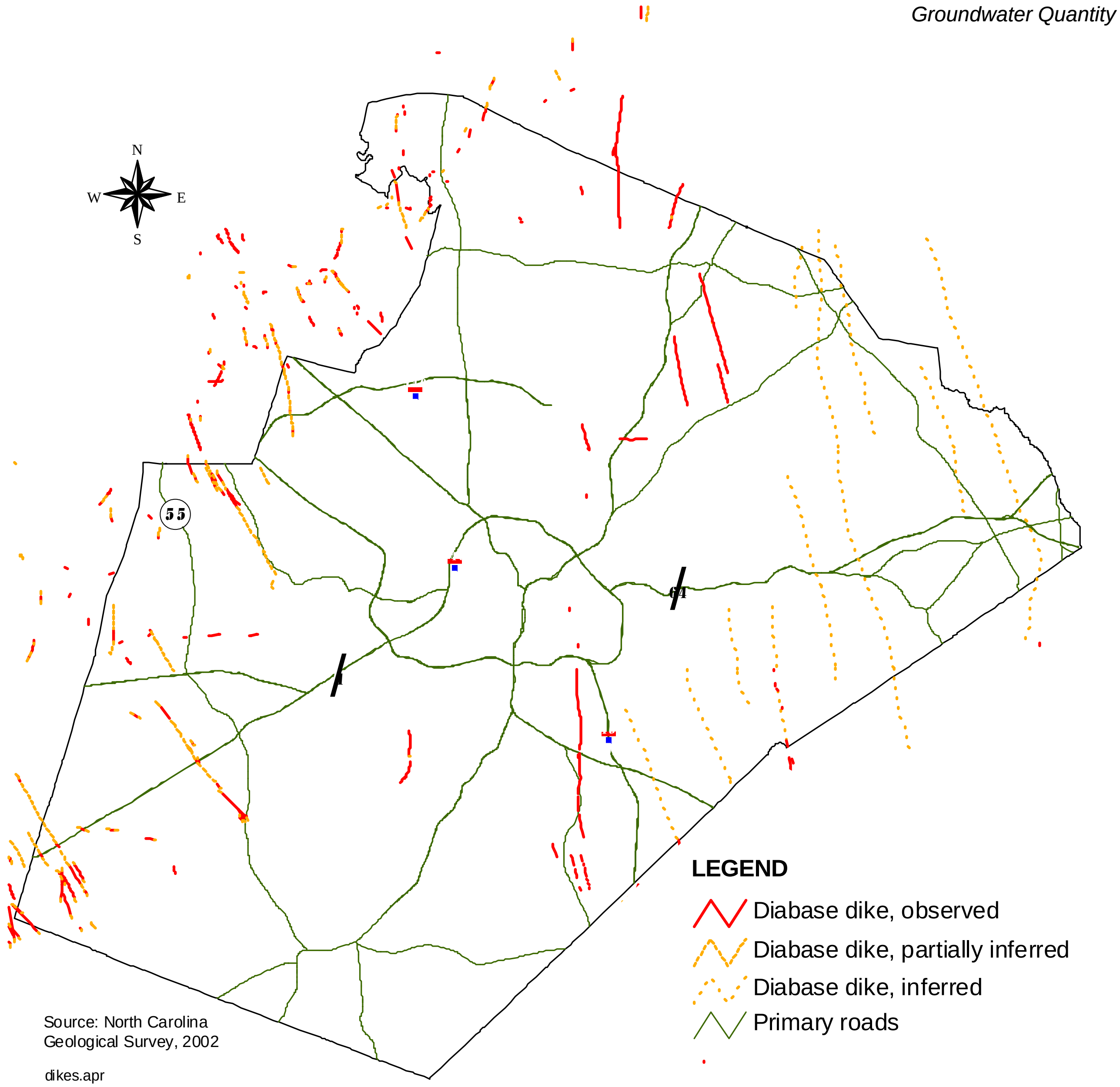



**Figure 3-13**
**Known Diabase Dike Locations**

comparing this residential unit groundwater demand to the average annual, 7Q10, and 30Q2 recharge rates, it becomes possible to estimate the number of acres required to support one residential unit, or conversely, the number of residential units that can be placed on one acre. **Table 3-18** shows the number of acres that will support a single residential unit withdrawing 300 gallons per day, without exceeding the given recharge rate. Under average annual conditions, the data indicates that between 0.5 and 1.5 acres are needed, depending on the drainage basin, to support one residential unit consuming 300 gallons per day, before groundwater in storage would begin to be depleted. Likewise, under drought conditions as represented by the 30Q2 flow, the data suggests that between 0.8 and 95.5 acres would be needed to support one residential unit.

**Table 3-17**
**Average Annual and Drought Condition Recharge Rates**

| Drainage Basin | Average Annual Baseflow (gal/acre/day) | 7Q10 Flow (gal/acre/day) | 30Q2 Flow (gal/acre/day) |
|---|---|---|---|
| Upper Falls Lake | 281 | 0 | 25 |
| Lower Falls Lake | 529 | 110 | 277 |
| Upper Neuse | 554 | 76 | 306 |
| Crabtree Creek | 559 | 19 | 80 |
| Walnut Creek | 625 | 20 | 235 |
| Lower Neuse | 588 | 103 | 366 |
| Swift Creek | 357 | 2 | 75 |
| Middle Creek | 475 | 3 | 103 |
| Black Creek | 592 | 0 | 13 |
| Little River | 620 | 12 | 100 |
| Beaver Dam | 578 | 3 | 88 |
| Jordan Lake | 203 | 0 | *NA* |
| Harris Lake | 272 | 0 | 3 |
| Kenneth Creek | 552 | 6 | 108 |

*NA* = No data available

The above analysis is representative of areas where public sewers have been extended, since none of the extracted groundwater is assumed to recharge the aquifer through an onsite wastewater treatment system. In areas where onsite wastewater treatment systems are used, a significant portion of water may be returned. In the water budget equation, a return rate of 90 percent was used based on winter pumping rates. On an average annual basis, a reasonable assumption of 68 percent can be made, accounting for 22 percent loss through consumptive use (as estimated in Local Water Supply Plan Updates), and 10 percent loss through evapotranspiration in the leaching field. The resulting net groundwater use for one residential unit would then be 96 gallons per day. **Table 3-18** also shows the number of acres that will support a single residential unit with a net groundwater use of 96 gallons per day, without exceeding the given recharge rate. Under average annual conditions, the data indicates that between 0.2 and 0.5 acres are needed, depending on the drainage basin, to support one residential unit with a net groundwater use of 96 gallons per day, before groundwater in storage would begin to be depleted.

**Table 3-18**
**Variations in Maximum Residential Density Based on Average Annual and Drought Condition Recharge Rates**

| HUC-11 Drainage Basin | Range of Maximum Residential Unit Densities Based on TOTAL Groundwater Consumption for: | | | Range of Maximum Residential Unit Densities Based on NET Groundwater Consumption for: | | |
|---|---|---|---|---|---|---|
| | Average Annual Baseflow (acre/RU) | 7Q10 Flow (acre/RU) | 30Q2 Flow (acre/RU) | Average Annual Baseflow (acre/RU) | 7Q10 Flow (acre/RU) | 30Q2 Flow (acre/RU) |
| Upper Falls Lake | 1.1 | -- | 11.9 | 0.3 | -- | 3.8 |
| Lower Falls Lake | 0.6 | 2.7 | 1.1 | 0.2 | 0.9 | 0.3 |
| Upper Neuse | 0.5 | 4.0 | 1.0 | 0.2 | 1.3 | 0.3 |
| Crabtree Creek | 0.5 | 15.8 | 3.8 | 0.2 | 5.1 | 1.2 |
| Walnut Creek | 0.5 | 15.3 | 1.3 | 0.2 | 4.9 | 0.4 |
| Lower Neuse | 0.5 | 2.9 | 0.8 | 0.2 | 0.9 | 0.3 |
| Swift Creek | 0.8 | 124.8 | 4.0 | 0.3 | 39.9 | 1.3 |
| Middle Creek | 0.6 | 88.3 | 2.9 | 0.2 | 28.2 | 0.9 |
| Black Creek | 0.5 | -- | 23.0 | 0.2 | -- | 7.4 |
| Little River | 0.5 | 24.0 | 3.0 | 0.2 | 7.7 | 1.0 |
| Beaver Dam | 0.5 | 98.4 | 3.4 | 0.2 | 31.5 | 1.1 |
| Jordan Lake | 1.5 | -- | *NA* | 0.5 | -- | *NA* |
| Harris Lake | 1.1 | -- | 95.5 | 0.4 | -- | 30.6 |
| Kenneth Creek | 0.5 | 52.0 | 2.8 | 0.2 | 16.6 | 0.9 |

Assumptions:
Persons per Residential Unit (RU): 3
Water use per person per day: 100 gallons
Total RU groundwater consumption per day: 300 gallons
Estimated return rate through onsite wastewater systems: 68%
Net RU groundwater consumption per day: 96 gallons

Notes:
NA = No supporting data
"--" indicates 7Q10 flow is 0

The information in **Tables 3-17** and **3-18** is presented for discussion purposes and does not represent direct recommendations for land use and zoning changes. Several important points should be considered with regard to the understanding and useability of this information.

- The data shown in **Tables 3-17** and **3-18** were developed at the HUC-11 drainage basin level, without consideration for variations in recharge that may occur at a subbasin level. Recharge rates within the HUC-11 basins may vary significantly depending on soil and rock type, slope, amount of impervious surface, and other factors.

- As previously mentioned, in 7 of the 14 drainage basins, low flow estimates were only available from one or two record stations, limiting the useability when extrapolating to the basin level. Collection and analysis of additional low flow data should be considered in support of residential and other zoning decisions in which groundwater availability is a factor.

- Neither of the analyses presented above account for the inevitable increase in the amount of impervious surface associated with residential development. The "acre/RU" values presented in **Table 3-18** are not conservative considering the likely decrease in recharge due to increased area of impervious surface.

- The "acre/RU" values presented in **Table 3-18** are based solely on groundwater availability and the assumption that recharge volumes can all be used for water supply. They do not consider constraints associated with placement of onsite wastewater treatment systems[2] at certain densities and in certain soil types.

- **Table 3-18** shows the minimum number of acres that will support a single residential unit, without exceeding the given recharge rate. The numbers do not necessarily indicate a level of sustainability since unacceptable consequences (e.g. reduced stream baseflow) would be expected to occur prior to exceeding the given recharge rate. In Wake County it is important to begin developing definitions for unacceptable consequences and sustainability.

- The information presented in **Tables 3-17** and **3-18** does not necessarily indicate a benchmark for achieving sustainability since unacceptable consequences such as reduced stream baseflow or reduced (or depleted) well yield during a drought may occur prior to exceeding the given recharge rate.

[2] The "Regulations Governing Sewage Treatment and Disposal Systems in Wake County" require a minimum of 30,000 square feet of suitable or provisionally suitable area for the installation of a wastewater treatment system.

### 3.5.2 Variations in Seasonal Demands and Groundwater Storage

In addition to recharge rates groundwater management planning should also consider the impact of seasonal variations in demand and the potential seasonal depletion of groundwater available from storage. The water budget approach does not account for significant variations in ET, baseflow, and groundwater withdrawals that can occur seasonally. In reality, recharge from precipitation is lowest in the summer, when groundwater withdrawals are typically at their peak. **Figure 3-14** illustrates this point by comparing the 10-year average daily baseflow of Middle Creek to monthly average groundwater withdrawals from a Wake County CWS. In this example baseflow, which approximates recharge, is approximately one-half of the annual average value for the months of June through October. Increased withdrawals representing irrigation use coincide with the five months of reduced recharge.

To illustrate this point further, the following example is offered. A residential development of 100 homes, with a density of two RUs per acre, is located in an area where the estimated average annual recharge rate is eight inches per year (597 gal/acre/day). Assuming an average annual RU demand of 300 gal/acre/day, and no on-site return of wastewater, the net groundwater withdrawal over the 50-acre development represents 50 percent of the average annual recharge.

During June through October, increased irrigation demand may be expected to result in a 30 percent increase in withdrawals, resulting in a summer RU demand of 390 gal/acre/day. Based on the pattern shown in **Figure 3-14**, baseflow (recharge) can be expected to decrease by 50 percent, from 597 gal/acre/day to 299 gal/acre/day. Therefore, for the five months from June through October, net groundwater withdrawals exceed baseflow (recharge) by just over 30 percent. It is during this time that the amount of groundwater stored in the regolith-fractured bedrock aquifer system is important.

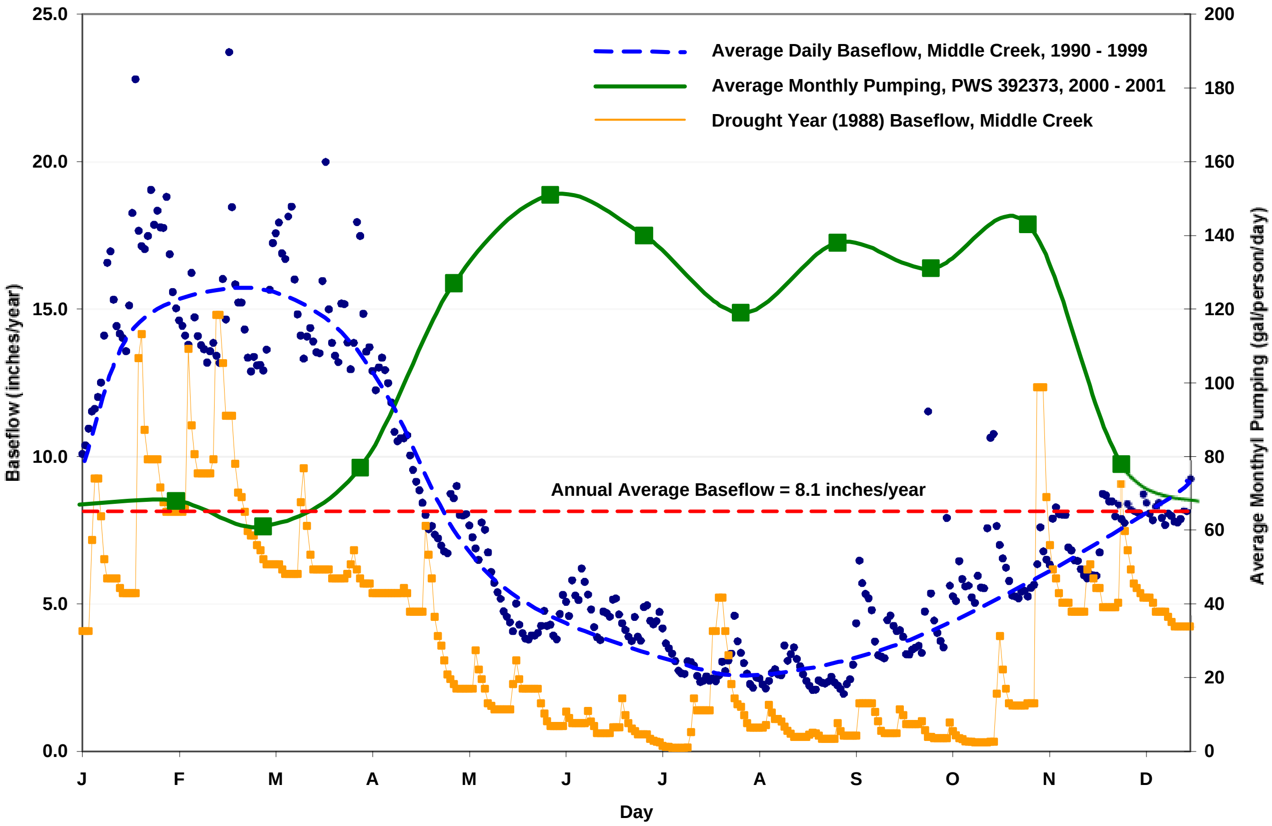



**Figure 3-14**
**Comparison of the Seasonal Variations in Stream Baseflow and CWS Pumping**

In the example above, nearly 700,000 gallons of groundwater will be removed from storage during the time when withdrawals exceed recharge. (Note: this example is simplistic in that it assumes that the cone(s) of depression from the well(s) serving the development are isolated to the 50 acre tract.) The significance of this is determined by estimating the total amount of storage in the regolith. As presented in Section 1, the quantity of water stored in the bedrock is small compared to that stored in the regolith. Therefore, in this example, the quantity of water stored in the bedrock is ignored. To estimate the quantity of water stored in the regolith, estimates of its saturated thickness and the specific yield are necessary. The saturated thickness of the regolith can be approximated by subtracting the depth to water from the depth to bedrock, which is approximated by the casing depth of a well. For the example development, it is assumed that the depth to water is 30 feet and the depth to bedrock is 60 feet, resulting in 30 feet of saturated regolith. Specific yield, rather than porosity, is used to determine the amount available to be withdrawn, since not all of the water stored in a rock is available when saturated. According to Heath (1980) a range of 20 to 30 (percent by volume) is reasonable for regolith of the Piedmont. Assuming a specific yield of 30 percent and a saturated thickness of 30 feet, then a total of 146 million gallons are available for withdrawal under the 50 acre tract before storage is completely depleted. In this example, less than one-half of one-percent of the total amount of groundwater in storage will be withdrawn during the five-month period.

The above example is meant to illustrate a simple approach to estimate the impact that seasonal variations in recharge and pumping may have on reducing the amount of groundwater in storage. It is not intended to represent the conditions of any specific area of Wake County.

The amount of groundwater available in storage for different hydrogeologic units and different areas of Wake County can be estimated based partly on the information presented in **Figures 3-15** and **3-16**. **Figure 3-15** presents a statistical analysis of domestic well casing depth for the seven major hydrogeologic units. The mean casing depth of each hydrogeologic unit can be used as a rough approximation of regolith thickness. **Figure 3-16** shows the distribution of mean domestic well casing depth, contoured into zones of equal depth. Driller reported casing depths from 2,710 wells were used in this analysis. To arrive at the mean casing depth for a particular area, a 5,000-foot by 5,000-foot grid was placed over the County map, and the mean casing depth within each grid was calculated. Depending on the density of wells in a particular area, grids may have contained between zero and 56 values that were used to calculate a mean.

As is evident in both figures, the regolith is the thinnest in the TRI unit (western Wake County) and the IFI unit (northeastern Wake County). These units are considered the least susceptible to weathering. Groundwater contained in storage is relatively low in areas underlain by these units, compared to other areas of the County. Consequently, these areas are most susceptible to impacts such as dry wells during extended droughts, when groundwater withdrawals decrease the amount available in storage.

The area of greatest groundwater storage occurs in the southeastern portion of Wake County, which marks the beginning of the Coastal Plain Province. Depth to bedrock ranges from 50 to over 200 feet in

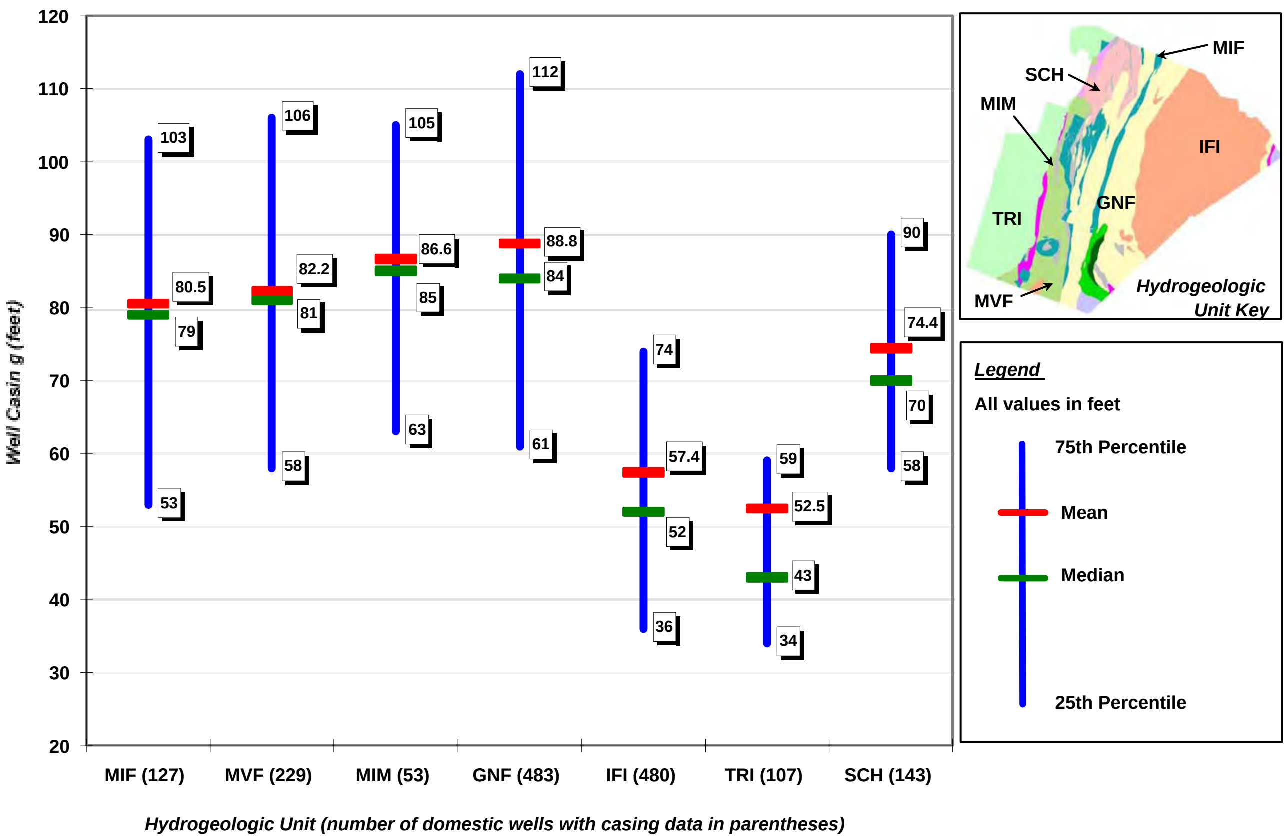



**Figure 3-15**
**Statistical Analysis of Domestic Well Depth of Casing by Hydrogeologic Unit. Depth of Casing Approximates the Depth to Bedrock and the Thickness of the Regolith.**

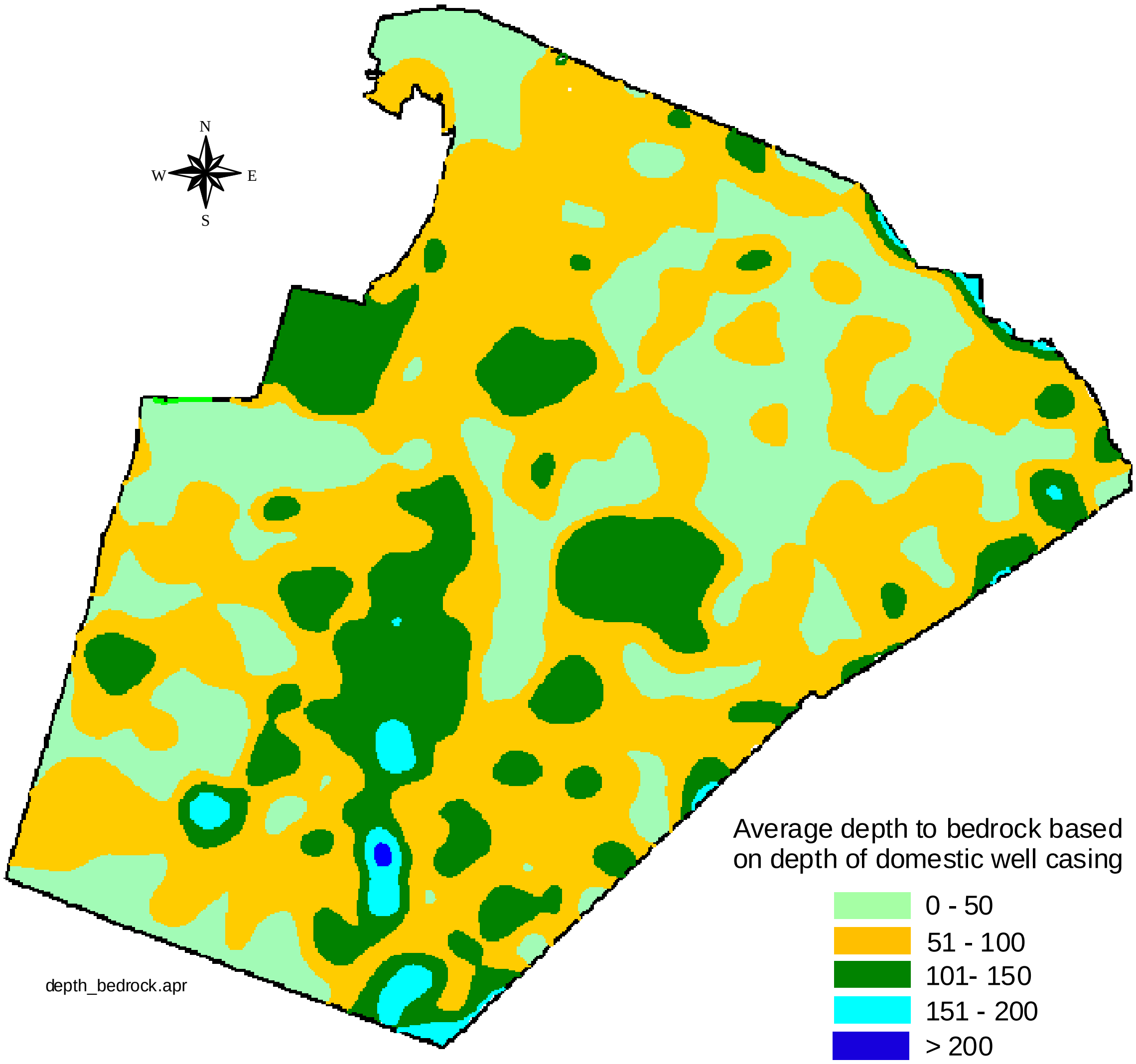



**Figure 3-16**
**Distribution of Average Depth to Bedrock**

this area. Most public supply wells still tap the bedrock aquifer, and are replenished by the increased storage contained in the relatively porous coastal plain sediments.

The depth to bedrock may vary significantly over short distances and within the same hydrogeologic unit. The information presented in the figures provides a gross approximation of the regolith thickness for a particular area or hydrogeologic unit. To estimate groundwater in storage, the saturated thickness of the regolith must be known. Unfortunately, the depth to water information reported by drillers (in the same well where casing depth was provided) is not considered representative of the actual depth to water. During well installation, depth to water is often only grossly approximated, and may be artificially lowered as a result of yield testing.

### 3.5.3 Summary

The preceding sections present information that can be used by Wake County to facilitate groundwater management and planning. The information includes:

- The minimum number of acres needed to support a residential unit based on the estimated average annual recharge rate (**Table 3-18**).

- The minimum number of acres needed to support a residential unit based on drought condition recharge rates (**Table 3-18**).

- Areas considered more and less favorable for development based on analysis of maximum well yield (**Figures 3-8** through **3-12**).

- Areas considered more and less favorable for development based on analysis of regolith thickness (**Figures 3-15** and **3-16**). This can be coupled with water level data and estimates of specific yield, to estimate the volume of groundwater contained in storage.

- This information can be used to begin to estimate the impact of proposed development on groundwater resources. Development of a Groundwater Resource Strategy is recommended to formalize an approach that would use the water quantity data collected during this investigation to develop principles and policies for groundwater resource sustainability.

# Section 4
# Groundwater Quality

Groundwater extracted from the crystalline rock aquifers of the Piedmont and Blue Ridge Provinces of North Carolina is generally characterized as suitable for drinking and most other purposes (Daniel and Dahlen, 2002). In Wake County, approximately 141,000 residents use groundwater for drinking water, most of which is withdrawn from the crystalline rock aquifer. Generally, the groundwater requires little or no treatment prior to consumption or use. In certain instances, however, groundwater quality may be degraded as a result of natural geochemical processes, human activities, and poor well construction. Natural water quality impacts may include elevated concentrations of iron and manganese or other trace metals, hydrogen sulfide, hardness, or radionuclides. Impacts to groundwater quality associated with human activities may result from failing septic tanks, leaking underground storage tanks, landfill leachate impacts, recharge of stormwater from urban areas, over-application of pesticides, herbicides and fertilizers, and improper handling or storage of chemicals.

## 4.1 Previous Investigations

Previous investigations of groundwater quality in Wake County have primarily been site specific and limited in area. Most typically, groundwater quality has been investigated in association with activities such as the development of a new public water supply well, assessment of groundwater impacts from known pollution incidents, or effectiveness monitoring of a waste containment system (e.g., municipal landfill liner). Few investigations have summarized groundwater quality countywide.

May and Thomas (1968) provided one of the first countywide assessments of groundwater quality through analysis of major ions and nutrients in water from 17 wells. Water from granite and metamorphic rocks was reported to be of good chemical quality and suitable for most uses. Throughout most of the County groundwater was characterized as soft and containing low concentrations of iron and other dissolved solids. Water quality in the Triassic basin was identified as being highly variable with hardness ranging from 34 to 370 milligrams per liter (mg/l) and dissolved solids ranging from 89 to 1,180 mg/l. Water from the Cretaceous-age sands and clays of southern Wake County was identified as having objectionable concentrations of iron.

Between 1962 and 1963 Chemerys (1967) sampled 62 domestic wells in the Raleigh area to look for the presence of alkylbenzenesulfonate (ABS) – a major component of hard synthetic detergents. All wells samples were from residences that had septic tanks. ABS was detected in very few wells. Ten of the 62 wells contained elevated nitrate and chloride concentrations. Although the report concluded that groundwater in the Raleigh area appeared to be relatively free of contamination in general, the presence of elevated levels of nitrate and chloride suggested that in certain areas, groundwater quality was being impacted by septic tank effluent.

Briel (1997) investigated the ambient inorganic water quality from 2,682 wells in North Carolina as part of the Appalachian Valleys-Piedmont Regional Aquifer System (APRASA) study. In is unclear how many of the water quality samples summarized in the APRASA study were from Wake County wells. Daniel and Dahlen (2002) cite the large variation in groundwater quality data presented by Briel as an indication that regional inorganic data from a water quality investigation cannot be used to estimate water quality at any one individual site in North Carolina.

As part of the National Uranium Resource Evaluation (NURE), groundwater samples were collected from 5,778 wells in North Carolina, between 1975 and 1979. NURE groundwater samples were analyzed for uranium, bromine, chlorine, fluorine, manganese, sodium, aluminum, vanadium, and dysprosium. Reid (1993) presents the information in the *Hydrogeochemical Atlas of North Carolina*.

Wade and others (1997) performed an interagency study to determine if the labeled uses of pesticide products were impacting the groundwater resources of North Carolina. The study included sampling and analysis for pesticides at 55 wells comprising the NCDENR Groundwater Section ambient monitoring well network, 97 newly installed shallow monitoring wells, and 46 domestic wells. Domestic wells were targeted for sampling based on the detections of pesticides in the newly installed nearby monitoring wells. The 97 new wells were installed in 37 counties, at areas targeted as highly vulnerable to impacts from pesticides. Included were 79 crop sites and 18 other sites such as electrical substations, golf courses, highway right of ways, mosquito abatement areas, and residential termite control sites. No wells were sampled in Wake County. Twenty-six pesticides or metabolites of pesticides were detected in 33 of the 152 monitoring wells samples. Ten of the 26 pesticides detected are no longer used in North Carolina. Two were detected above health-based guidelines. Five of 46 domestic wells contained pesticides above health-based guidelines.

## 4.2 Water Quality Characterization

To characterize the groundwater quality in Wake County, historical data from CWSs, NCWSs, and domestic wells were obtained and reviewed. CWSs are defined as public water systems that serve 15 or more service connections or which regularly serve at least 25 year-round residents. NCWSs are those that do not meet the definition of a CWS. They may be transient (TNCWS) or non-transient (NTNCWS). NTNCWS regularly serve at least 25 of the same persons over 6 months per year. Domestic wells serve only one household, and are owned and operated by the homeowner. The locations of active CWS wells are shown in **Figure 4-1**. CWSs are primarily located in the north, east, and south portions of the County, and outside of corporate limits. Water quality data from the CWSs generally does not provide an indication of groundwater quality in the more urbanized areas of the County. Domestic wells, however, are more evenly distributed throughout the County. **Figure 4-1** also shows the approximate locations of 276 of the over 600 domestic wells for which water quality data were available[1]. The 276 wells shown in **Figure 4-1** represent less than one percent of the estimated 37,000 domestic wells in Wake County.

### 4.2.1 Community Water Systems

Historical water quality data from Wake County CWSs were provided in an electronic format by the NCDENR Division of Environmental Health, Public Water Supply (PWS) Section. The electronic format allowed the database to be readily accessed, queried, and summarized. The PWS also provided a database containing location (latitude and longitude) information of each CWS well, which enabled the data to be analyzed spatially using a geographic information system (GIS).

All water quality data from the PWS database characterizes treated water; therefore the data should not be considered as entirely characteristic of raw groundwater quality. In the majority of Wake County CWSs disinfection and pH adjustment are the only treatment methods used. In certain instances, additional treatment methods are used to provide higher quality water or to bring the water in compliance with drinking water standards. The addition of sequestering chemicals occurs in approximately one-half of the systems to control dissolved ion content, primarily iron and manganese. Sequestering chemicals, such as sodium phosphate or polyphosphates, surround the ions and prevent them from precipitating in water. Because the ions are still present in water, albeit in an insoluble form, the actual dissolved ion content of the water is not changed as a result of

[1] Only 276 of the over 600 domestic wells were able to be located using basic GIS techniques. A more rigorous geo-processing exercise is necessary to locate the remaining well locations.

sequestration. Therefore, although water quality samples from CWS are collected after sequestration, their total ion content still generally reflects that found in the raw groundwater.

Additional treatment methods used in Wake County CWSs include ion exchange (for removal of constituents such as nitrates and radionuclides), sand filtration (for high concentration mineral removal), and aeration or granular activated carbon (GAC) treatment (for removal of organic compounds).

The most recent data contained in the PWS database were used to summarize groundwater quality from the 275 CWSs that rely solely on groundwater in Wake County. The information is grouped by category. Categories include: inorganic constituents, dissolved nutrients, radionuclides, synthetic organic compounds (SOCs), and volatile organic compounds (VOCs). The categories, chemical constituents, reporting units and limits, and water quality standards for those constituents that are currently regulated under the North Carolina Rules Governing Public Water Systems (referred to herein as "the Rules") are presented in **Table 4-1**.

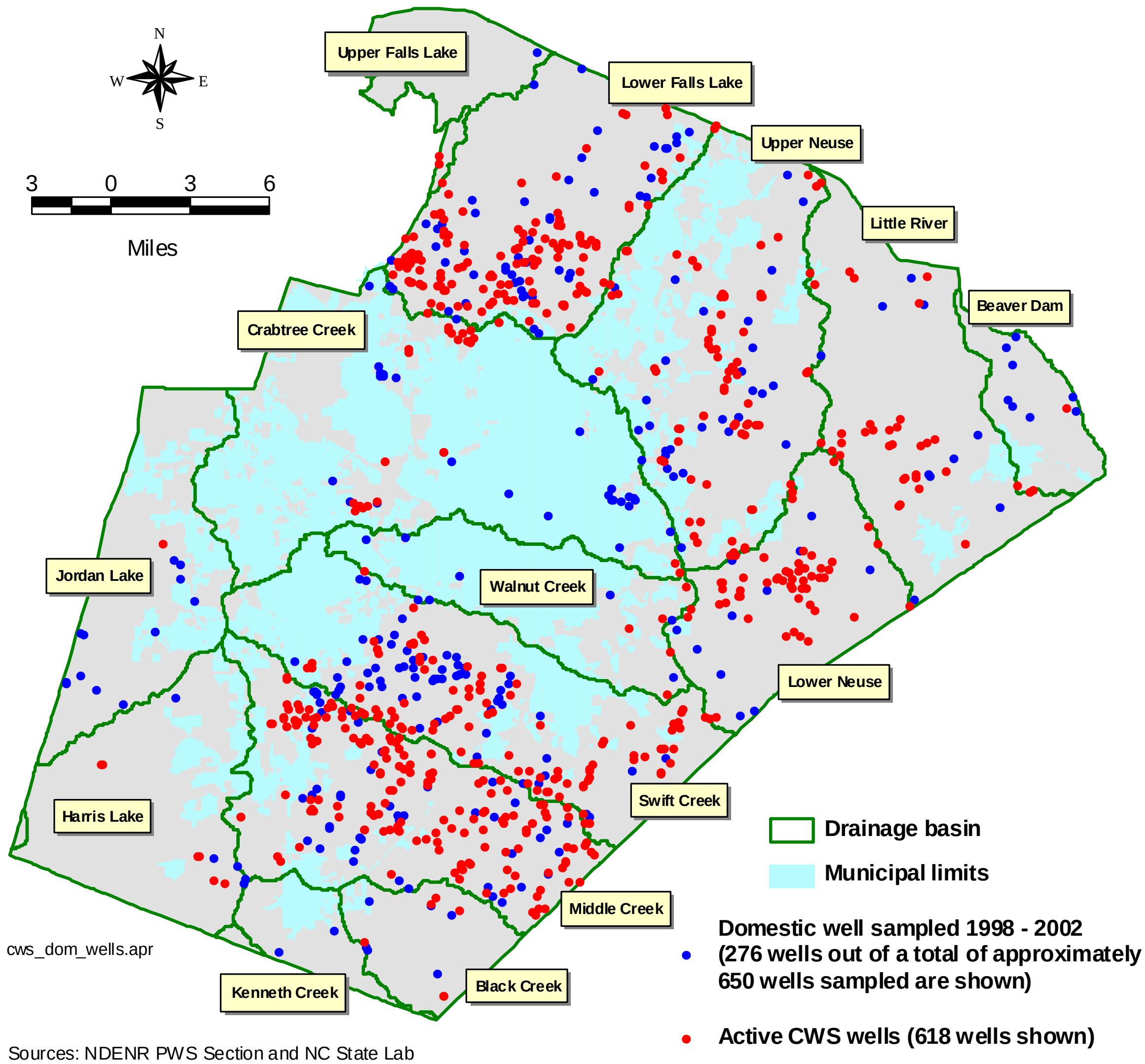



**Figure 4-1**
**Location of Wells with Water Quality Data Used in this Investigation**

**Table 4-1**
**Chemical Constituents, Reporting Limits and Regulatory Limits for CWSs**

| Contaminant Category | Constituent | Reporting Limit | Units | MCL or MCLG[1] |
|---|---|---|---|---|
| Inorganics | Arsenic | 5.0 | µg/L | 10 |
| Inorganics | Barium | 400.0 | µg/L | 2000 |
| Inorganics | Cadmium | 1.0 | µg/L | 5 |
| Inorganics | Chromium | 20.0 | µg/L | 100 |
| Inorganics | Cyanide | 40.0 | µg/L | 200 |
| Inorganics | Flouride | 100.0 | µg/L | 4000 |
| Inorganics | Iron | 60.0 | µg/L | 300 |
| Inorganics | Manganese | 10.0 | µg/L | 50 |
| Inorganics | Mercury | 0.4 | µg/L | 2 |
| Inorganics | Nickel | 100.0 | µg/L | N/A |
| Inorganics | Selenium | 10.0 | µg/L | 50 |
| Inorganics | Sodium | 1000.0 | µg/L | N/A |
| Inorganics | Sulfate | 5000.0 | µg/L | 250000 |
| Inorganics | Antimony | 3.0 | µg/L | 6 |
| Inorganics | Beryllium | 2.0 | µg/L | 4 |
| Inorganics | Thallium | 1.0 | µg/L | 2 |
| Inorganics | pH | N/A | | 6.50 - 8.50 |
| Dissolved Nutrients | Nitrate | 1.0 | mg/L | 10 |
| Dissolved Nutrients | Nitrite | 0.10 | mg/L | 1 |
| DBPs | Chloroform | 1.0 | µg/L | 100 |
| DBPs | Bromoform | 1.0 | µg/L | 100 |
| DBPs | Bromodichloromethane | 1.0 | µg/L | 100 |
| DBPs | Chlorodibromomethane | 1.0 | µg/L | 100 |
| DBPs | Total Trihalomethanes | 1.0 | µg/L | 100 |
| DBPs | Monochloroacetic Acid | 2.0 | µg/L | 60 |
| DBPs | Dichloroacetic Acid | 1.0 | µg/L | 60 |
| DBPs | Trichloroacetic Acid | 1.0 | µg/L | 60 |
| DBPs | Monobromoacetic Acd | 1.0 | µg/L | 60 |
| DBPs | Dibromoacetic Acid | 1.0 | µg/L | 60 |
| DBPs | Total Haloacetic Acids | 2.0 | µg/L | 60 |
| Radiologicals | Gross Alpha | 3.0 | pCi/L | 15 |
| Radiologicals | Radon | 100.0 | pCi/L | N/A |
| Radiologicals | Uranium | 2.0 | pCi/L | 20.1 |
| Radiologicals | Combined Radium | N/A | N/A | 5 |
| Radiologicals | Radium 226 | 1.0 | pCi/L | 3 |
| Radiologicals | Radium 228 | 1.0 | pCi/L | 2 |
| Radiologicals | Gross Beta | 4.0 | pCi/L | 50 |
| Radiologicals | Tritium | 1000.0 | pCi/L | 20,000 |
| Radiologicals | Strontium 89 | 10.0 | pCi/L | N/A |
| Radiologicals | Strontium 90 | 2.0 | pCi/L | 8,000 |
| Radiologicals | Iodine 131 | 1.0 | pCi/L | N/A |
| Radiologicals | Cesium 134 | 10.0 | pCi/L | N/A |

**Table 4-1 (continued)**
**Chemical Constituents, Reporting Limits and Regulatory Limits for CWSs**

| Contaminant Category | Constituent | Reporting Limit | Units | MCL or MCLG[1] |
|---|---|---|---|---|
| SOCs | Endrin | 0.01 | µg/L | 2 |
| SOCs | Lindane | 0.02 | µg/L | 2 |
| SOCs | Methoxychlor | 1.0 | µg/L | 40 |
| SOCs | Toxaphene | 1.0 | µg/L | 3 |
| SOCs | Carbaryl | 4.0 | µg/L | N/A |
| SOCs | Methomyl | 4.0 | µg/L | N/A |
| SOCs | Dalapon | 1.0 | µg/L | 20 |
| SOCs | Di(2-ethylhexyl)adipate | 6.0 | µg/L | 40 |
| SOCs | Oxamyl(vydate) | 2.0 | µg/L | 20 |
| SOCs | Simazine | 0.07 | µg/L | 4 |
| SOCs | Picloram | 1.0 | µg/L | 50 |
| SOCs | Dinoseb | 2.0 | µg/L | 7 |
| SOCs | Hexachlorocyclopentadiene | 0.10 | µg/L | 50 |
| SOCs | Aldicarb Sulfoxide | 0.50 | µg/L | N/A |
| SOCs | Aldicarb Sulfone | 0.80 | µg/L | N/A |
| SOCs | Metalochlor | 0.80 | µg/L | N/A |
| SOCs | Carbofuran | 0.90 | µg/L | 40 |
| SOCs | Aldicarb | 0.50 | µg/L | N/A |
| SOCs | Atrazine | 0.10 | µg/L | 3 |
| SOCs | Alachlor | 0.20 | µg/L | 2 |
| SOCs | Heptachlor | 0.04 | µg/L | 0.4 |
| SOCs | 3-Hydroxycarbofuran | 4.0 | µg/L | N/A |
| SOCs | Heptachlor Epoxide | 0.02 | µg/L | 0.2 |
| SOCs | Dieldrin | 0.20 | µg/L | N/A |
| SOCs | Butachlor | 8.0 | µg/L | N/A |
| SOCs | Propachlor | 6.0 | µg/L | N/A |
| SOCs | 2,4-D | 0.10 | µg/L | 70 |
| SOCs | 2,4,5-TP (Silvex) | 0.20 | µg/L | 50 |
| SOCs | Hexachlorobenzene | 0.10 | µg/L | 1 |
| SOCs | Di(2-ethylhexyl)pthalate | 1.32 | µg/L | 6 |
| SOCs | Benzo(a)pyrene | 0.02 | µg/L | 0.2 |
| SOCs | Pentachlorophenol | 0.04 | µg/L | 1 |
| SOCs | Aldrin | 0.20 | µg/L | N/A |
| SOCs | PCB's | 0.10 | µg/L | 0.5 |
| SOCs | Dicamba | 1.0 | µg/L | N/A |
| SOCs | Metribuzin | 0.80 | µg/L | N/A |
| SOCs | DBCP | 0.02 | µg/L | 0.05 |
| SOCs | Ethylene Dibromide (EDB) | 0.01 | µg/L | 0.05 |
| SOCs | Chlordane | 0.20 | µg/L | 2 |

**Table 4-1 (continued)**
**Chemical Constituents, Reporting Limits and Regulatory Limits for CWSs**

| Contaminant Category | Constituent | Reporting Limit | Units | MCL or MCLG[1] |
|---|---|---|---|---|
| VOCs | p-Isopropyltoluene | 0.50 | µg/L | N/A |
| VOCs | Chloromethane | 0.50 | µg/L | N/A |
| VOCs | Dichlorodifluoromethane | 0.50 | µg/L | N/A |
| VOCs | Bromomethane | 0.50 | µg/L | N/A |
| VOCs | Chloroethane | 0.50 | µg/L | N/A |
| VOCs | Flourotrichloromethane | 0.50 | µg/L | N/A |
| VOCs | Hexachlorobutadiene | 0.50 | µg/L | N/A |
| VOCs | Naphthalene | 0.50 | µg/L | N/A |
| VOCs | 1,2,4-Trichlorobenzyne | 0.50 | µg/L | 70 |
| VOCs | Cis-1,-Dichloroethylene | 0.50 | µg/L | 70 |
| VOCs | Dibromomethane | 0.50 | µg/L | N/A |
| VOCs | 1,1-Dichloropropene | 0.50 | µg/L | N/A |
| VOCs | 1,3-Dichloropropane | 0.50 | µg/L | N/A |
| VOCs | 1,3-Dichloropropene | 0.50 | µg/L | N/A |
| VOCs | 1,2,3-Trichloropropane | 0.50 | µg/L | N/A |
| VOCs | 2,2-Dichloropropane | 0.50 | µg/L | N/A |
| VOCs | 1,2,4-Trimethlbenzene | 0.50 | µg/L | N/A |
| VOCs | 1,2,3-Trichlorobenzene | 0.50 | µg/L | N/A |
| VOCs | n-Butylbenzene | 0.50 | µg/L | N/A |
| VOCs | 1,3,5-Trimethylbenzene | 0.50 | µg/L | N/A |
| VOCs | Tert-Butylbenzene | 0.50 | µg/L | N/A |
| VOCs | Sec-Butylbenzene | 0.50 | µg/L | N/A |
| VOCs | Bromochloromethane | 0.50 | µg/L | N/A |
| VOCs | Chloroform | 0.50 | µg/L | N/A |
| VOCs | Bromoform | 0.50 | µg/L | N/A |
| VOCs | Bromodichloromethane | 0.50 | µg/L | N/A |
| VOCs | Chlorodibromomethane | 0.50 | µg/L | N/A |
| VOCs | Xylenes (Total) | 0.50 | µg/L | 10,000 |
| VOCs | Dichloromethane | 0.50 | µg/L | 5 |
| VOCs | o-Chlorotoluene | 0.50 | µg/L | N/A |
| VOCs | p-Chlorotoluene | 0.50 | µg/L | N/A |
| VOCs | m-Dichlorobenzene | 0.50 | µg/L | N/A |
| VOCs | o-Dichlorobenzene | 0.50 | µg/L | 60 |
| VOCs | p-Dichlorobenzene | 0.50 | µg/L | 7.5 |
| VOCs | Vinyl Chloride | 0.50 | µg/L | 2 |
| VOCs | 1,1-Dichloroethylene | 0.50 | µg/L | 7 |
| VOCs | 1,1-Dichloroethane | 0.50 | µg/L | N/A |
| VOCs | Trans-1,2,-Dichloroethylene | 0.50 | µg/L | 10 |
| VOCs | 1,2-Dichloroethane | 0.50 | µg/L | 5 |
| VOCs | 1,1,1-Trichloroethane | 0.50 | µg/L | 20 |
| VOCs | Carbon Tetrachloride | 0.50 | µg/L | 5 |
| VOCs | 1,2-Dichloropropane | 0.50 | µg/L | 5 |
| VOCs | Trichloroethylene | 0.50 | µg/L | 5 |
| VOCs | 1,1,2-Trichloroethane | 0.50 | µg/L | 5 |
| VOCs | 1,1,1,2-Tetrachloroethane | 0.50 | µg/L | N/A |

**Table 4-1 (continued)**
**Chemical Constituents, Reporting Limits and Regulatory Limits for CWSs**

| Contaminant Category | Constituent | Reporting Limit | Units | MCL or MCLG[1] |
|---|---|---|---|---|
| VOCs | Tetrachloroethylene | 0.50 | µg/L | 5 |
| VOCs | 1,1,2,2-Tetrachloroethane | 0.50 | µg/L | N/A |
| VOCs | Chlorobenzene | 0.50 | µg/L | 10 |
| VOCs | Benzene | 0.50 | µg/L | 5 |
| VOCs | Toluene | 0.50 | µg/L | 1000 |
| VOCs | Ethylbenzene | 0.50 | µg/L | 700 |
| VOCs | Bromobenzene | 0.50 | µg/L | N/A |
| VOCs | Isopropylbenzene | 0.50 | µg/L | N/A |
| VOCs | Styrene | 0.50 | µg/L | 100 |
| VOCs | n-Propylbenzene | 0.50 | µg/L | N/A |

Notes:
[1] MCL = Maximum Contaminant Level; MCLG = Maximum Contaminant Level Goal
N/A = Not Applicable
DBPs = Disinfection By-Products
SOCs = Synthetic Organic Chemicals
VOCs = Volatile Organic Chemicals

According to the Rules, the sampling frequency for each category is generally every three years with the exception of nitrate, which is sampled annually. If exceedances of a maximum contaminant level (MCL) occur, more frequent sampling and analysis is required. For new systems and/or wells quarterly sampling is required for some contaminant categories during the first year. An MCL is the maximum permissible level of a contaminant in water which is delivered to any user of a public water system. MCLs are health-based limits promulgated by the EPA's Safe Drinking Water Act and amendments, and adopted by the State of North Carolina.

The tables presented in this section summarize the results of the latest sample for each unique PWS system entry point. The latest sample is defined as the most recent sample taken from active entry points between the period of June 1999 and June of 2002. An entry point typically refers to a well; however, entry points may also designate a distribution sample, meaning that the sample originated from somewhere in the CWS distribution system. The number of entry points per CWS in Wake County ranges from one to approximately 50, depending on the size of the system.

For each constituent that currently requires monitoring according to the Rules, the summary tables provide the method detection limit (MDL), which describes the lowest concentration for which the constituent could be detected (within the quality limits of the instrument and analytical method); the number of analyses; the number of times the constituent was detected above the MDL; the percentage of times the constituent was detected above the MDL; the number of times the constituent was detected above the MCL; and the minimum and maximum detection from the entire sample set.

#### 4.2.1.1 Inorganic Constituents

Water quality data for inorganic constituents is summarized in **Table 4-2**. The PWS database includes 13 trace metals and the major ions, sodium, fluoride, and sulfate. The measure of pH is also included and is reported in **Table 4-2**.

**Table 4-2**
**Summary of Inorganic Constituents in Groundwater Samples from Wake County CWSs**

| Constituent | Units | Detection Limit | Number of Analyses | Number of Detections | Percent Detections | Number of Detections Above the MCL | Minimum Detection | Maximum Detection |
|---|---|---|---|---|---|---|---|---|
| antimony | mg/L | 0.003 | 659 | 2 | 0 | 0 | 0.004 | 0.004 |
| arsenic | mg/L | 0.005 | 740 | 19 | 3 | 4 | 0.001 | 0.028 |
| barium | mg/L | 0.4 | 740 | 253 | 34 | 0 | 0.005 | 0.63 |
| beryllium | mg/L | 0.002 | 657 | 10 | 2 | 0 | 0.0001 | 0.001 |
| cadmium | mg/L | 0.001 | 739 | 23 | 3 | 1 | 0.0001 | 0.01 |
| chromium | mg/L | 0.02 | 741 | 23 | 3 | 0 | 0.001 | 0.018 |
| cyanide | mg/L | 0.04 | 656 | 7 | 1 | 0 | 0.005 | 0.015 |
| flouride | mg/L | 0.1 | 833 | 503 | 60 | 0 | 0.0017 | 2.1 |
| iron | mg/L | 0.06 | 741 | 425 | 57 | 115 | 0.003 | 15.06 |
| lead | mg/L | 0.001 | 85 | 26 | 31 | N/A | 0.0004 | 0.04 |
| manganese | mg/L | 0.01 | 740 | 356 | 48 | 194 | 0.002 | 2.504 |
| mercury | mg/L | 0.0004 | 739 | 14 | 2 | 4 | 0.0002 | 0.2 |
| nickel | mg/L | 0.1 | 656 | 42 | 6 | N/A | 0.011 | 0.069 |
| ph | SU | -- | 742 | 742 | 100 | N/A | 4.2 | 12.3 |
| selenium | mg/L | 0.01 | 741 | 20 | 3 | 0 | 0.001 | 0.011 |
| silver | mg/L | 0.001 | 83 | 7 | 8 | N/A | 0.001 | 0.011 |
| sodium | mg/L | 1 | 748 | 740 | 99 | N/A | 0.0005 | 535 |
| sulfate | mg/L | 5 | 657 | 296 | 45 | 3 | 0 | 347.4 |
| thallium | mg/L | 0.001 | 657 | 12 | 2 | 2 | 0.001 | 6.7 |

Sodium, fluoride, iron, manganese, sulfate, and barium were the most frequently detected inorganic constituents. The trace metals, antimony, arsenic, beryllium, cadmium, chromium, mercury, selenium, and thallium were detected in less than three percent of the samples. Lead and silver are only analyzed in distribution samples and are not meant to assess raw groundwater quality. Their presence is an indication of their potential leaching from distribution system piping.

Between one and four exceedances of the MCL were observed for arsenic, mercury, sulfate, and thallium. Three of the arsenic and two of the mercury MCL exceedances occurred in distribution system samples. Iron and manganese were detected at levels above the maximum contaminant level goal[2] (MCLG) in 16 and 26 percent of the samples, respectively.

The PWS water quality database was queried for the period 1979 to 2002 to identify the total number of MCL exceedances for the constituents which in the latest sample set had exceeded the MCL. **Figure 4-2** shows the locations of CWSs that have experienced MCL exceedances for arsenic, cadmium, mercury, and thallium since 1979. Arsenic has been detected above the MCL once in eight different CWSs and twice in one CWS. Cadmium has been detected above the MCL once in 11 different CWSs. Mercury has been detected above the MCL once in eight different CWSs. Thallium has been detected above the MCL once in two different CWSs.

Arsenic in groundwater may result from natural sources, including minerals dissolved from rocks such as metal arsenides and arsenates, sulfide ore (arsenopyrite), and arsenite. Major man-made sources of arsenic relate to its current and former use in the lumber and agriculture industries. Although most agricultural uses of arsenic were phased out in the 1960s and early 1970s, arsenic is still used in the organic herbicide disodium methanearsonate which is applied to cotton fields (EPA, 2000). Arsenic in the lumber industry is used in the production of the wood preservative, chromated copper arsenate. It may leach from the treated lumber over time. Cadmium may be present naturally in groundwater from dissolution of minerals such as zinc carbonate and sulfide ores. Mercury may be present at low levels naturally in soil and rocks or introduced by man through improper disposal of industrial components containing mercury or agricultural use as a fungicide.

Arsenic, cadmium, mercury and thallium are detected in Wake County groundwater infrequently, at low levels, and are generally not pervasive (i.e., do not appear in consecutive samples from the same well). However, it is unclear whether their presence is the result of the dissolution of naturally occurring minerals into groundwater or anthropogenic factors.

The North Carolina Department of Health and Human Services has recommended a groundwater standard of 0.02 micrograms per liter (μg/l). The current MCL for arsenic is 10 μg/l. The Occupational and Environmental Epidemiology Branch has determined that arsenic levels above the recommended standard may pose a slightly increased cancer risk upon consumption of 2 liters of water per day over an extended period (over 30 years.) Since the reporting limit (i.e., detection limit) for arsenic is typically no less than 1 μg/l, it is unclear how many domestic and CWS wells in Wake County contain arsenic above the recommended standard.

High concentrations of iron and manganese have been identified as the most common water quality problems in the Piedmont and Blue Ridge Provinces (Daniel and Dahlen, 2002), and in Wake County (Hardy, 2003). Analysis of the CWS data reflects this fact. Since 1979, an average of 15 percent of the CWS samples have exceeded the maximum contaminant level goal (MCLG) of 0.30 mg/l for iron for each year, and an average of 24

[2] The MCLG is defined as the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, and which allows an adequate margin of safety. MCLGs are nonenforceable health goals.

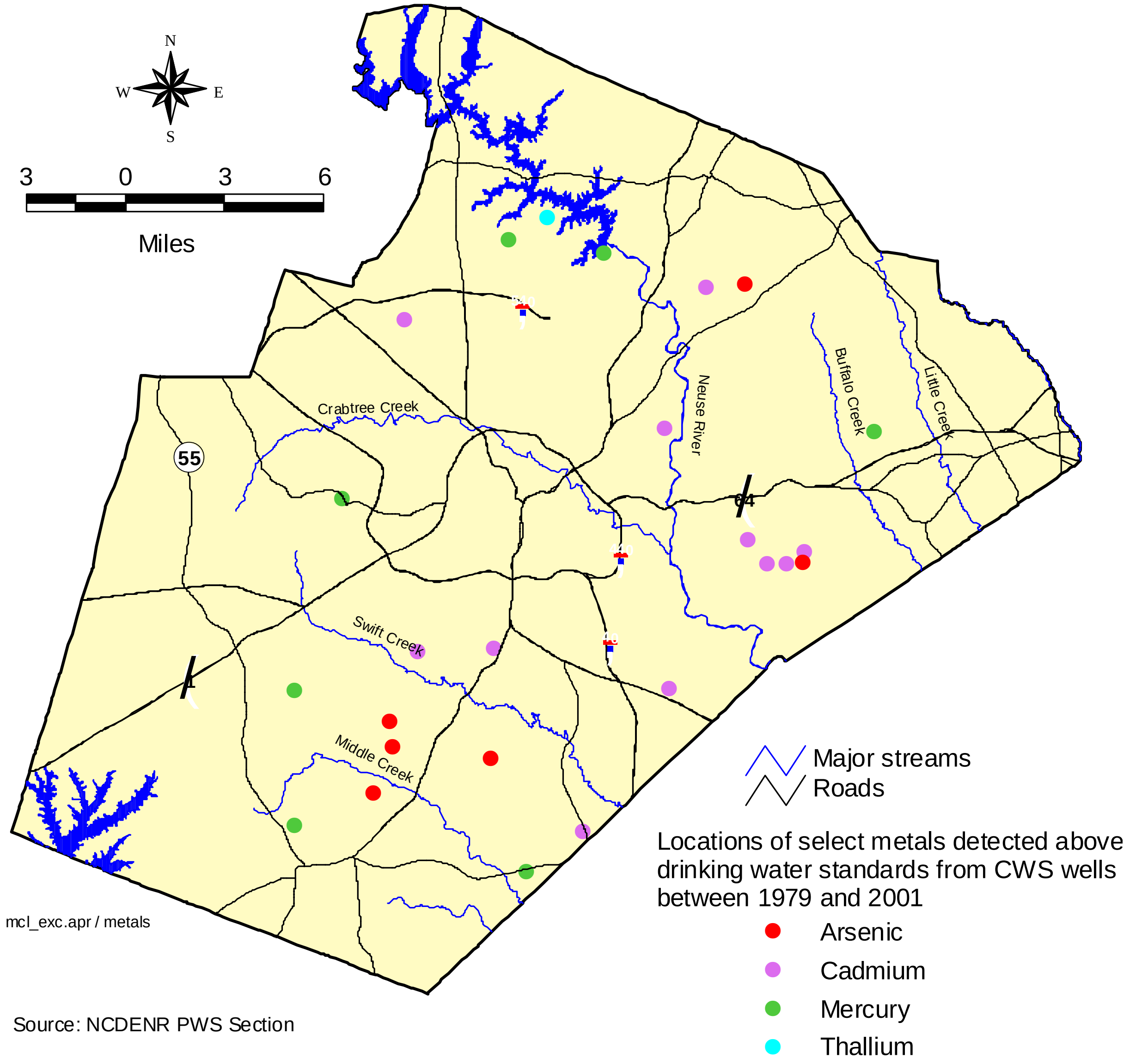
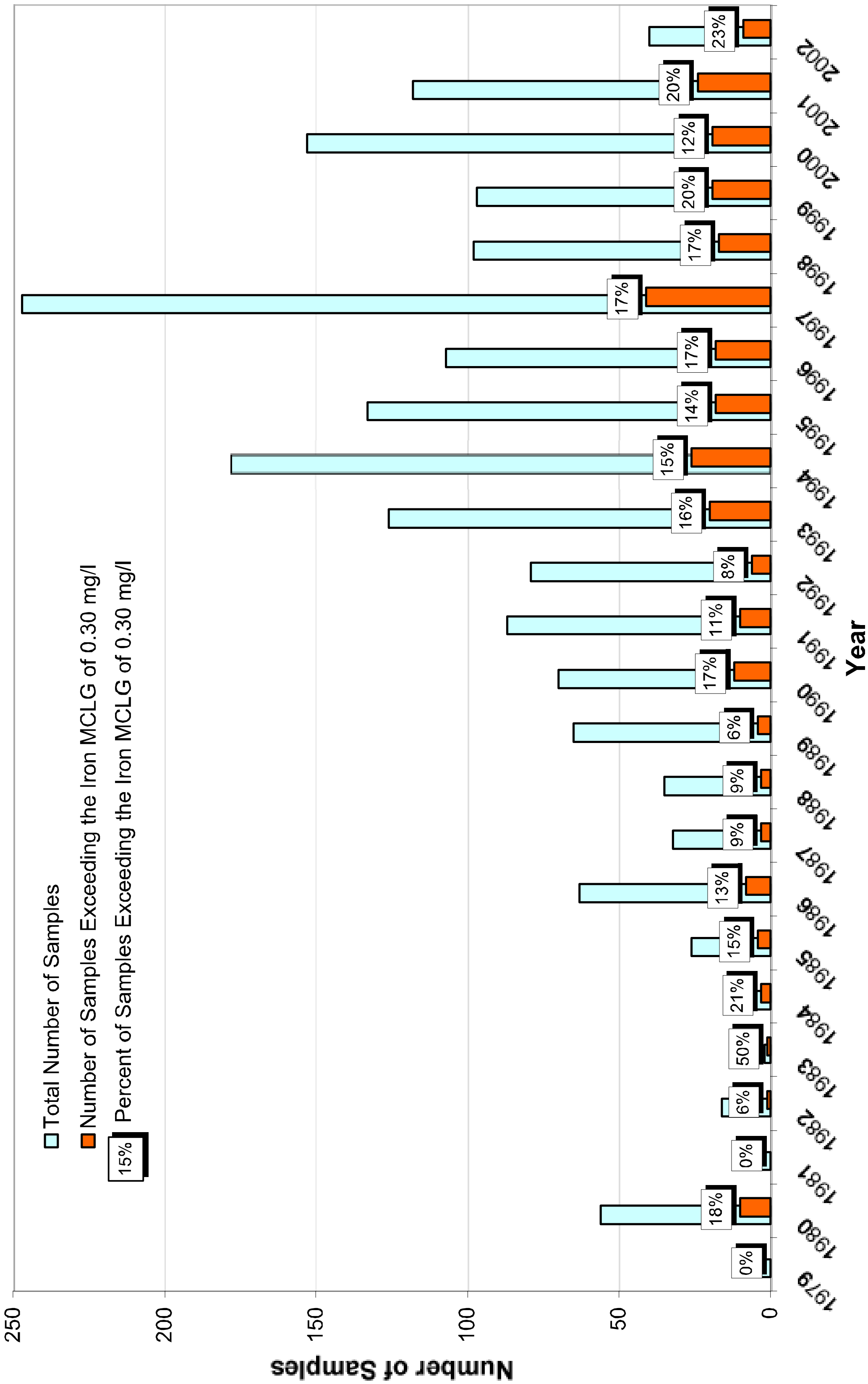



**Figure 4-2**
**Locations of Select Trace Metals Detected Above Drinking Water Standards, 1979 – 2001**

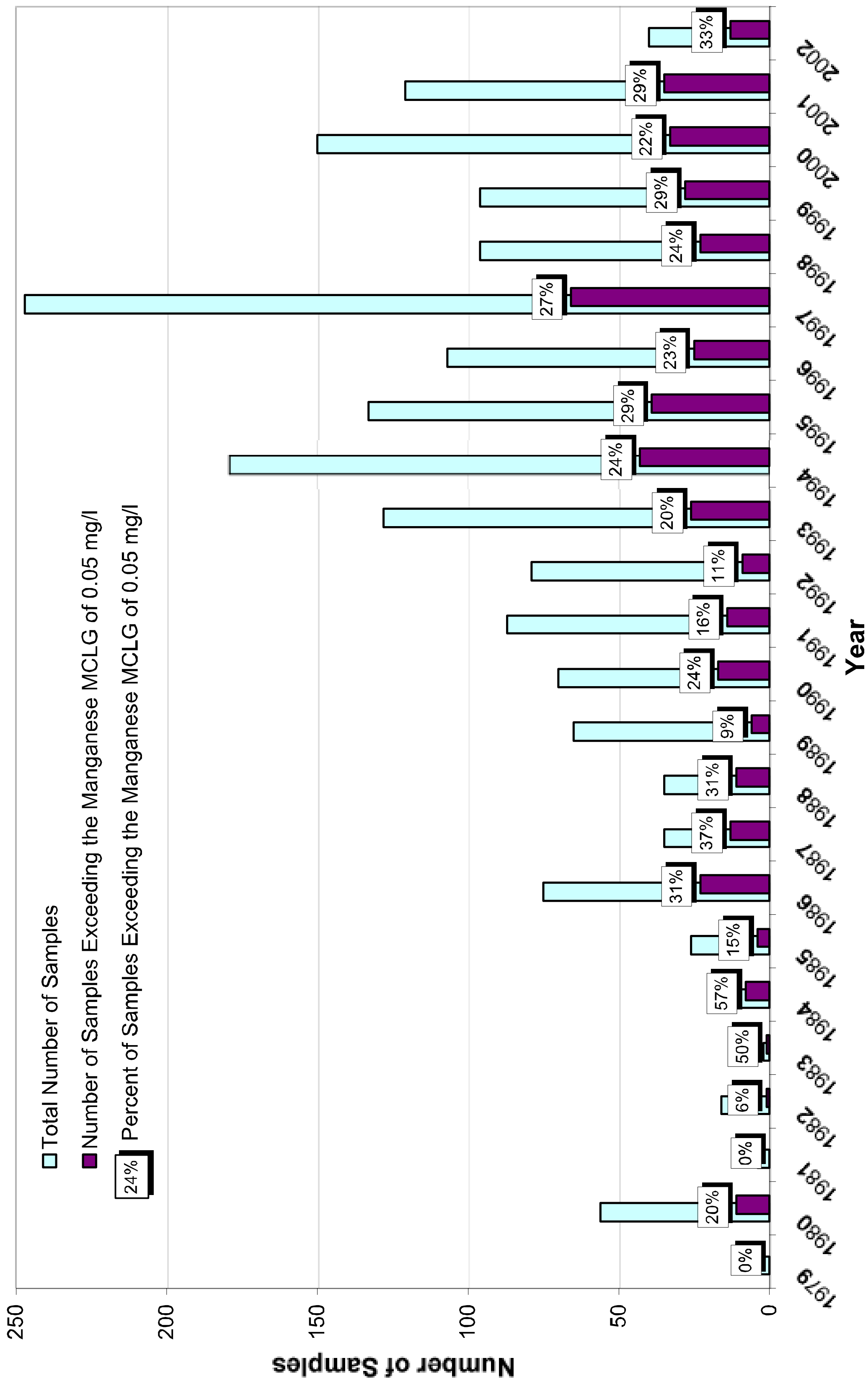
percent have exceeded the MCLG for manganese for a each year. **Figures 4-3** and **4-4** show the number of samples analyzed for iron and manganese annually between 1979 and 2002, the number of times they were detected above their MCLG, and the percentage of MCLG exceedances for each year. As required by the NC Rules, CWSs that exceed the MCLG for iron or manganese are required to provide treatment to reduce the concentration of their soluble form. Sequestration is the most commonly used treatment alternative and is likely to occur in most of those systems identified. As previously mentioned, laboratory analysis of iron and manganese recognizes both soluble and insoluble forms; therefore the data presented in **Figures 4-3** and **4-4** are generally characteristic of raw groundwater quality. The soluble form of iron and manganese is expected to be present in significantly lower concentrations if sequestration has been performed.




Data source: NCDENR PWS section. Data are from June 1979 thorugh June 2002. Distribution samples are not included.

*Fe by Year.xls Fe Chart*

**Figure 4-3**
**Iron Results from Wake County CWS Wells**




Data source: NCDENR PWS Section. Data are from June, 1979 thorugh June 2002. Distribution samples are not included.

*Mn by year.xls Mn Chart*

**Figure 4-4**
**Manganese Results from Wake County CWS Wells**



CDM

Iron and manganese are essential to the human diet and are not known to cause adverse health effects. However, water containing high concentrations of (soluble) iron and manganese can stain clothes, skin, or teeth, discolor plumbing fixtures, or result in poor taste or odor. Iron and manganese in water also promote the growth of iron bacteria, a group of organisms that obtains energy for growth from the chemical reaction that occurs when iron and manganese mix with dissolved oxygen. These bacteria form thick slime growths on the walls of the piping system and on well screens and often contribute to well problems such as clogging and reduced yield.

Iron and manganese results from samples collected from CWSs between 1999 and 2002 were compared to the hydrogeologic unit map of Wake County developed by the NCGS to investigate if elevated concentrations are associated with one or more hydrogeologic units. **Table 4-3** presents the iron and manganese results grouped by hydrogeologic

**Table 4-3**
**Analysis of Iron and Manganese Concentrations from CWSs by Hydrogeologic Unit**

| Hydrogeologic Unit | Iron | | | | | Manganese | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | Number of Samples | Number of MCLG[1] Exceedances | Percentage of MCLG[1] Exceedances | Mean | Median | Number of Samples | Number of MCLG[2] Exceedances | Percentage of MCLG[2] Exceedances |
| *Felsic rocks* | | | | | | | | | | |
| GNF | 0.19 | 0.05 | 68 | 11 | 16% | 0.08 | 0.02 | 68 | 24 | 35% |
| IFI | 0.17 | 0.05 | 98 | 8 | 8% | 0.03 | 0.01 | 98 | 9 | 9% |
| MIF | 0.59 | 0.22 | 18 | 8 | 44% | 0.13 | 0.03 | 18 | 8 | 44% |
| MVF | 0.24 | 0.05 | 25 | 7 | 28% | 0.12 | 0.04 | 25 | 10 | 40% |
| **All Felsic Rocks** | **0.22** | **0.05** | **209** | **34** | **16%** | **0.07** | **0.01** | **209** | **51** | **24%** |
| *Mafic Rocks* | | | | | | | | | | |
| MII | 0.16 | 0.08 | 7 | 1 | 14% | 0.17 | 0.08 | 7 | 4 | 57% |
| MIM | 0.19 | 0.05 | 12 | 1 | 8% | 0.04 | 0.01 | 12 | 1 | 8% |
| MVM | 0.06 | -- | 1 | 0 | 0% | 0.01 | -- | 1 | 0 | 0% |
| **All Mafic Rocks** | **0.17** | **0.05** | **20** | **2** | **10%** | **0.08** | **0.01** | **20** | **5** | **25%** |
| *Undifferentiated* | | | | | | | | | | |
| MVU | 0.12 | -- | 2 | 0 | 0% | 0.05 | -- | 2 | 1 | 50% |
| SCH | 0.08 | 0.05 | 11 | 1 | 9% | 0.03 | 0.01 | 11 | 1 | 9% |
| TRI | 0.07 | -- | 1 | 0 | 0% | 0.11 | -- | 1 | 1 | 100% |
| **All Rock Types** | **0.21** | **0.05** | **243** | **37** | **15%** | **0.07** | **0.01** | **243** | **59** | **24%** |

Notes:
[1] Maximum contaminant level goal for iron is 0.30 mg/l.
[2] Maximum contaminant level goal for manganese is 0.05 mg/l.
Iron and Manganese results are from Wake County community water systems. Samples were collected between 1999 and 2002.
Mean and median concentrations were calculated using the method detection limit (MDL) for results where the constituent was not detected above the MDL.

GNF = gneiss, felsic
IFI = igneous, felsic intrusive
MIF = metaigneous, felsic
MVF = metavolcanic, felsic
MII = metaigneous, intermediate
MVM = metavolcanic, mafic
MIM = metaigneous, mafic
SCH = schist
MVU = metavolcanic, undifferentiated
TRI = triassic sedminents

unit. Results are also grouped by the rock type categories of felsic and mafic. Water from most light-colored, felsic metamorphic and igneous rocks is generally soft (hardness less than 60 mg/l as CaCO3) and contains low concentrations of dissolved solids (Powell and Abe, 1985). Water from dark-colored mafic metamorphic and igneous rocks is generally hard and contains higher concentrations of dissolved solids. The hydrogeologic units, locations of CWSs, and concentration ranges of iron and manganese are shown in **Figure 4-5**.

The highest mean concentration of iron and highest percentage of MCLG exceedances occurred in samples from the metaigneous felsic (MIF) unit. The highest mean concentration of manganese and largest percentage of MCLG exceedances occurred in samples from the metaigneous intermediate (MII) unit. The lowest mean concentration and the lowest percentage of MCLG exceedances for both iron and manganese occurred in samples from the igneous felsic intrusive (IFI) unit for those units with more than two samples. The mean concentration of iron was higher (0.22 mg/l) in samples from felsic rocks compared to mafic rocks (0.17 mg/l). The mean concentration of manganese from felsic rocks (0.07 mg/l) was nearly equal to that from mafic rocks (0.08 mg/l).

The Neuse Crossing CWS located just north of the Neuse River in North Raleigh experienced elevated

iron and manganese concentrations in its water supply beginning in 1995, and increasing in 1998. The mean iron concentration from eight samples collected in 1995 was 1.66, or greater than five times the MCLG. The mean manganese concentration from the same eight samples was 0.15, or nearly three times above the MCLG. In 2001, the system was removed from service and the subdivision was connected to the City of Raleigh water supply.

The Neuse Crossing subdivision is located at the western edge of the Rolesville granite, a felsic unit not typically associated with high iron and manganese concentrations. Nearby CWS wells, also located in the Rolesville granite, have not produced water containing high concentrations of iron or manganese. Field reconnaissance conducted by the NCGS identified the presence of a diabase dike running in a northwest to southeast direction, and passing adjacent to one of the subdivision's wells (Clark, 2003). Diabase dikes are igneous intrusions that are forced into place, fracturing the native rock, and fracture themselves upon cooling. The associated fractures locally increase the chance for higher yielding wells. Diabase dikes may range in width from only a few inches to over 200 feet. The presence of the dike, which is classified as mafic, was identified as a likely contributor to the elevated iron and manganese concentrations. However, the exact cause of the marked increase in iron and manganese concentrations in the late 1990s remains unknown.

The NCGS has recently developed a GIS map of the observed and inferred locations of diabase dikes in Wake County (**Figure 3-13**). The map can be used to help understand and explain variations in water quality from wells located in the same hydrogeologic area.

#### 4.2.1.2 Dissolved Nutrients

**Table 4-4** summarizes the results of analyses for nitrate and nitrite. The MCL for nitrate and nitrite is 10 mg/l and 1 mg/l respectively. Nitrate was detected in 56 percent of the water samples at concentrations ranging up to 7.04 mg/l. Two distribution samples were detected in exceedances of the MCL from the most recent sample set[3]. Nitrite was not detected in any of the samples non-distribution samples. All nitrite detections were below the MCL.

The NC Rules require annual monitoring for nitrate. If nitrate concentrations are detected above 5.0 mg/l (one-half the MCL), quarterly monitoring is required.

[3] The two samples which exceeded the MCL in the latest sample set are not included in Table 4-4 since the table summarizes only non-distribution samples.

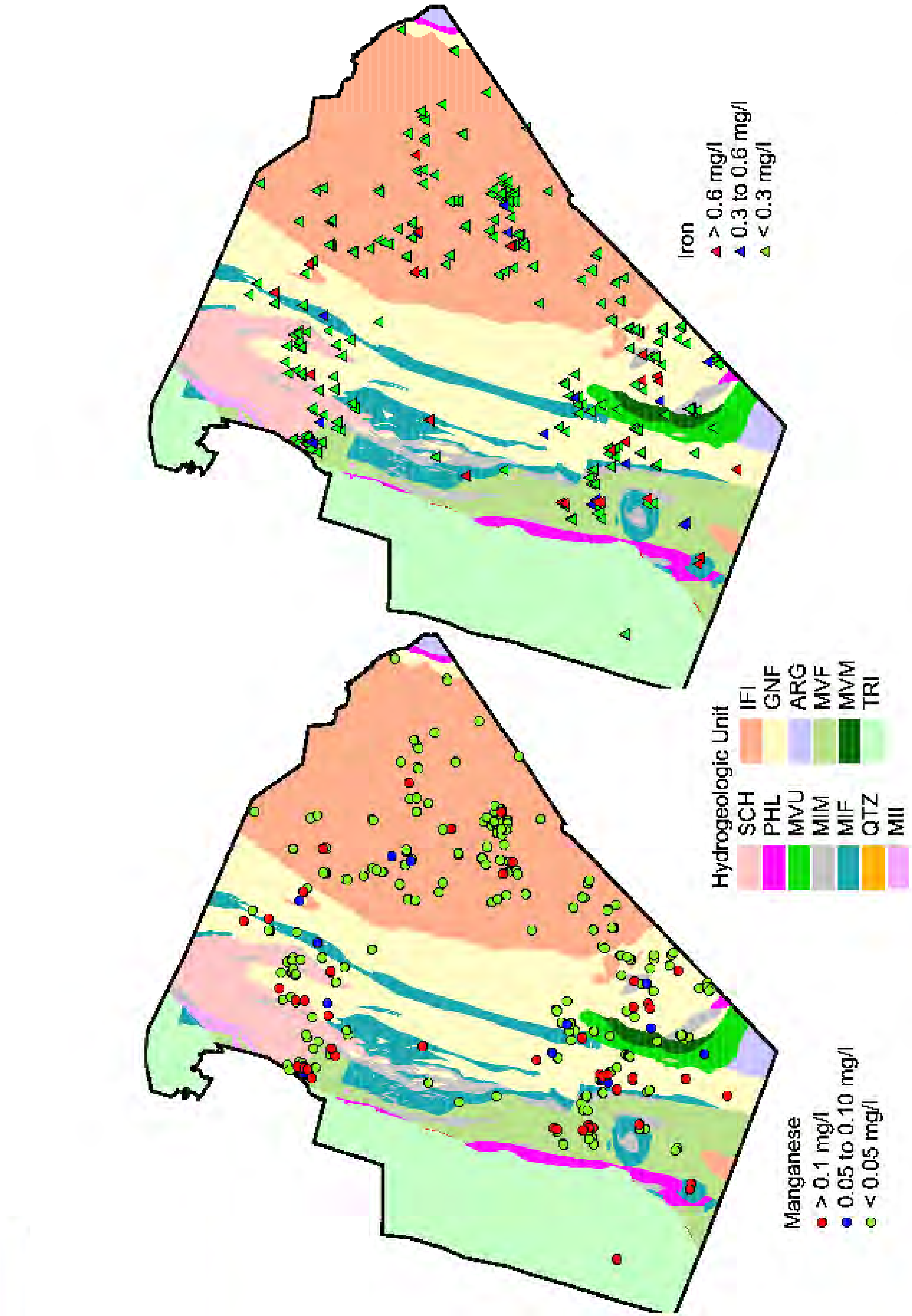



**Figure 4-5**
**Iron and Manganese Concentrations in Groundwater from CWS Wells**

**Table 4-4**
**Summary of Nutrients in Groundwater Samples from Wake County CWSs**

| Constituent | Units | Detection Limit | Number of Analyses | Number of Detections | Percent Detections | Number of Detections Above the MCL | Minimum Detection | Maximum Detection |
|---|---|---|---|---|---|---|---|---|
| nitrate | mg/L | 1 | 494 | 276 | 56 | 0 | 0.02 | 7.04 |
| nitrite | mg/L | 0.1 | 13 | 0 | 0 | 0 | -- | -- |

Since 1993, nitrate has been found at levels above 10 mg/l in only 19 out of 5,899 samples. The locations of MCL exceedances for nitrate since 1993 are shown in **Figure 4-6**. The infrequent detections of nitrate in CWSs can be primarily attributed to proper well siting and well construction methods. Nitrate contamination may indicate direct connection with the surface by a poor well seal or insufficient well casing or incomplete denitrification of septic tank effluent prior to its reaching the saturated zone. Bachman (1984) estimated that nitrate concentrations above 3.0 mg/l are the result of anthropogenic factors. In Wake County, 1,150 or 19.5 percent of the 5,899 CWS samples contained nitrate at 3.0 mg/l or greater.

Onsite wastewater treatment system effluent can be a source of nitrate contamination to groundwater. The rules that govern the applicability, location, design and operation of onsite wastewater treatment systems are meant to reduce the impact of nitrate, among other constituents, to groundwater. Over-application of fertilizers and land application of solids derived from wastewater treatment may also contribute to increased concentrations of nitrate in groundwater. Excessive application of wastewater and sludge at the City of Raleigh's Neuse River Wastewater Treatment Plant (NRWWTP) has contributed to elevated nitrate levels in groundwater near the plant. A study in the 1990s demonstrated nitrate contamination of the groundwater at the NRWWTP from sludge (biosolids) application (Welby, 2000). Currently, an investigation of nitrate contamination in the NRWWTP spray fields is characterizing the extent and severity of nitrate contamination and addressing the potential impacts to local domestic wells and the Neuse River.

The Village of White Oak, located in southeastern Wake County (east of Garner), experienced elevated nitrate levels ranging between 5.0 mg/l and 11.7 mg/l in its water supply between 1994 and 2000. As a result, the owner and operator, HUI, began providing bottled water to the residents served by the system. In early 2001 an ion exchange treatment system to reduce the levels of nitrate. Anecdotal information suggests that the Village has a history of failing septic systems (Strickler, 2002).

### 4.2.1.3 Radionuclides

Water quality results for radionuclides are shown in **Table 4-5**. All radionuclide samples are distribution samples and therefore may reflect a composite sample of water originating from multiple wells. Radionuclide samples may also be composite samples with respect to time since samples collected from different dates may be composited to produce one result.

Uranium was detected in all groundwater samples at concentrations ranging up to 205.07 pCi/L. Sixteen samples exceeded the State MCL of 20.1 pCi/L for uranium. Gross alpha and beta emitters were detected in nearly all samples at concentrations ranging up to 181.1 pCi/L and 103.96 pCi/L, respectively. Radium-226 and radium-228 were detected above the MCL in five and one sample, respectively.

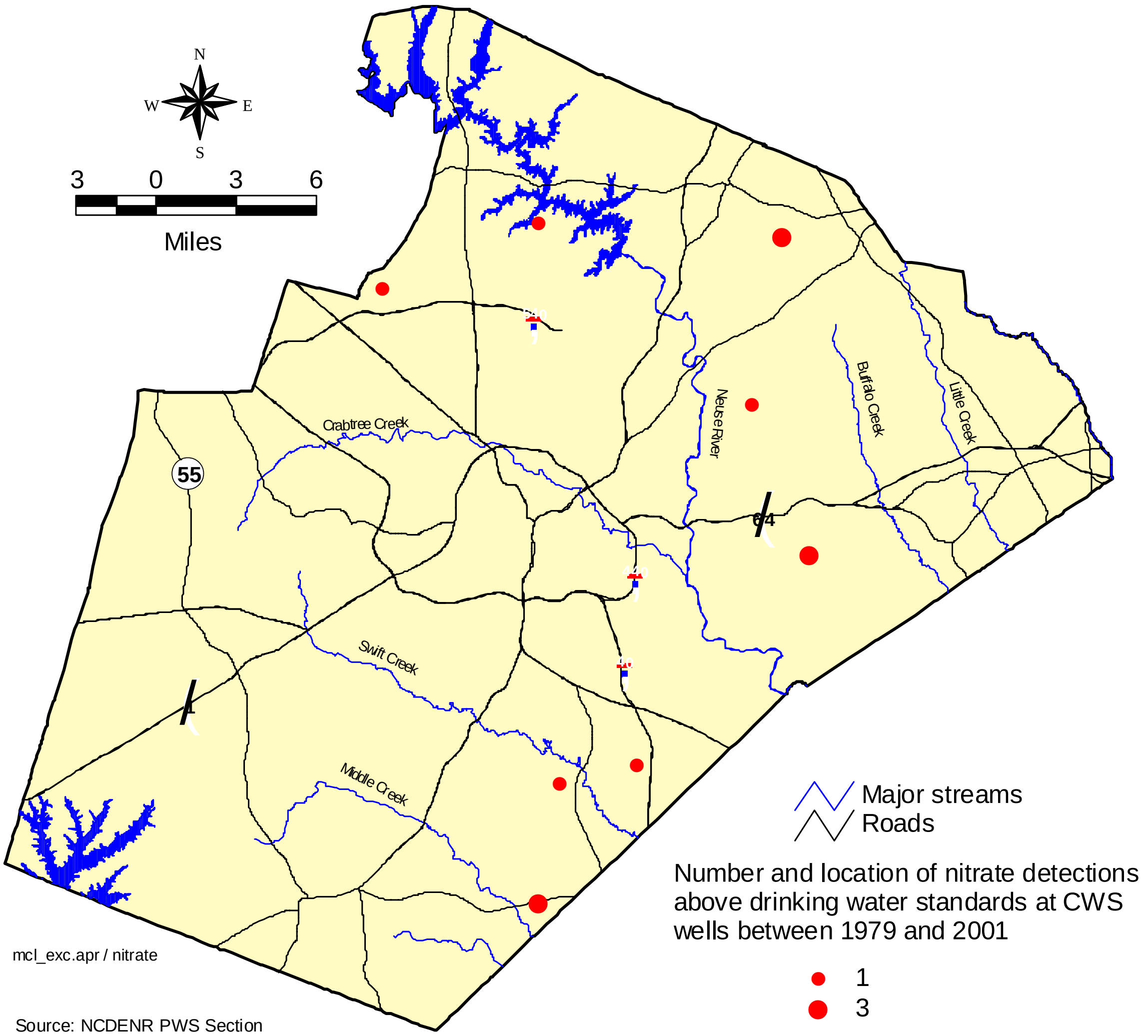



**Figure 4-6**
**Locations and Number of Detections of Nitrate Above Drinking Water Standards at CWS Wells, 1979 - 2001**

Radioactivity in water is typically a naturally occurring phenomenon but can be a result of human activity. Major sources of man-made radiation are atmospheric deposition from nuclear weapon testing, radiopharmaceuticals, and nuclear fuel processing and use.

**Figure 3-7** shows the location of CWSs where gross alpha was detected above the MCL between 1979 and 2002. The gross alpha MCL of 15 pCi/L applies to samples where the uranium concentration has been subtracted from the total gross alpha concentration.

Elevated concentrations of gross alpha particles and associated radionuclides are most often found east of the Neuse River, in the northeastern part of Wake County, and coincide with the granitic rock of the Rolesville series. The Rolesville granite, as it is commonly known, contains relatively high concentrations of uranium which is present to varying degrees in almost all rocks. The Rolesville granite comprises the IFI hydrogeologic unit (**Figure 2-3**). The IFI unit has also been associated with elevated concentrations of radon, one of the decay products of uranium, in Guilford County, North Carolina (Spruill et al, 1997). Uranium

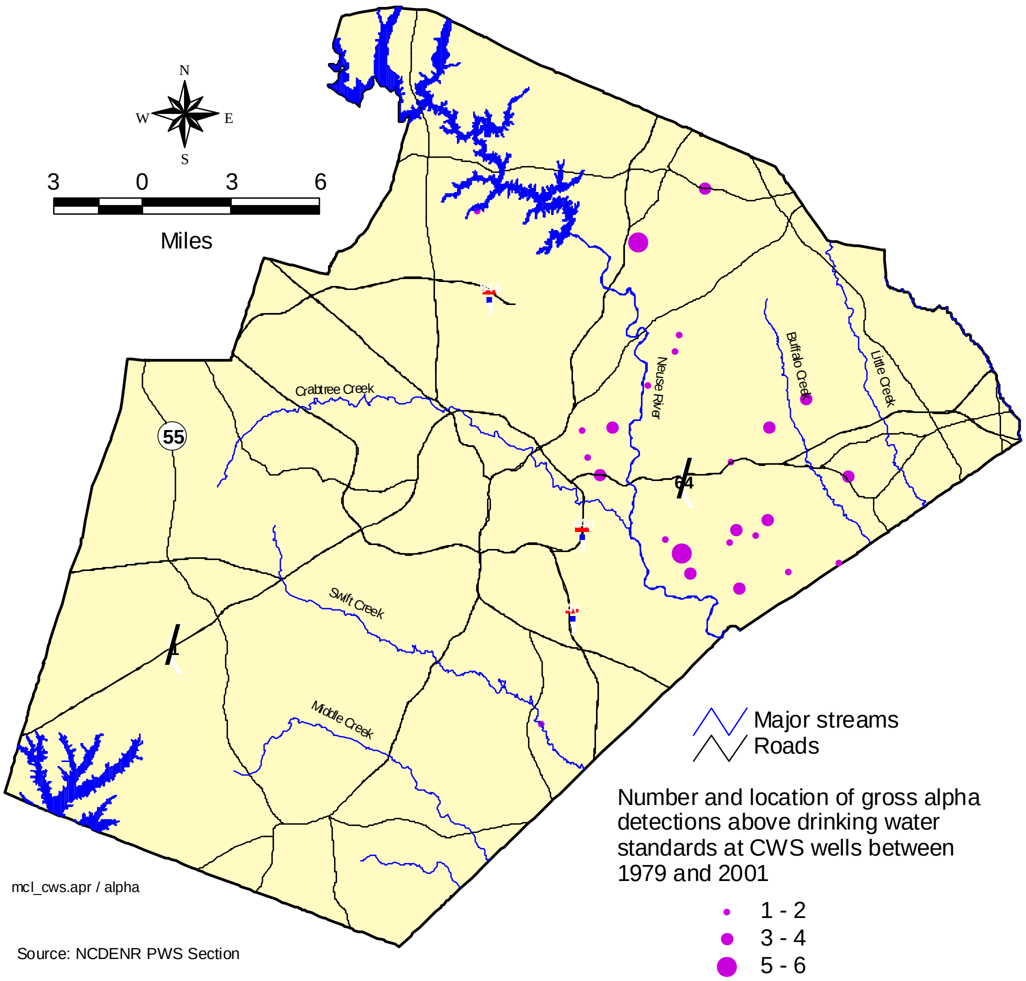



**Figure 4-7**
**Locations and Number of Detections of Gross Alpha Radioactivity Above Drinking Water Standards at CWS Wells, 1979 - 2001**

concentrations measured in stream sediment show increasing levels of radioactivity along the Wake County-Franklin County border (Carpenter, 1993). The same spatial trend is not replicated by the CWS data, due to the fact that few CWSs are located in the northernmost part of Wake County. Groundwater in this area may be expected to show similar, if not higher concentrations of uranium, gross alpha, and associated radionuclides.

### 4.2.1.4 Radon

Radon is a colorless and odorless gas that may be present in groundwater in a dissolved form. It is very volatile and will readily escape from water with agitation. Radon is one of the many decay products that result from the radioactive decay of Uranium-238 to Lead-206. There are three naturally occurring isotopes of radon; however, health risks due to inhalation and ingestion of radon refer to Radon-222 (Rn-222). Of the naturally occurring radionuclides, radon presents the largest risk to human health. The EPA estimates radon in indoor air causes between 15,000 and 22,000 lung cancer deaths each year in the United States, largely because radon substantially increases the lung cancer risk for smokers.

Radon in drinking water is not currently regulated by the Environmental Protection Agency (EPA), or the State of North Carolina, although the EPA has issued a proposed rule. Under the proposed Radon in Drinking Water Rule (November 2, 1999),

**Table 4-5**
**Summary of Radiological Constituents in Groundwater Samples from Wake County CWSs**

| Constituent | Units | Detection Limit | Number of Analyses | Number of Detections | Percent Detections | Number of Detections Above the MCL | Minimum Detection | Maximum Detection |
|---|---|---|---|---|---|---|---|---|
| combined radium | pCi/L | -- | 1 | 1 | 100 | 1 | 7.7 | 7.7 |
| gross alpha | pCi/L | 3 | 396 | 372 | 94 | 6 | 0 | 181.1 |
| gross beta | pCi/L | 4 | 144 | 142 | 99 | 3 | 0 | 103.96 |
| radium 226 | pCi/L | 1 | 57 | 56 | 98 | 5 | 0 | 6.38 |
| radium 228 | pCi/L | 1 | 7 | 6 | 86 | 1 | 0.48 | 3.5 |
| uranium | pCi/L | 2 | 30 | 30 | 100 | 16 | 0.84 | 205.07 |

EPA will allow states to control radon health risks using one of two options. States can 1) choose to develop statewide Multimedia Mitigation (MMM) programs to reduce radon in indoor air from all sources while also limiting radon levels in drinking water to an alternate maximum contaminant limit (AMCL) of 4,000 pCi/L; or 2) if states choose not to develop an MMM program, then community water suppliers will be required to meet a MCL of 300 pCi/L for radon.

Because radon is not currently regulated, no water quality data for radon was available from the PWS database. However, several studies have investigated radon in North Carolina and Wake County groundwater (Loomis, 1987; Dusenbury, 1992; Spruill et al., 1997; Cunningham and Daniel, 2001). These investigations are summarized in the following paragraphs.

Dusenbury prepared a compilation of radon in North Carolina groundwater from studies conducted by the EPA, the North Carolina Division of Radiation Protection (DRP), and the University of North Carolina at Chapel Hill (UNC) between 1975 and 1986. Although the report presents radon concentrations in groundwater statewide, data from 31 samples collected primarily from CWSs in Wake County is presented. The concentrations of radon measured in groundwater, and the location of the sample points are shown in **Figure 4-8**. The report provides location information with respect to subdivision, and in a few instances town; therefore the locations shown in **Figure 4-8** are approximate. Sample locations are concentrated in the north and eastern portion of Wake County, coinciding with the Rolesville granite. Radon concentrations in groundwater are expected to be generally lower elsewhere in the County, based on the distribution of gross alpha concentration from CWSs in PWS database. All of the samples compiled by Dusenbury exceeded the proposed MCL of 300 pCi/l. Over 50 percent of the samples exceeded the alternative MCL of 4,000 pCi/L.

Loomis investigated the distribution and relationship of radon in North Carolina groundwater to rock type. The highest measured values and the highest average concentrations of radon were found in areas of the Piedmont underlain by granites. Intermediate concentrations were found in metavolcanic rocks, gneisses, and schists. The lowest average radon concentrations were associated with coastal plain sediments and mafic igneous rocks.

Spruill et al. summarized results from 70 samples from wells throughout Guilford County in North Carolina. The study showed a relationship between geology and radon concentration with the highest concentrations found in younger granites, biotite gneiss and schist units, and lower activity associated with the older metamorphosed volcanic units.

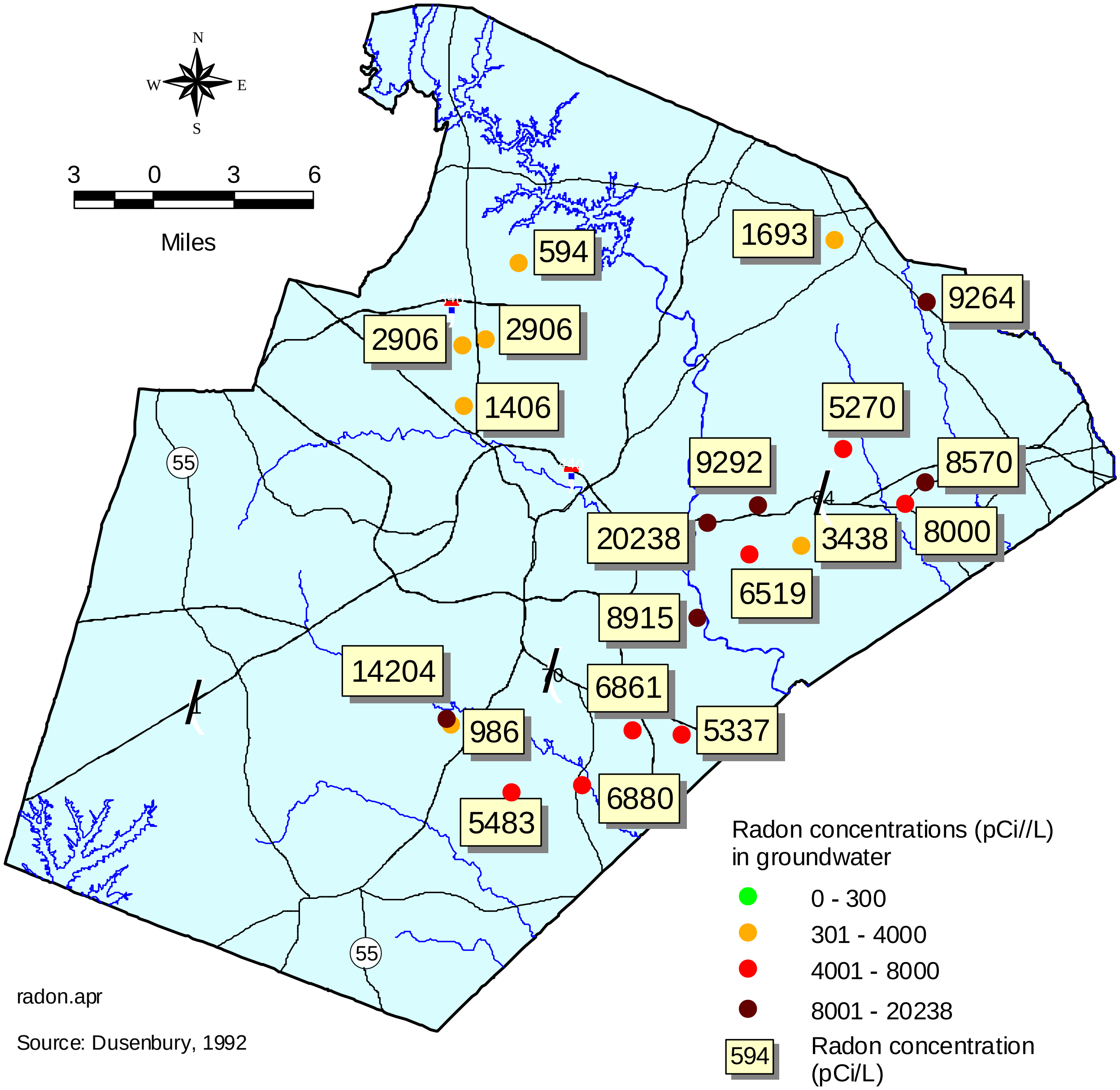



**Figure 4-8**
**Radon Concentrations in Groundwater**

A USGS study included sampling and analysis of radon from 51 domestic wells in Orange County (Cunningham and Daniel, 2001). The highest median concentrations were found in felsic rocks and the lowest median concentrations were found in mafic rocks. Sixty-seven percent of the samples exceeded the proposed MCL of 300 pCi/l, and one sample exceeded the alternative MCL of 4,000 pCi/L.

Recent groundwater sampling and analysis from wells at the North Carolina State Lake Wheeler Field Research Laboratory identified radon at concentrations up to 11,979 pCi/L. The Lake Wheeler Station is located in the south central part of Wake County. It has been hypothesized that the elevated concentrations of radon in groundwater at the site may be a result of the numerous brittle faults known to occur in the area (Bolich, 2002). Fault zones may accelerate the weathering process of rock, thereby releasing radon gas. Fault zones also create natural pathways for the migration of radon gas. From a water quantity standpoint, these areas are preferred locations for water supply wells because water moves more quickly through them than in the surrounding rock. The NCDENR Groundwater Section has identified the need to investigate further the relationship between brittle faults and high levels of radon in groundwater. Working with the NCDENR DRP, they will conduct a pilot study to collect and analyze approximately 25 groundwater samples from water supply wells located in the vicinity of known brittle fault zones.

#### 4.2.1.5 Synthetic Organic Chemicals

Water quality results for SOCs are shown in **Table 4-6**. SOCs include pesticides, herbicides, fungicides, and other man-made organic chemicals. From the most recent CWS data, nine out of a possible 42 SOCs were detected in groundwater. No exceedances of an MCL were noted.

The presence of SOCs in groundwater may be due to over-application of pesticides, herbicides, or fungicides. In Wake County, detections of EDB in groundwater have resulted in CWS well abandonment and/or installation of GAC treatment to remove the contaminant. In 1994, EDB was found in the water supply (obtained from a CWS well) of the Pear Meadows subdivision in southwestern Wake County, resulting in abandonment of the system and connection to the Town of Fuquay-Varina's public water supply. EDB was previously used as a soil fumigant in tobacco farming and is currently used as an anti-knock agent in leaded gasoline. The EPA has set the MCL for EDB at 0.05 μg/l, based on the risk for cancer and other health effects. The locations of past EDB detections and MCL exceedances are shown in **Figure 4-9.**

EDB was not detected at any of the 55 NCDENR Groundwater Section ambient monitoring wells samples as part of the Wade (1997) study. However, the reporting limit used during that phase of the study was 20 times greater than the MCL; so detections between the MCL (0.05 μg/l) and the reporting limit (1.0 μg/l) may have gone unnoticed. None of the 55 wells sampled were located in Wake County. EDB was also not detected during the second phase of the study that included sampling from 97 wells installed in or near areas of known pesticide use. The reporting limit for EDB from these samples ranged between 1.0 mg/l and 0.3 mg/l. Again, none of the wells sampled were located in Wake County.

Chlordane was previously detected in one CWS well above the MCL, resulting in the well being taken out-of-service. Until 1988, chlordane was used as an insecticide. No commercial uses of chlordane are currently permitted.

#### 4.2.1.6 Volatile Organic Chemicals

Water quality results for VOCs are shown in **Table 4-7**. The most recent CWS data show that out of 58 possible constituents, 26 VOCs were detected in groundwater. Only 1,2-dichloropropane was detected at concentrations exceeding the MCL of 5 μg/l. It was detected in three samples above the MCL and 14 samples total.

1,2-dichloropropane has been used as a soil fumigant, industrial solvent, additive to paint strippers, varnishes, and furniture finish removers, and a chemical intermediate. Current uses are limited to the production of other chemicals. Its use as a soil fumigant was discontinued prior to 1984 (Wade et al, 1997). **Figure 4-10** shows the location of CWSs where 1,2-dichloropropane has been detected since 1991. These locations are most likely attributed to its past use as a soil fumigant in tobacco farming.

The most commonly detected VOCs are the disinfection byproducts (DBPs) bromoform, chloroform, chlorodibromomethane and bromodichloromethane. These constituents are not considered to be naturally present in groundwater but result from reaction of naturally occurring organic compounds with disinfecting agents such as chlorine. Petroleum compounds benzene, toluene, ethylbenzene, and xylene (BTEX) are

**Table 4-6**
**Summary of Synthetic Organic Chemicals in Groundwater Samples from Wake County CWSs**

| Constituent | Units | Detection Limit | Number of Analyses | Number of Detections | Percent Detections | Number of Detections Above the MCL | Minimum Detection | Maximum Detection |
|---|---|---|---|---|---|---|---|---|
| 2,4,5-tp (silvex) | μg/L | 0.02 | 624 | 0 | 0 | 0 | -- | -- |
| 2,4-d | μg/L | 0.01 | 624 | 5 | <1 | 0 | 0.0003 | 0.002 |
| 3-hydroxycarbofuran | μg/L | 0.4 | 583 | 0 | 0 | N/A | -- | -- |
| alachlor | μg/L | 0.02 | 594 | 0 | 0 | 0 | -- | -- |
| aldicarb | μg/L | 0.05 | 583 | 0 | 0 | N/A | -- | -- |
| aldicarb sulfone | μg/L | 0.08 | 584 | 0 | 0 | N/A | -- | -- |
| aldicarb sulfoxide | μg/L | 0.05 | 584 | 0 | 0 | N/A | -- | -- |
| aldrin | μg/L | 0.02 | 594 | 0 | 0 | N/A | -- | -- |
| atrazine | μg/L | 0.01 | 585 | 0 | 0 | 0 | -- | -- |
| benzo(a)pyrene | μg/L | 0.002 | 584 | 0 | 0 | 0 | -- | -- |
| butachlor | μg/L | 0.8 | 585 | 0 | 0 | N/A | -- | -- |
| carbaryl | μg/L | 0.4 | 584 | 0 | 0 | N/A | -- | -- |
| carbofuran | μg/L | 0.09 | 583 | 0 | 0 | 0 | -- | -- |
| chlordane | μg/L | 0.02 | 594 | 0 | 0 | 0 | -- | -- |
| dalapon | μg/L | 0.1 | 624 | 6 | 1 | 0 | 0.0011 | 0.023 |
| dbcp | μg/L | 0.002 | 623 | 0 | 0 | 0 | -- | -- |
| di(2-ethylhexyl)adipate | μg/L | 0.6 | 598 | 5 | <1 | 0 | 0.0007037 | 0.00261 |
| di(2-ethylhexyl)pthalate | μg/L | 0.132 | 598 | 3 | <1 | 0 | 0.00143 | 0.00197 |
| dicamba | μg/L | 0.1 | 623 | 2 | <1 | N/A | 0.001 | 0.0043 |
| dieldrin | μg/L | 0.02 | 596 | 7 | 1 | N/A | 0.000009 | 0.000048 |
| dinoseb | μg/L | 0.2 | 624 | 0 | 0 | 0 | -- | -- |
| diquat | μg/L | 0.001 | 16 | 0 | 0 | N/A | -- | -- |
| endothal | μg/L | 0.001 | 17 | 0 | 0 | N/A | -- | -- |
| endrin | μg/L | 0.001 | 594 | 0 | 0 | 0 | -- | -- |
| ethylene dibromide (edb) | μg/L | 0.001 | 629 | 1 | <1 | 0 | 0.00004 | 0.00004 |
| glyphosate | μg/L | 0.001 | 17 | 0 | 0 | N/A | -- | -- |
| heptachlor | μg/L | 0.004 | 595 | 0 | 0 | 0 | -- | -- |
| heptachlor epoxide | μg/L | 0.002 | 595 | 1 | <1 | 0 | 0.00002 | 0.00002 |
| hexachlorobenzene | μg/L | 0.01 | 592 | 0 | 0 | 0 | -- | -- |
| hexachlorocyclopentadiene | μg/L | 0.01 | 596 | 0 | 0 | 0 | -- | -- |
| lindane | μg/L | 0.002 | 595 | 0 | 0 | 0 | -- | -- |
| metalochlor | μg/L | 0.08 | 585 | 0 | 0 | N/A | -- | -- |
| methomyl | μg/L | 0.4 | 584 | 0 | 0 | N/A | -- | -- |
| methoxychlor | μg/L | 0.1 | 595 | 0 | 0 | 0 | -- | -- |
| metribuzin | μg/L | 0.08 | 584 | 0 | 0 | N/A | -- | -- |
| oxamyl(vydate) | μg/L | 0.2 | 583 | 0 | 0 | 0 | -- | -- |
| pcb's | μg/L | 0.01 | 593 | 0 | 0 | 0 | -- | -- |
| pentachlorophenol | μg/L | 0.004 | 622 | 0 | 0 | 0 | -- | -- |
| picloram | μg/L | 0.1 | 624 | 0 | 0 | 0 | -- | -- |
| propachlor | μg/L | 0.6 | 584 | 0 | 0 | N/A | -- | -- |
| simazine | μg/L | 0.007 | 585 | 0 | 0 | 0 | -- | -- |
| toxaphene | μg/L | 0.001 | 593 | 1 | <1 | 0 | 0.0027 | 0.0027 |

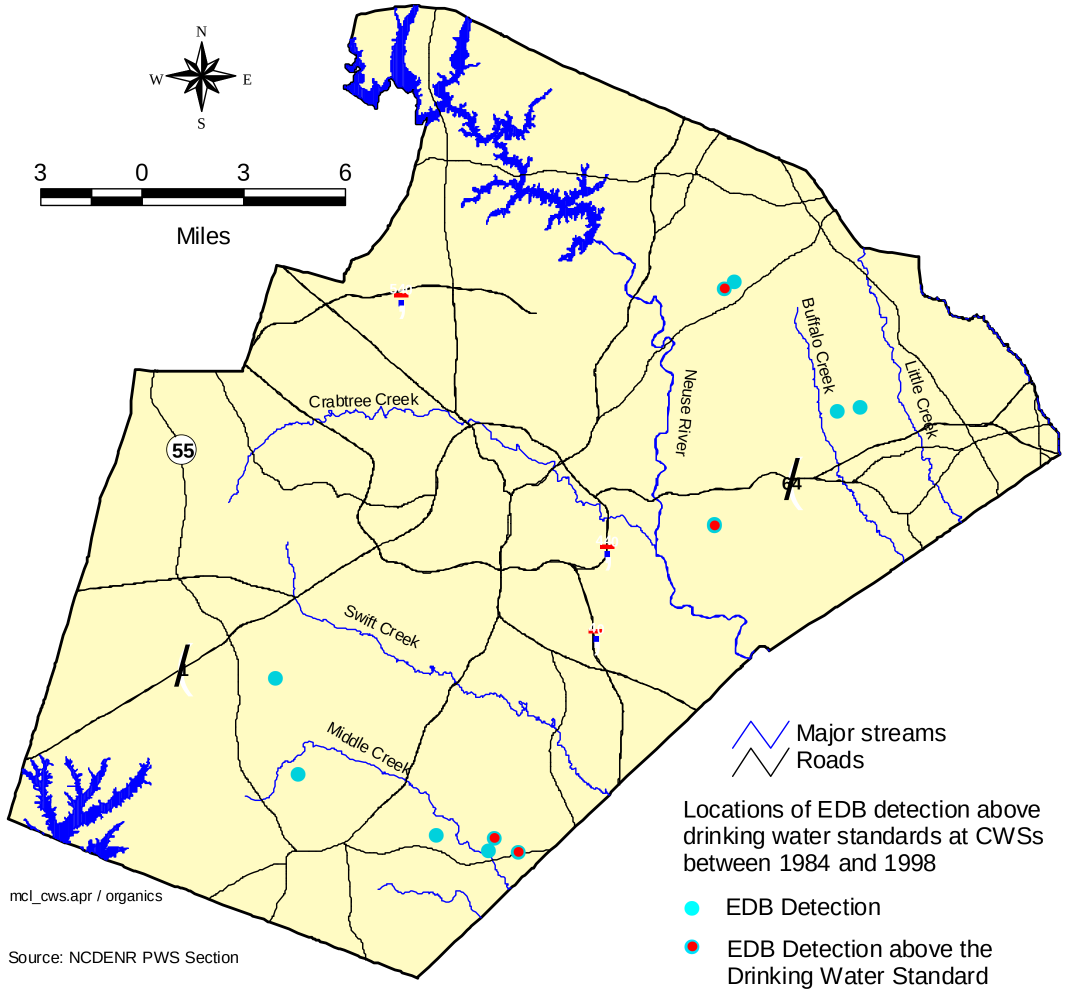



**Figure 4-9**
**Locations of EDB Detections and Exceedances of Drinking Water Standards, 1984 - 1998**

sporadically detected in CWS samples and most occur typically well below their MCL. In the latest sample set, benzene, toluene, ethylbenzene, and xylene were detected one, four, 10 and 20 times, respectively, out of a total of approximately 700 samples. Chlorinated solvents are also infrequently detected and most often at levels below their MCL. Trichloroethylene and tetrachloroethylene, two of the most common chlorinated solvents, were detected two and five times, respectively, out of approximately 700 samples. In each instance, the detections were below the MCL.

Since the VOCs are man-made chemicals, their detection generally indicates that a pollution incident has occurred in the vicinity of the well. The pollution may be due to the nearby presence of a leaking underground storage tank (UST), spill, unlined landfill, or other disposal site.

### 4.2.2 Non-Community Water Systems

Historical water quality data for the NCWSs was obtained from the PWS Section to characterize further nutrient levels in groundwater. Anecdotal information suggested that NCWS wells might be better indicators of nitrate contamination than CWS wells, which are typically subject to a more rigorous site selection process.

**Table 4-7**
**Summary of Volatile Organic Chemicals in Groundwater Samples from Wake County CWSs**

| Constituent | Units | Detection Limit | Number of Analyses | Number of Detections | Percent Detections | Number of Detections Above the MCL | Minimum Detection | Maximum Detection |
|---|---|---|---|---|---|---|---|---|
| 1,1,1,2-tetrachloroethane | µg/L | 0.05 | 695 | 1 | <1 | N/A | 0.00133 | 0.00133 |
| 1,1,1-trichloroethane | µg/L | 0.05 | 711 | 1 | <1 | 0 | 0.0008 | 0.0008 |
| 1,1,2,2-tetrachloroethane | µg/L | 0.05 | 695 | 0 | 0 | N/A | -- | -- |
| 1,1,2-trichloroethane | µg/L | 0.05 | 695 | 0 | 0 | 0 | -- | -- |
| 1,1-dichloroethane | µg/L | 0.05 | 695 | 2 | <1 | N/A | 0.0005 | 0.0014 |
| 1,1-dichloroethylene | µg/L | 0.05 | 711 | 2 | <1 | 0 | 0.0006 | 0.0009 |
| 1,1-dichloropropene | µg/L | 0.05 | 695 | 1 | <1 | N/A | 0.0012 | 0.0012 |
| 1,2,3-trichlorobenzene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| 1,2,3-trichloropropane | µg/L | 0.05 | 695 | 2 | <1 | N/A | 0.00078 | 0.0008 |
| 1,2,4-trichlorobenzyne | µg/L | 0.05 | 689 | 0 | 0 | 0 | -- | -- |
| 1,2,4-trimethlbenzene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| 1,2-dichloroethane | µg/L | 0.05 | 711 | 1 | <1 | 0 | 0.0006 | 0.0006 |
| 1,2-dichloropropane | µg/L | 0.05 | 695 | 14 | 2 | 3 | 0.0006 | 0.0064 |
| 1,3,5-trimethylbenzene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| 1,3-dichloropropane | µg/L | 0.05 | 695 | 0 | 0 | N/A | -- | -- |
| 1,3-dichloropropene | µg/L | 0.05 | 686 | 0 | 0 | N/A | -- | -- |
| 2,2-dichloropropane | µg/L | 0.05 | 695 | 0 | 0 | N/A | -- | -- |
| benzene | µg/L | 0.05 | 710 | 1 | <1 | 0 | 0.0014 | 0.0014 |
| bromobenzene | µg/L | 0.05 | 694 | 0 | 0 | N/A | -- | -- |
| bromochloromethane | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| bromodichloromethane | µg/L | 0.1 | 695 | 33 | 5 | N/A | 0.0005 | 0.018 |
| bromoform | µg/L | 0.1 | 695 | 18 | 3 | N/A | 0.0006 | 0.012 |
| bromomethane | µg/L | 0.05 | 695 | 0 | 0 | N/A | -- | -- |
| carbon tetrachloride | µg/L | 0.05 | 711 | 0 | 0 | 0 | -- | -- |
| chlorobenzene | µg/L | 0.05 | 695 | 1 | <1 | 0 | 0.0101 | 0.0101 |
| chlorodibromomethane | µg/L | 0.1 | 695 | 44 | 6 | N/A | 0.0005 | 0.0053 |
| chloroethane | µg/L | 0.05 | 695 | 0 | 0 | N/A | -- | -- |
| chloroform | µg/L | 0.1 | 695 | 91 | 13 | N/A | 0.0005 | 0.072 |
| chloromethane | µg/L | 0.05 | 695 | 16 | 2 | N/A | 0.0005 | 0.0091 |
| cis-1,-dichloroethylene | µg/L | 0.05 | 695 | 4 | <1 | 0 | 0.0006 | 0.0012 |
| dibromomethane | µg/L | 0.05 | 695 | 0 | 0 | N/A | -- | -- |
| dichlorodifluoromethane | µg/L | 0.05 | 693 | 1 | <1 | N/A | 0.0005 | 0.0005 |
| dichloromethane | µg/L | 0.05 | 695 | 1 | <1 | 0 | 0.0006 | 0.0006 |
| ethylbenzene | µg/L | 0.05 | 694 | 10 | 1 | 0 | 0.0005 | 0.0132 |
| flourotrichloromethane | µg/L | 0.05 | 693 | 2 | <1 | N/A | 0.0005 | 0.0026 |
| hexachlorobutadiene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| isopropylbenzene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |

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**Table 4-7 (continued)**
**Summary of Volatile Organic Chemicals in Groundwater Samples from Wake County CWSs**

| Constituent | Units | Detection Limit | Number of Analyses | Number of Detections | Percent Detections | Number of Detections Above the MCL | Minimum Detection | Maximum Detection |
|---|---|---|---|---|---|---|---|---|
| m-dichlorobenzene | µg/L | 0.05 | 695 | 0 | 0 | N/A | -- | -- |
| naphthalene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| n-butylbenzene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| n-propylbenzene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| o-chlorotoluene | µg/L | 0.05 | 695 | 0 | 0 | N/A | -- | -- |
| o-dichlorobenzene | µg/L | 0.05 | 695 | 0 | 0 | 0 | -- | -- |
| p-chlorotoluene | µg/L | 0.05 | 695 | 0 | 0 | N/A | -- | -- |
| p-dichlorobenzene | µg/L | 0.05 | 711 | 1 | <1 | 0 | 0.0019 | 0.0019 |
| p-isopropyltoluene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| sec-butylbenzene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| styrene | µg/L | 0.05 | 695 | 1 | <1 | 0 | 0.0196 | 0.0196 |
| tert-butylbenzene | µg/L | 0.05 | 693 | 0 | 0 | N/A | -- | -- |
| tetrachloroethylene | µg/L | 0.05 | 695 | 5 | <1 | 0 | 0.0006 | 0.0017 |
| toluene | µg/L | 0.05 | 694 | 4 | <1 | 0 | 0.0011 | 0.0012 |
| trans-1,2,-dichloroethylene | µg/L | 0.05 | 695 | 0 | 0 | 0 | -- | -- |
| trichloroethylene | µg/L | 0.05 | 711 | 2 | <1 | 0 | 0.0007 | 0.0036 |
| vinyl chloride | µg/L | 0.05 | 709 | 0 | 0 | 0 | -- | -- |
| xylenes (total) | µg/L | 0.05 | 686 | 20 | 3 | 0 | 0.0006 | 0.015 |

**Table 4-8** presents a summary of nitrate and nitrite in groundwater samples from NCWS wells between the period April 1993 and March 2003. Nitrate was detected in 72 percent of samples from NCWSs compared to 58 percent from CWSs. During the 10 year period, nitrate was detected above the MCL in 10 samples from three NCWSs. Nitrite was detected at the same frequency in NCWSs as from CWSs. No detections of nitrite above the MCL were reported

### 4.2.3 Domestic Water Wells

Data characterizing water quality from domestic wells were provided by the North Carolina Department of Health and Human Services (NCDHHS) State Laboratory of Public Health database. The State Laboratory database contains a total of 10,051 records from samples collected between 1998 and 2002. Sample results were available for inorganics (representing approximately 600 to 800 samples) and organic pesticides (representing 27 samples). Fifteen organic pesticides were analyzed for including heptachlor, bifenthrin, permethrin, diazinon, alachlor, cypermethrin, heptachlor epoxide, endrin, methoxychlor, chlorpyrifos, fenvalerate, chlordane, toxaphene, lindane, and dieldrin.

Water quality samples submitted to the State Laboratory were collected by the well owner or a member of the Wake County Department of Environmental Services Well Program Unit. The majority of samples were collected from a faucet or other source inside the home. A smaller percentage of samples was collected directly from the wellhead. The samples are generally considered representative of raw groundwater quality since treatment of groundwater from domestic wells (other than disinfection of the well following installation) typically is not performed.

The data presented in **Tables 4-9** through **4-11** are grouped into the categories of field measurements, major ions, trace elements, and organic

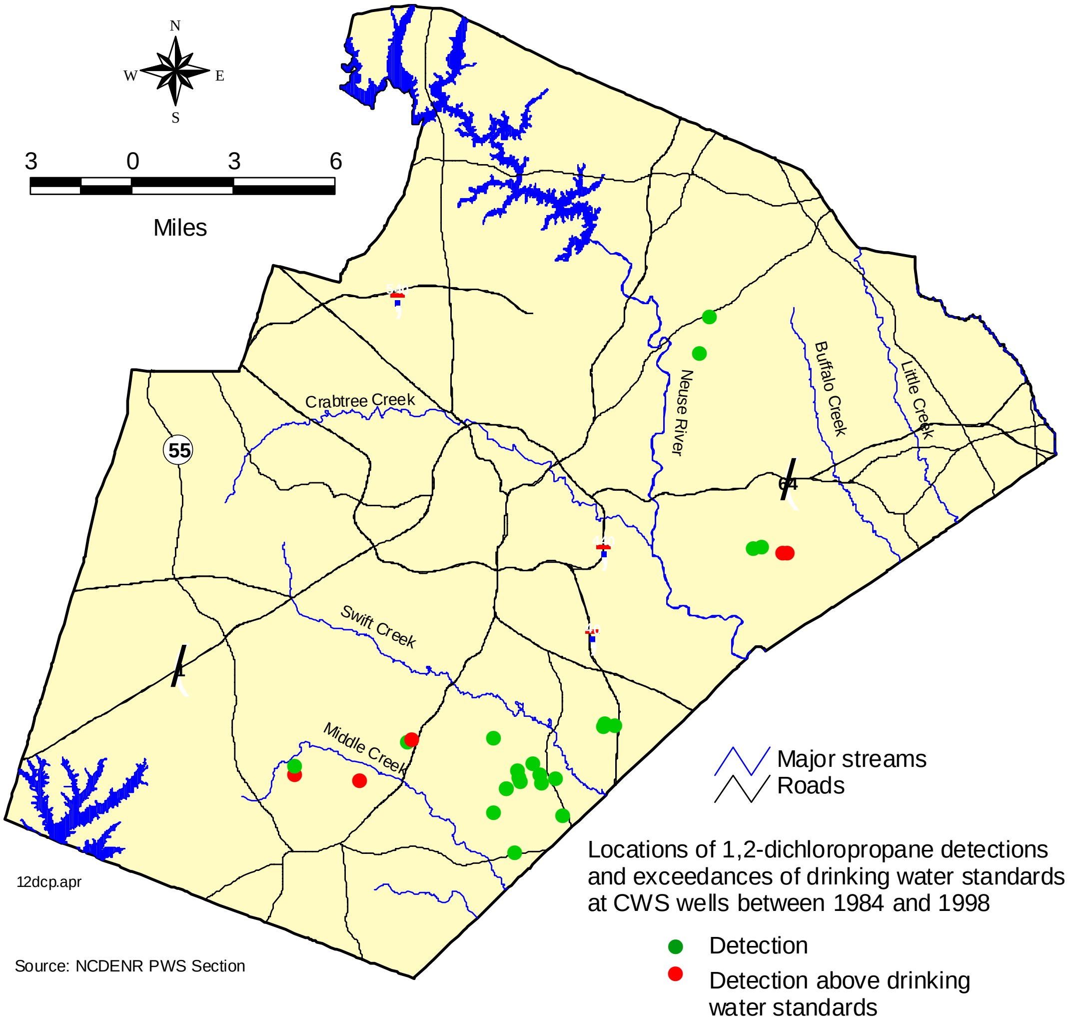



**Figure 4-10**
**Locations of 1,2-Dichloropropane Detections and Exceedances of Drinking Water Standards, 1984 - 1998**

compounds. Concentrations in groundwater are expressed using the median, mean, minimum and maximum. The available data were also compared to MCLs, where appropriate, to provide an indication of degraded water quality.

### 4.2.3.1 Field Measurements

Measuring physical properties and water quality constituents in the field can provide a broad indication of water quality conditions. pH, hardness, and alkalinity results are presented in **Table 4-9**. The median pH from water collected from domestic wells was 7.0, with the minimum and maximum pH being 4.6 and 10.3, respectively.

Hardness in natural waters is caused by the presence of divalent metallic cations. The principal hardness-causing cations are calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), strontium ($Sr^{2+}$), ferrous iron ($Fe^{2+}$), and manganous ($Mn^{2+}$) ions. Because the most prevalent of these species are $Ca^{2+}$ and $Mg^{2+}$, total hardness is typically defined as the sum of the concentrations of these two elements and is usually expressed in terms of milligrams per liter as calcium carbonate (mg/l as $CaCO_3$). The median hardness in Wake County groundwater was 31.0 mg/l as $CaCO_3$.

Alkalinity is a measure of the ability of water to

**Table 4-8**
**Summary of Nutrients in Groundwater Samples from Wake County NCWSs**

| Constituent | Units | Detection Limit | Number of Analyses | Number of Detections | Percent Detections | Number of Detections Above the MCL | Minimum Detection | Maximum Detection |
|---|---|---|---|---|---|---|---|---|
| nitrate | mg/L | 1 | 1223 | 876 | 72 | 10 | 0.02 | 55.2 |
| nitrite | mg/L | 0.1 | 397 | 12 | 11 | 0 | 0.01 | 0.22 |

neutralize acids and bases. Although many compounds may contribute to the alkalinity of water, most of it is caused by three major compound classes. These include hydroxide ($OH^-$), carbonates ($CO_3^{2-}$), and bicarbonates ($HCO_3^-$). For most practical purposes alkalinity due to other compounds is insignificant and may be ignored. The median alkalinity in the Wake County groundwater was 38.0 mg/l as $CaCO_3$.

#### 4.2.3.2 Major Ions

Major ions dissolved in groundwater can be used to describe its general chemical composition. These major ions include cations and anions. The most common cations in ground water are calcium, magnesium, potassium and sodium. The most common anions are bicarbonate, sulfate, chloride, nitrate and fluoride. Results of major ions analyzed in domestic wells are presented in **Table 4-10**.

Presence of calcium and magnesium in groundwater leads to hardness. Hardness in water is generally considered undesirable because hard water consumes soap before it lathers. Hard water also results in the formation of scales in pipes. The median concentrations of calcium and magnesium in groundwater from domestic wells were 8.3 mg/l and 2.5 mg/l, respectively.

#### 4.2.3.3 Trace Elements and Organic Pesticides

With the exceptions of iron and manganese trace elements were detected infrequently, as shown in **Table 4-11**. Detections above the MCL were observed for arsenic (nine out of 670 analyses, in concentrations up to 220 mg/l), iron (146 out of 667 analyses, in concentrations up to 42,000 mg/l), and manganese (151 out of 672 analyses, in concentrations up to 25,710 mg/l). Among the organic compounds analyzed only chlordane, dieldrin, and heptachlor epoxide were detected in 11, 19, and eight percent of analyses, respectively. None of these compounds were detected above MCLs.

## 4.3 Contaminant Source Inventory

The identification of known and potential contaminant sources is an important component of protecting groundwater resources. Both known and potential contaminant sources in Wake County were identified from databases maintained by the NCDENR Division of Water Quality Groundwater Section; the Division of Waste Management's UST, Solid Waste, Superfund, and Hazardous Waste Sections; and the NCCGIA.

The NCDENR Incident Management Database[4], maintained by the USTand Groundwater Sections, contains information pertaining to reported incidents of groundwater and soil contamination statewide. Information contained in the database includes ownership, operation type, pollution source, pollutant type, location, and setting (e.g. residential, industrial, rural, or urban). The database was queried to select only those incidents that occurred in Wake County. A GIS layer was then created to map the locations of the incidents. **Figure 4-11** shows the locations of potential

[4] The Incident Management Database is classified as a "working database", subject the normal inconsistencies and errors associated with a database that is changed, manipulated and updated frequently. NCDENR provides access to the database with the understanding that the data is provided "as is".

**Table 4-9**
**Summary of Field Measuremets for Domestic Wells in Wake County**

| Chemical Constituent | Units | Number of Analyses | Minimum Detection | Maximum Detection | Mean | Median | Standard Deviation |
|---|---|---|---|---|---|---|---|
| pH, field | standard units | 665 | 4.6 | 10.3 | 7.0 | 7.0 | 0.7 |
| Hardness | mg/L as $CaCO_3$ | 667 | 4.0 | 1,125 | 52.9 | 31.0 | 82.0 |
| Alkalinity | mg/L as $CaCO_3$ | 664 | 2.0 | 280 | 56.3 | 38.0 | 44.6 |

**Table 4-10**
**Summary of Major Ions in Domestic Wells in Wake County**

| Chemical Constituent | Units | Number of Analyses | Number of Detections | Percent Detections | Number of Detections Above the MCL | Minimum Detection | Maximum Detection | Mean | Median | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|
| Calcium, dissolved | mg/L | 667 | 634 | 95 | N/A | 0.5 | 411.3 | 15.2 | 8.3 | 28.3 |
| Magnesium, dissolved | mg/L | 667 | 637 | 96 | N/A | 0.0 | 50.3 | 3.7 | 2.5 | 4.3 |
| Sodium, dissolved | mg/L | 5 | 5 | 100 | N/A | 8.0 | 50 | 17.8 | 11.0 | 18.0 |
| Sulfate, dissolved | mg/L | 5 | 5 | 100 | 3 | 6.0 | 1,100 | 462 | 472 | 462.8 |
| Chloride, dissolved | mg/L | 664 | 374 | 56 | N/A | 2.0 | 863 | 18.6 | 11.0 | 53.1 |
| Fluoride, dissolved | mg/L | 673 | 300 | 45 | 1 | 0.1 | 5.5 | 0.6 | 0.5 | 0.5 |
| Silica, dissolved | mg/L | 2 | 2 | 100 | N/A | 12.0 | 18.5 | 15.3 | 15.3 | 4.6 |
| Total Solids, dissolved | mg/L | 3 | 3 | 100 | N/A | 75.0 | 113 | 87.7 | 75 | 21.9 |

**Table 4-11**
**Summary of Trace Metals, Nutrients, and Organic Pesticides in Domestic Wells in Wake County**

| Chemical Constituent | Detection Limit (μg/l) | Number of Analyses | Number of Detects | Percent Detects | Number of Detections Above the MCL or MCLG[1] | Minimum Detection (μg/l) | Maximum Detection (μg/l) |
|---|---|---|---|---|---|---|---|
| **Trace Metals and Nutrients** | | | | | | | |
| Aluminum, dissolved | NR | 2 | 2 | 100 | N/A | 10 | 30 |
| Arsenic, dissolved | 1.0 | 670 | 41 | 6 | 9 | 1.0 | 220 |
| Barium, dissolved | 10 | 62 | 11 | 18 | 0 | 10 | 50 |
| Cadmiun, dissolved | 5.0 | 66 | 0 | 0 | 0 | - | - |
| Chromium, dissolved | 10 | 66 | 1 | 2 | 0 | - | 56 |
| Copper, dissolved | 50 | 671 | 236 | 35 | N/A | 50 | 15,670 |
| Iodide, dissolved | 100 | 2 | 0 | 0 | N/A | - | - |
| Iron, dissolved | 50 | 667 | 353 | 53 | 146 | 50 | 42,000 |
| Lead, dissolved | 5.0 | 790 | 84 | 11 | N/A | 5 | 1,150 |
| Manganese, dissolved | 30 | 672 | 214 | 32 | 151 | 30 | 25,710 |
| Mercury | 0.5 | 280 | 0 | 0 | 0 | - | - |
| Nickel, dissolved | 10 | 5 | 1 | 20 | N/A | - | 50 |
| Nitrate | 1000 | 30 | 11 | 37 | 0 | 1,410 | 9,910 |
| Nitrite | 100 | 7 | 0 | 0 | 0 | - | - |
| Silver, dissolved | 50 | 63 | 0 | 0 | 0 | - | - |
| Zinc, dissolved | 50 | 670 | 303 | 45 | N/A | 50 | 19,740 |
| Selenium, dissolved | 5.0 | 59 | 0 | 0 | N/A | - | - |
| **Organic Pesticides** | | | | | | | |
| Alachlor | NR | 36 | None | 0 | 0 | - | - |
| Chlordane | NR | 36 | 4 | 11 | 0 | 1 | 0.4 |
| Chlorpyrifos | NR | 36 | None | 0 | N/A | - | - |
| Cypermethrin | NR | 36 | None | 0 | N/A | - | - |
| Diazinon | NR | 36 | None | 0 | N/A | - | - |
| Dieldrin | NR | 36 | 7 | 19 | N/A | Trace | 0.5 |
| Endrin | NR | 36 | None | 0 | 0 | - | - |
| Fenvalerate | NR | 36 | None | 0 | N/A | - | - |
| Heptachlor | NR | 36 | None | 0 | 0 | - | - |
| Heptachlor Epoxide | NR | 36 | 3 | 8 | 0 | Trace | Trace |
| Lindane | NR | 36 | None | 0 | 0 | - | - |
| Methoxychlor | NR | 36 | None | 0 | 0 | - | - |
| Permethrin | NR | 36 | None | 0 | N/A | - | - |
| Toxaphene | NR | 36 | None | 0 | 0 | - | - |

Notes:
MCLs and MCLGs are not enforceable limits for drinking water from domestic wells.
NR = Not Reported
N/A = Not Applicable

contamination from the various pollution sources identified in the database. Location information (latitude and longitude) was available for 715 of the 1,210 incidents in Wake County. The incidents do not necessarily indicate that contamination of groundwater occurred.

The rules governing construction of private and

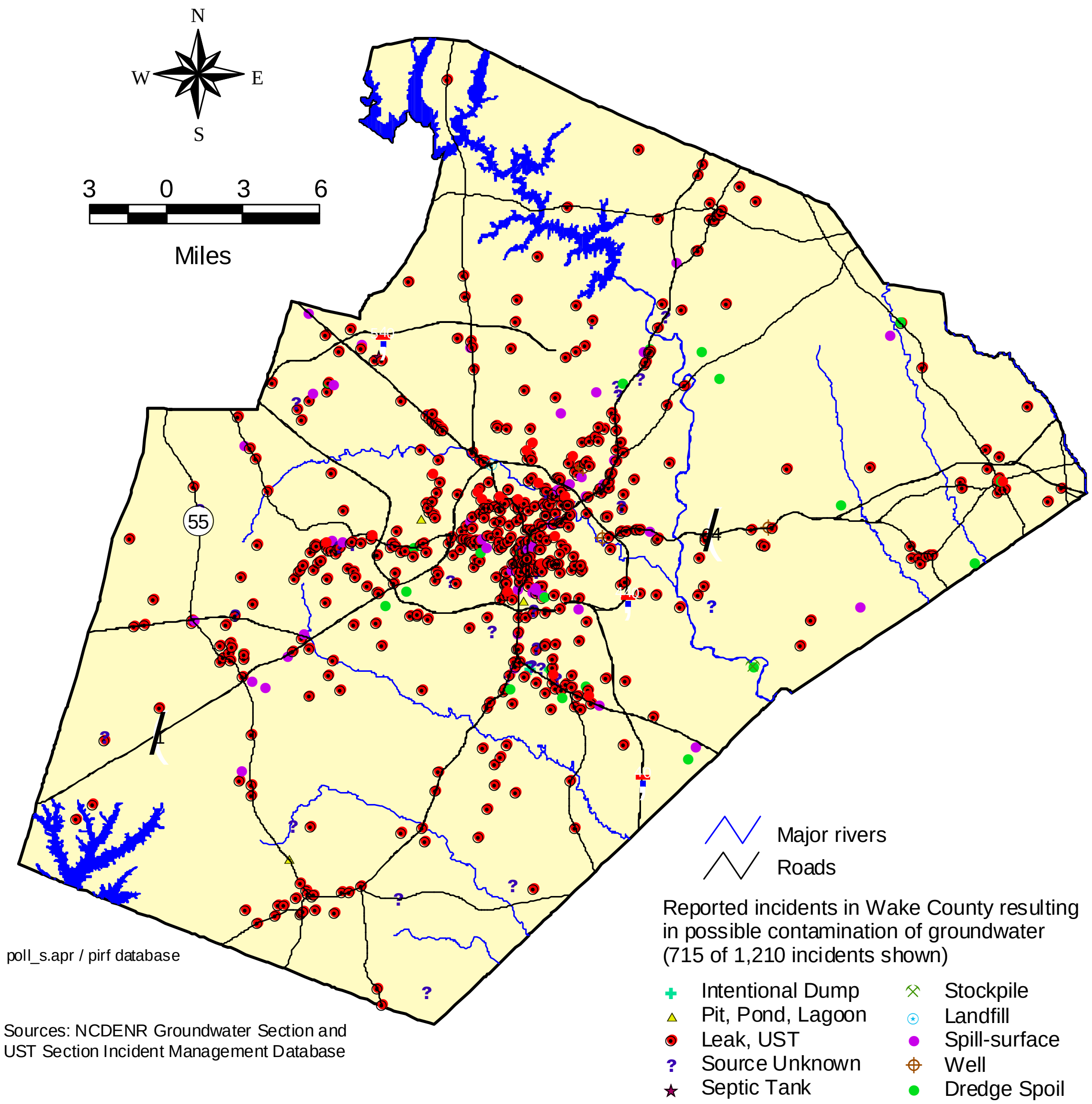



**Figure 4-11**
**Possible Pollution Sources to Groundwater in Wake County**

semi-private wells in Wake County require a horizontal separation of 100-feet from most potential sources of groundwater contamination. The Incident Management Database can be used as one means to prevent the installation of wells near potential or known sources of groundwater contamination.

The UST section maintains a database of current and former USTs located throughout the state. The database was queried to select USTs that are registered in Wake County. A GIS layer was created to map the locations of USTs, by status. **Figure 4-12** shows the locations of operational, permanently closed, and temporarily closed USTs. Location information (latitude and longitude) was available for 2,353 of the 4,725 registered USTs in Wake County. The rules governing construction of private and semi-private wells in Wake County require a horizontal separation of 100-feet from chemical or petroleum USTs without secondary

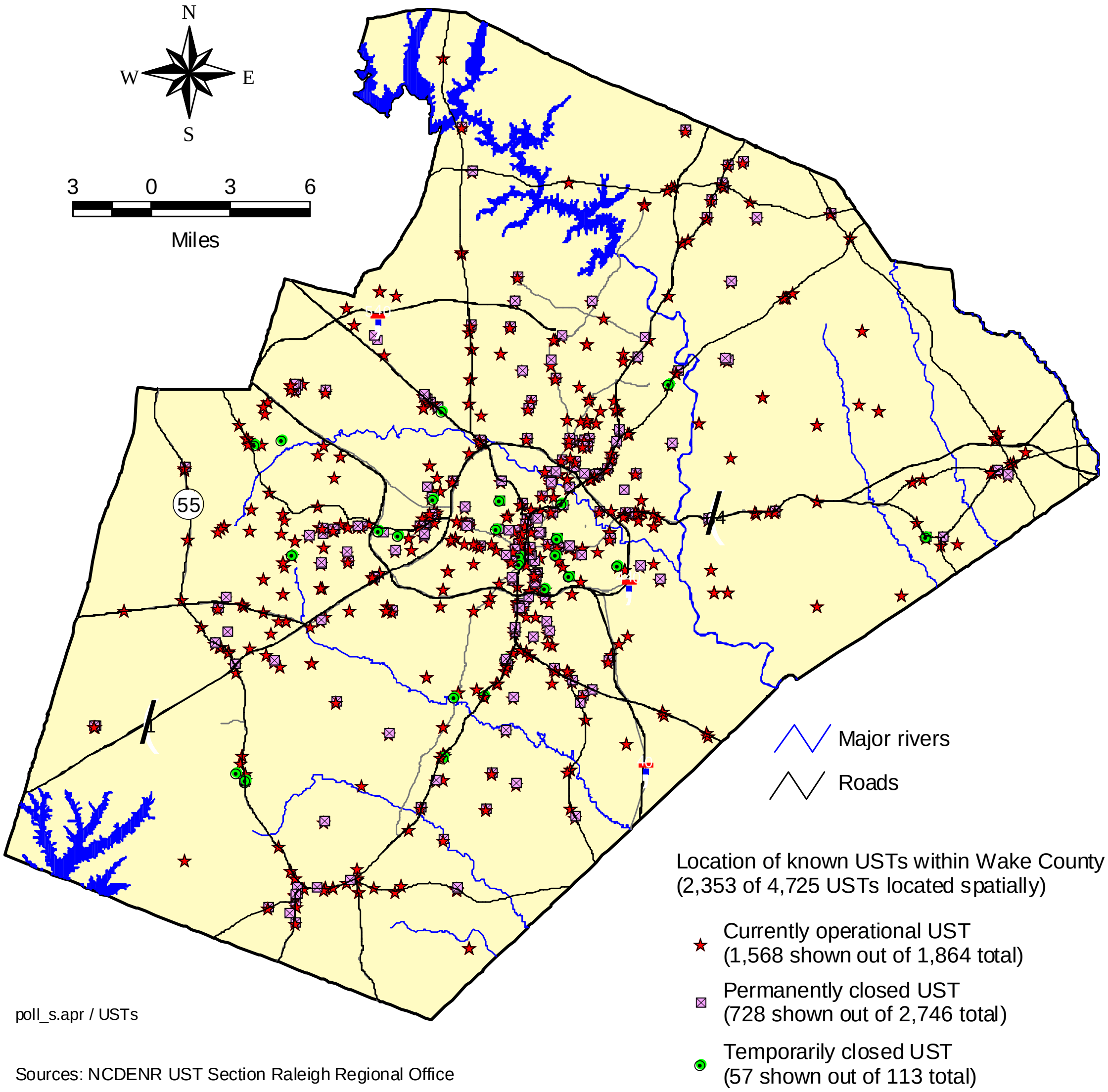



**Figure 4-12**
**Known Locations of Underground Storage Tanks in Wake County**

containment and a horizontal separation of 50-feet for those with secondary containment.

The locations of landfills, livestock operation, solid waste convenience centers and transfer stations, and uncontrolled and unregulated hazardous waste sites are shown in **Figure 4-13**. The hazardous waste sites include sites on the National Priorities List and the State Inactive Hazardous Sites List. Landfills, convenience centers, transfer stations, and other associated waste management sites are included on this map not as known sources of contamination but to identify those areas where the rules stipulating minimum horizontal separations for construction of private and semi-private wells in Wake County may apply.

The GIS layers and associated contaminant source information described above are being provided to the Wake County Department of Environmental Services Well Programs staff as a groundwater resource management tool (Appendices B and C).

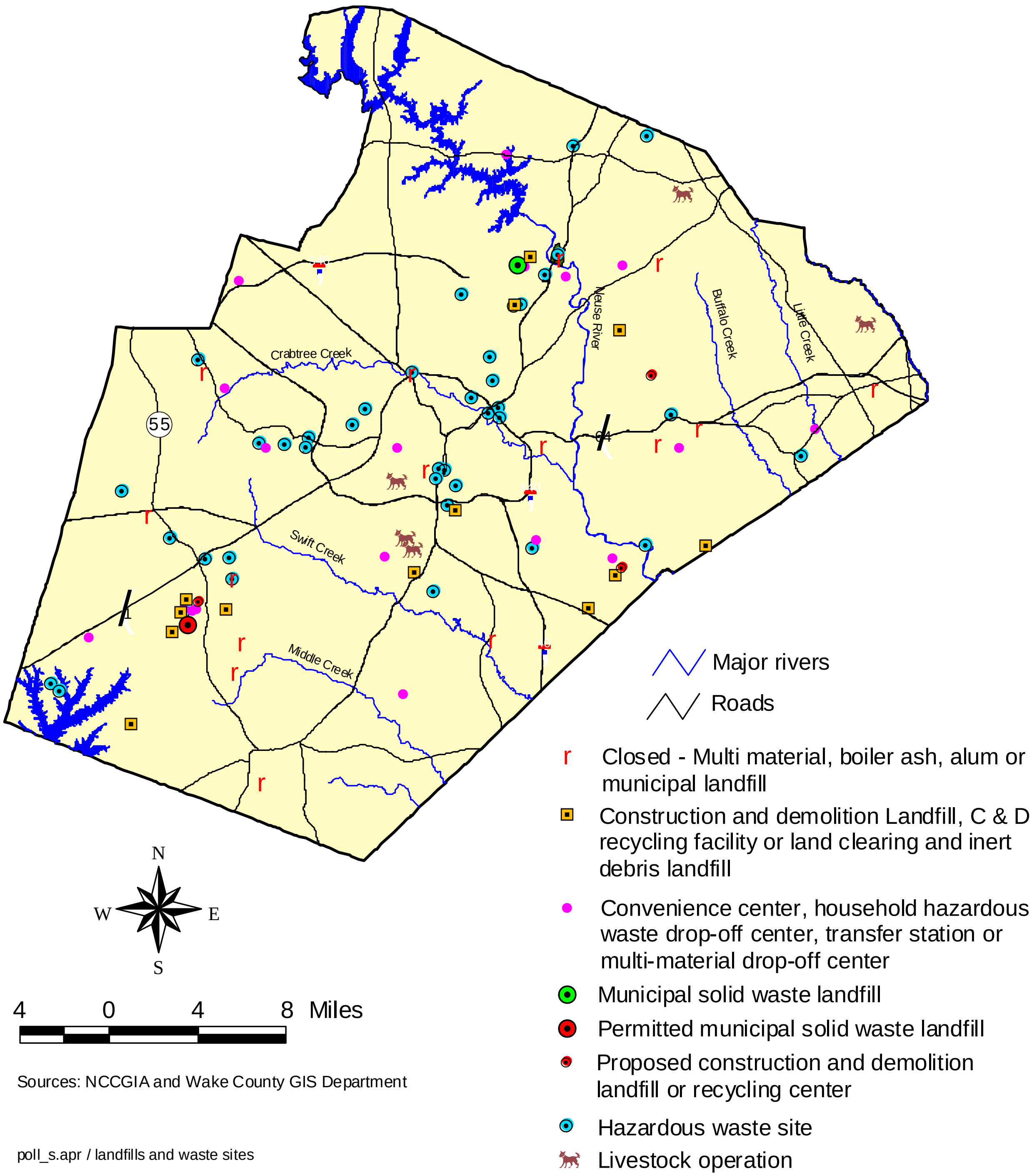



**Figure 4-13**
**Landfills, Hazardous Sites and other Facilities in Wake County**

The GIS layers and databases can be referenced to identify possible or known pollution sources when locating, permitting, or approving new wells.

## 4.4 Source Water Assessment Program

The Federal Safe Drinking Water Act (SDWA) Amendments of 1996 require that all states establish Source Water Assessment Programs (SWAP). The SWAP process is intended to allow the states to address systematically issues of potential contamination of public water supplies using existing data from established environmental programs. The basic components of the SWAP process include 1) the delineation of source water areas, 2) an inventory significant contaminants in these areas, and 3) determination of the susceptibility of each public water supply to contamination.

In North Carolina, the NCDENR PWS Section is administering the SWAP program. Source water assessments are currently being finalized for the 275 CWSs, the 206 TNCWSs, and 23 NTNCWSs in Wake County that rely solely on groundwater.

Once completed, the source water assessments are expected to provide updated information to improve the decision-making regarding Wake County's groundwater resources. The assessments should result in an increased understanding of the susceptibility of CWS wells to various types of contaminants within the different major hydrogeologic regions of the County (e.g., Coastal Plain, Triassic basin and Slate Belt). The information contained in the source water assessment reports for public groundwater supply systems in Wake County should be taken into account in making groundwater resource management decisions.

# Section 5
# Assessment of Future Conditions

As presented in Section 3, the water budget approach was used to provide a current quantitative assessment of the County's groundwater resources. Based on current conditions, net groundwater consumption in Wake County was found to represent a relatively small percentage of the water budget, which is dominated by the natural components of precipitation, ET, runoff, and baseflow.

To assess future conditions, the water budgets can be modified to determine if *projected* net groundwater consumption is significant when compared to the natural flows within the groundwater portion of the aquifer system, and if *projected* net groundwater consumption is expected to have a greater impact on stream baseflow during periods of drought.

The following sections present a discussion of future water supply trends, the approach to estimating projected water consumption, and the sustainability of Wake County's groundwater resources from both a quantity and quality standpoint.

## 5.1 Water Supply Trends

It is estimated that 141,000 Wake County residents currently rely on groundwater for drinking and other everyday uses. One-third (48,000) of that total are served by a CWS operated by HUI or Carolina Water Service. There are currently 275 CWSs in Wake County that rely solely on groundwater. The majority of the remaining 93,000 residents using groundwater are served by individual (domestic) wells. A small percentage of the 93,000 are served by a CWS operator other than HUI or Carolina Water Service.

1997 LWSPs for Raleigh, Wake Forest, Zebulon, Wendell, Garner, Fuquay-Varina, Knightdale, and Rolesville; and the 2001 Jordan Lake Water Supply Storage Allocation Applications for Cary, Apex, Holly Springs, and Morrisville, were obtained and reviewed as indicators of future water supply use in Wake County. **Table 5-1** presents the population served by each municipality for the years 2000, 2010 and 2020. With the exception of Rolesville, which uses some groundwater, all current municipal water supplies in Wake County are derived from surface water sources. Information contained in the LWSPs and the more recent Jordan Lake Water Supply Storage Allocation Applications suggest that all future sources (through at least 2020) are expected to be surface water with the exception of Rolesville.

**Table 5-1** also provides the current (2000) and projected Wake County population. The population served by surface water provided in the LWSPs is subtracted from the Wake County population to calculate the current and projected population served by groundwater.

Several observations are evident from the data presented in **Table 5-1**.

- The estimated population served by groundwater derived from the LWSP and Wake County Planning Department data for year 2000 is 15 percent lower than the 141,000 estimated in this investigation.
- The estimated population served by groundwater is expected to decline slightly by year 2010, and by 13 percent by year 2020.

Both observations can be partially explained by the fact that the LWSP future population estimates are conservative. For water supply planning purposes, the potential cost of underestimating future demand is higher than overestimating future demand. For this reason, LWSP future population and water demand estimates tend to err on the high side. For instance, population projections

**Table 5-1**
**Wake County Water Supply Trends**

| Municipality | Population 2000 | Projected Population 2010 | Projected Population 2020 |
|---|---|---|---|
| Raleigh[1] | 316,700 | 421,300 | 513,700 |
| Wake Forest[1] | 12,200 | 19,703 | 31,820 |
| Zebulon[1] | 5,121 | 6,874 | 8,594 |
| Wendell[1] | 4,210 | 4,985 | 5,902 |
| Cary/Apex[2] | 118,670 | 183,022 | 244,744 |
| Garner[1] | 21,000 | 36,000 | 62,000 |
| Fuquay-Varina[1] | 8,760 | 18,268 | 38,942 |
| Holly Springs[2] | 9,192 | 37,275 | 71,403 |
| Knightdale[1] | 4,890 | 7,726 | 11,254 |
| Morrisville[2] | 6,500 | 17,750 | 23,900 |
| Rolesville[1] | 950 | 2,000 | 4,000 |
| Total: | 508,193 | 754,903 | 1,016,259 |
| Wake County Population[3]: | 627,846 | 873,725 | 1,120,309 |
| Difference (Population Served by Groundwater): | 119,653 | 118,822 | 104,050 |

Sources: [1] – 1997 LWSP; [2] – 2001 Jordan Lake Water Supply Storage Allocation Application; [3] – Wake County Planning Department.

***Note:*** Other data can be used to arrive at different estimates of the future groundwater supply demand in Wake County. Please refer to Section 5.1.4.

provided by the Planning Departments of Raleigh and Fuquay-Varina forecast their 2020 populations at 494,311 and 25,188, or 4 and 35 percent lower than that estimated in the 1997 LWSPs, respectively. LWSP projections also tend to use the most conservative estimates of demand to strengthen their case when applying for State approval of water supply allocations.

Based on this information, even if the assumption is made that the population projections in the LWSPs are conservative by 10 to 15 percent, the population served by groundwater would be expected to decline, or remain flat through 2020. For the population served by groundwater to decline, existing users must convert from a domestic well or CWS to a surface water source at a faster rate than new wells are built or new CWSs are established. The following sections present the available information with respect to each of these trends.

### 5.1.1 Conversion from a Domestic Well or CWS to a Surface Water Supply

Existing groundwater users may be converted to a municipally-supplied surface water source after a municipality annexes their property. According to the Wake County Land Use Plan, parcels that are brought into a municipality's extraterritorial jurisdiction (ETJ) should be annexed (i.e. provided municipal water and sewer service) within five years of the ETJ extension.

Wake County's twelve municipalities follow different guidelines for providing water and sewer service once a property has been annexed. For example, the Town of Wake Forest generally requires that all annexed properties with nearby municipal water and sewer lines connect to the municipal water and sewer service. Wells must be disconnected and abandoned. The City of Raleigh will allow the homeowner of an annexed property to continue using the well for drinking and other purposes, unless there is a problem with water quality. Some of the policies and/or guidelines established by each municipality are presented in **Table 5-2**. The information presented in the table is based on conversations with municipal engineering, public works, or planning department staff. Since the municipalities do not routinely track the number of properties that convert from a well or CWS to municipal water, it is not possible

Table 5-2
Municipal Policies or Guidelines Regarding Wells and Onsite Wastewater Systems of Annexed Properties

| Municipality | **Policies or Guidelines Concerning Use of Wells and Onsite Wastewater Systems** |
|---|---|
| **Apex** *(Source: Public Works)* | ■ Voluntary annexations are typically for the purpose of connecting to municipal water and sewer.<br>■ Generally, do not annex properties connected to CWSs using groundwater.<br>■ Involuntary annexations are not required to connect to municipal water and sewer as long as the existing well and onsite wastewater system (OWS) are functional.<br>■ If a developed property is annexed, it can continue to use OWS if connected to municipal water, but cannot use a well if connected to municipal sewer.<br>■ Once connected to municipal water, the well must be disconnected from the house, but does not have to be abandoned. |
| **Cary** *(Source: Planning Department, Engineering Department, Town of Cary Policy Statement 23)* | ■ Voluntary annexations are required to connect to the municipal water and sewer.<br>■ Involuntary annexations are not required to connect to municipal water and sewer as long as the existing well and OWS are functional.<br>■ Purchased one Heater Utilities, Inc. CWS since 2000, and provided municipal water and sewer to those properties.<br>■ If improvements to a well or OWS are needed, connection to municipal water and sewer is required.<br>■ Once connected to municipal water, the well must be disconnected from the house, but does not have to be abandoned. |
| **Fuquay-Varina** *(Source: Planning Department)* | ■ Voluntary annexations are not required to connect to municipal water and sewer.<br>■ Involuntary annexations are not required to connect to municipal water and sewer as long as the existing well and OWS are functional.<br>■ If a developed property is annexed, it can continue to use OWS if connected to municipal water, but cannot use a well if connected to the sewer.<br>■ Once connected to municipal water, the well must be disconnected from the house, but does not have to be abandoned. |
| **Holly Springs** *(Source: Engineering Department)* | ■ Once connected to municipal water, the well must be disconnected from the house, but does not have to be abandoned if located on the opposite side of the building from the public water service connection.<br>■ Town policy stipulates that irrigation wells are subject to the Town's seasonal conservation measures. |
| **Knightdale** *(Source: Town website)* | ■ Voluntary annexations are typically for the purpose of connecting to municipal water and sewer.<br>■ Once connected to municipal water, the well must be disconnected from the house, but does not have to be abandoned. |
| **Morrisville** *(Source: Engineering Department)* | ■ Annexations do not require connection to municipal water and sewer.<br>■ Typically do not annex properties connected to CWSs using groundwater. |
| **Raleigh, Garner and Rolesville** *(Source: Raleigh Planning & Public Works Departments; Rolesville Town Manager)* | ■ The City of Raleigh will provide municipal water to properties within its jurisdiction that are served by CWSs on groundwater, if there is a water quality concern.<br>■ Annexed properties with wells are not required to connect unless a water quality problem is apparent.<br>■ Once connected to municipal water, the well must be disconnected from the house, but does not have to be abandoned. |
| **Wake Forest** *(Source: Engineering Department)* | ■ All properties with nearby municipal water and sewer service must connect.<br>■ Isolated areas have been provided municipal water but not sewer (e.g. Jones Dairy Farm).<br>■ Once connected to municipal water, a well must be abandoned. |
| **Wendell** *(Source: Planning Department)* | ■ Residents in jurisdiction must petition for annexation before connecting to municipal water and sewer.<br>■ Some properties have only been provided municipal water (and still maintain an OWS); some properties have only been provided municipal sewer (and still maintain a well).<br>■ Once connected to municipal water, the well must be disconnected from the house. Consideration for keeping the well for other purposes is on a case-by-case basis. |
| **Zebulon** *(Source: Public Works)* | ■ All properties with nearby municipal water and sewer service must connect.<br>■ Several wells within town limits are still used for drinking water supply (grandfathered).<br>■ Some properties have only been provided municipal water (and still maintain an OWS); some properties have only been provided municipal sewer (and still maintain a well).<br>■ Once connected to municipal water, the well must be disconnected from the house, but does not have to be abandoned. |

to estimate the number of properties that convert on an annual basis.

HUI operates CWSs that serve approximately 90 percent of all Wake County residents that receive their water from CWSs. Expansion of corporate limits generally occurs around these systems, leaving them intact. Some CWSs (owned and operated by purveyors other than HUI) that are within corporate limits or ETJs, have been abandoned, and the residents have been connected to municipal water due to groundwater quality concerns. A recent example of this is the Neuse Crossing subdivision, which was connected to the City of Raleigh water system due to degraded water quality associated with elevated iron and manganese levels. However, for the most part, the recent trend in Wake County has been for the continued use of CWSs, even though corporate limits may have expanded around them.

The locations of CWS wells with respect to current municipal limits and ETJs are shown in **Figure 5-1**. Approximately 80 of the 275 CWSs have wells within an ETJ. If the current trend continues, the majority of these 80 CWSs will remain, even as municipal water and sewer service is provided to areas surrounding the CWS service area.

### 5.1.2 New CWSs and Expansion of Existing CWSs

The number of Wake County residents served by CWSs increases as new systems are built and existing systems are expanded. Data provided by HUI show that, since 1995, 52 new HUI-owned CWSs representing 2,158 new connections were added (**Table 5-3**). Also since 1995, an additional 3,438 connections were added as a result of the expansion of existing CWSs. Assuming an average of 2.75 people per connection, the total number of new residents served by HUI-owned systems increased by approximately 15,400 between 1995 and the end of 2002. The average increase during the period was just under 2,000 persons per year. In recent years, HUI has accounted for over 90 percent of the CWS growth in Wake County; therefore, the figures presented above generally reflect the total growth of CWSs (Strickler, 2003).

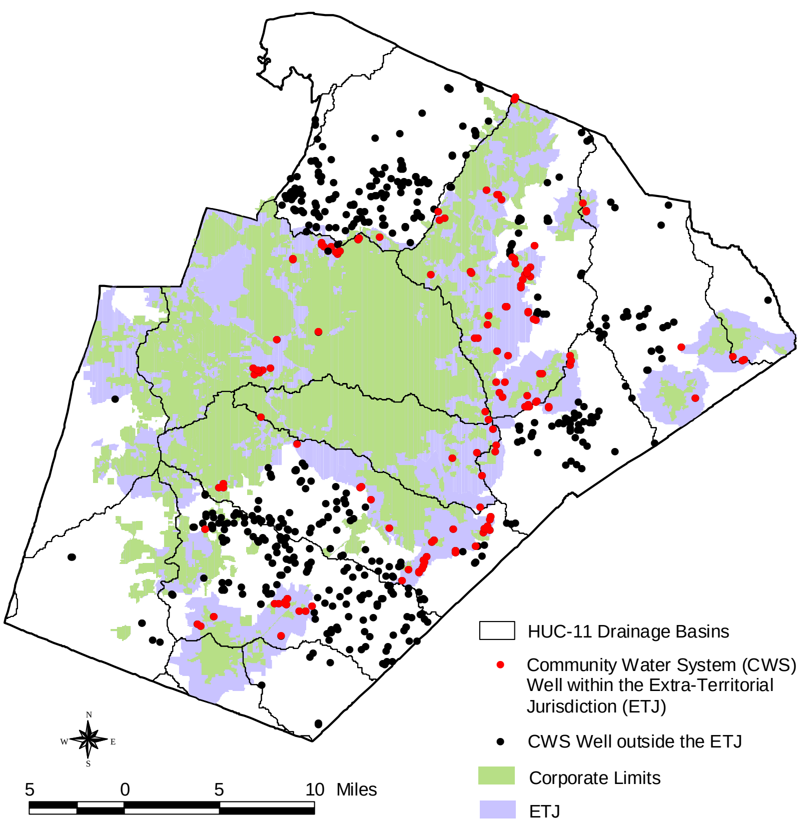



**Figure 5-1**
**Community Water System Well Locations**

### 5.1.3 New Domestic Wells

Data from the Wake County Department of Environmental Services indicate that between 550 to 800 new domestic wells have been constructed annually, since the mid-1990's. Assuming an average of 2.75 people per well, the total number of residents served by



CDM

**Table 5-3**
**Number of HUI Community Water Systems Added per Year in Wake County**

| Year | New CWSs | | Additons to Existing CWSs | | Total New or Additions | | Number of New Residents Served[1] |
|---|---|---|---|---|---|---|---|
| | CWSs | CWS Connections | CWSs | CWS Connections | CWSs | CWS Connections | |
| 1995 | 9 | 340 | 11 | 273 | 20 | 613 | 1,686 |
| 1996 | 3 | 99 | 10 | 239 | 13 | 338 | 930 |
| 1997 | 8 | 256 | 11 | 323 | 19 | 579 | 1,592 |
| 1998 | 6 | 234 | 13 | 392 | 19 | 626 | 1,722 |
| 1999 | 4 | 122 | 18 | 697 | 22 | 819 | 2,252 |
| 2000 | 6 | 374 | 12 | 304 | 18 | 678 | 1,865 |
| 2001 | 10 | 520 | 23 | 768 | 33 | 1288 | 3,542 |
| 2002 | 6 | 213 | 12 | 442 | 18 | 655 | 1,801 |
| Total (1995 - 2002) | 52 | 2,158 | 110 | 3,438 | 162 | 5,596 | 15,389 |
| Average | 6.5 | 270 | 13.8 | 430 | 20.3 | 700 | 1,924 |

Notes:
[1] - Assumes 2.75 residents per connection
Source: Jill Strickler, Heater Utilities, Inc.

new domestic wells each year is on the range of 1,500 to 2,200 – similar to the number served by new or expanding CWSs.

### 5.1.4 Summary of Water Supply Trends

If the annual increase in the number people served by new domestic wells and new or expanding CWSs continues to average approximately 4,000 through the year 2020, and no existing users of groundwater are converted to a municipal water service, then the population of Wake County served by groundwater would increase by 68,000, to a total of 209,000. LWSP population projections, when compared to Wake County Planning Department population projections, suggest that the expansion of municipal water service will result in only 104,000 persons served by groundwater by the year 2020. Considering the LWSP projections are based on conservative (high) estimates of water demand and population, a more realistic range of persons served by groundwater in the year 2020 is 150,000 to 200,000. However, the actual rate of population growth in Wake County over the next two decades will likely have more impact on the number of people served by groundwater than will water supply trends.

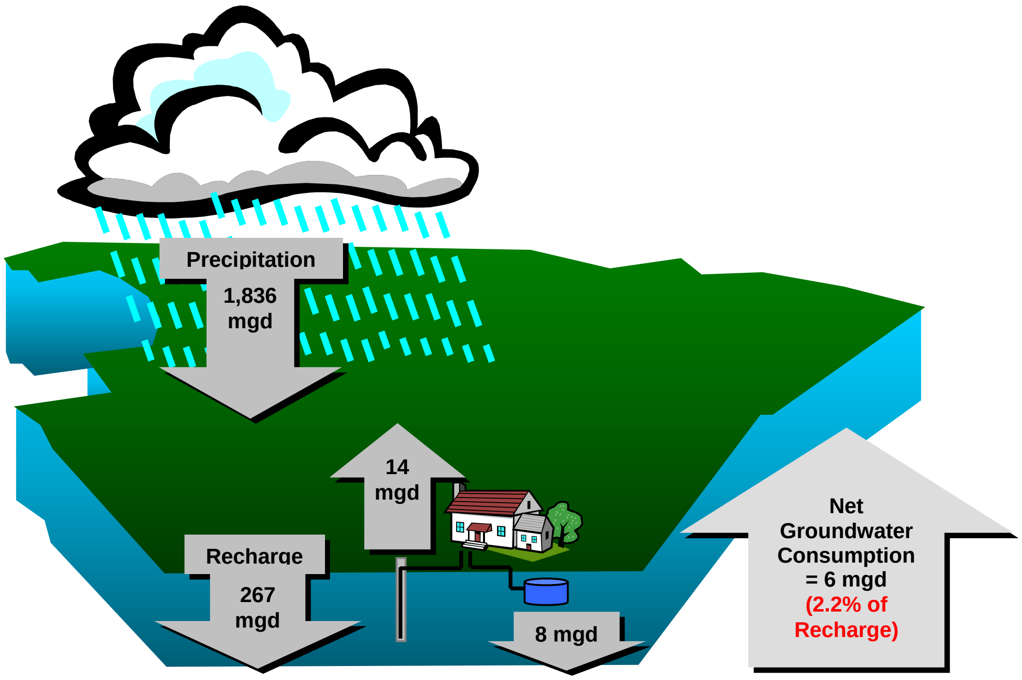
As the population of Wake County continues to grow, decisions regarding the development of future water supply sources should consider the potential for the conjunctive use[1] of groundwater and surface water. The continued use of existing CWSs, and the expansion of these systems where appropriate, may help to alleviate some of the demand placed on the County's surface water supplies and prolong the time before new ones are needed. However, the increased use of groundwater resources in Wake County should only occur once an acceptable definition of groundwater resource sustainability has been established.

## 5.2 Future Groundwater Consumption

### 5.2.1 Countywide Water Budget

A simplified example of the present-day average annual water budget for Wake County, with respect to groundwater resources, is shown in **Figure 5-2**.

[1] Conjunctive use is defined as the combined use of surface water and groundwater to optimize resource use and minimize adverse effects of using a single source.




Note: The budget assumes average annual conditions of precipitation.

**Figure 5-2**
**Present Day Wake County Groundwater Budget**

An extended period of below average precipitation will result in lower recharge. The timing of precipitation is also important. An equal amount of precipitation in two consecutive years may result in significantly different amounts of recharge. For example, if a majority of the precipitation occurred in the summer of one year and in the winter of the next, the ET which is significantly higher in the summer, uses more of the precipitation leading to a lower recharge than in the winter when the ET is less.

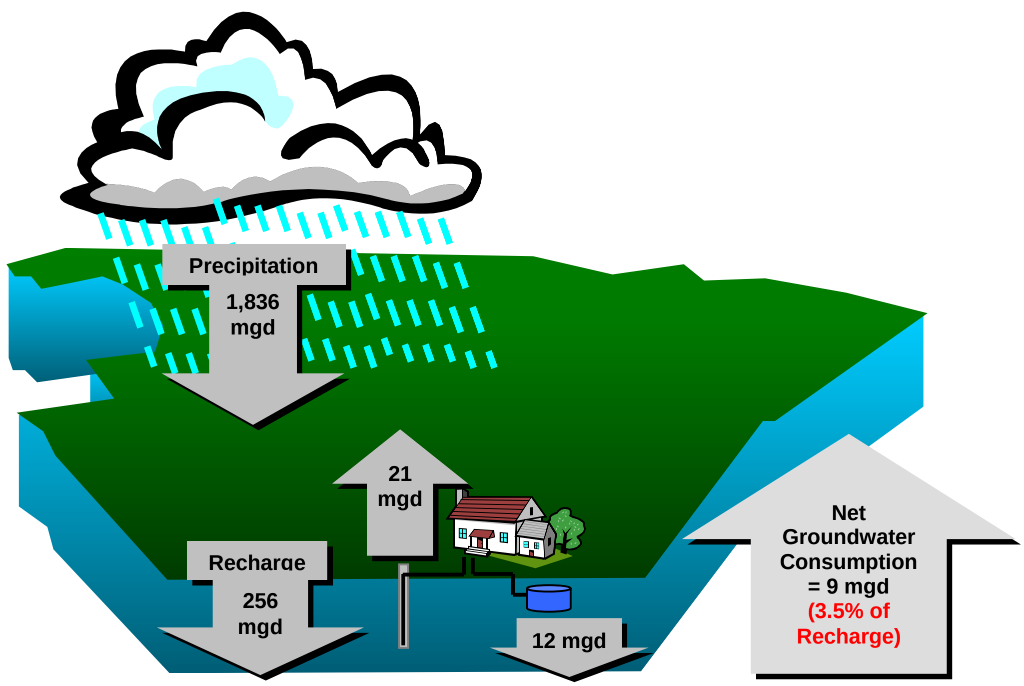
The values shown in the figure are derived from the water budget presented in Section 3. Each of the 14-drainage basin values was converted from inches per year to mgd by accounting for the area of each drainage basin. Groundwater withdrawals, representing withdrawals for domestic, public supply, commercial, industrial, and all other known uses, is estimated to be 14 mgd. The return of water through onsite wastewater treatment systems or other means (e.g., spray infiltration systems) is estimated to be 8 mgd. Net groundwater consumption is calculated by subtracting the returns from the groundwater withdrawals. Countywide, current net groundwater consumption represents just over two percent of average annual recharge.

It is important to note that values presented in **Figure 5-2** represent average annual conditions. The numbers do not reflect the fact that annual and seasonal variations in recharge and withdrawals routinely occur. It cannot be assumed that year after year, recharge in Wake County is 267 mgd.

A very basic approach can be used to estimate net groundwater consumption as a percentage of recharge for the year 2020. Conservatively assuming that the population served by domestic wells or CWSs increases by 50 percent (to 211,500), and other withdrawals (e.g., commercial, industrial, irrigation and quarries) of groundwater increase at the same rate, then the total amount of groundwater withdrawn in 2020 would be approximately 21 mgd. Assuming that the same relative percentage of groundwater users have onsite wastewater treatment systems in 2020 as today, then artificial recharge would increase to nearly 12 mgd. Countywide, net groundwater withdrawals in 2020 would still represent less than four percent of current average annual recharge. However, recharge from precipitation is expected to decline as a result of increased area of impervious surface associated with development. In Wake County, runoff from impervious surfaces was estimated to range from 0.30 inches per year (in/yr) in the relatively undeveloped Upper Falls Lake drainage basin, to 6.77 in/yr in the Walnut Creek drainage basin. Under future conditions, not all of the increased runoff would have entered the aquifers as recharge under the existing conditions. Some would have run off, some would have been lost to ET and some would have recharged the aquifer. The water budgets presented in Section 3 provide a means of understanding how much of the increased runoff would have recharged the aquifer under present day conditions. Of the 45 annual inches of precipitation, nearly 70 percent is lost to ET and another 15 percent becomes runoff. Only about 15 percent of precipitation recharges the aquifer. It is that amount which would be lost to recharge under 2020 conditions.

The amount of impervious surface in Wake County was estimated using GIS data developed by Wake County GIS Department, as detailed in Section 3. Currently, just over eight percent of land in Wake County is considered impervious. The total amount of impervious surface runoff for the entire County under present (average annual) conditions is estimated to be 129 mgd. The amount of impervious surface in each of the 14 drainage basins was compared to their current population density to determine the relationship between impervious surface and population density (see TM No. 5). Based on the observed linear relationship, it was estimated that if current development patterns and practices continued, approximately 13 percent of the County would be considered impervious in the year 2020, assuming a population of 1,120,309. The resulting increase in runoff from impervious surface would be approximately 75 mgd. Only about 15 percent of this amount would have entered the aquifer as recharge under present day conditions. The majority (nearly 70 percent) would have been lost to ET and the remaining 15 percent would have runoff from pervious surfaces. The loss of recharge for 2020 would therefore be 11 mgd, resulting in a total recharge of 256 mgd. The 2020 water budget is shown in **Figure 5-3**. After accounting for reduced recharge due to increased impervious surface, net groundwater consumption in 2020 would represent less than four percent of average annual recharge.

Under the conditions presented above, groundwater consumption in 2020 will continue to contribute to the loss of the already low baseflow during periods of low precipitation in the Swift Creek and Middle Creek drainage basins, and to a lesser extent in the Crabtree Creek, Kenneth Creek,




Note: The budget assumes average annual conditions of precipitation.

**Figure 5-3**
**2020 Wake County Groundwater Budget**

and Beaver Dam drainage basins. However, without knowing where future groundwater withdrawals will be located, it is difficult to predict in which basins the greatest impacts will be observed. In the Upper Falls Lake, Jordan Lake, Harris Lake, and Black Creek drainage basins, where streams routinely dry up during periods of low precipitation, future net groundwater consumption will further extend the period of dry streams.

What remains unclear, under both current and projected conditions, is the link between the magnitude of groundwater consumption and the impacts that diminished streamflow will have on the aquatic habitats and instream uses. Studies to establish this link are recommended so that issues of water consumption and streamflow can be better understood and more effectively managed.

### 5.2.2 Water Budget in Non-Urban Areas of Water Supply Watersheds

The previous sections illustrated that (1) on a Countywide basis future groundwater consumption is expected to remain significantly lower than recharge from precipitation; and (2)

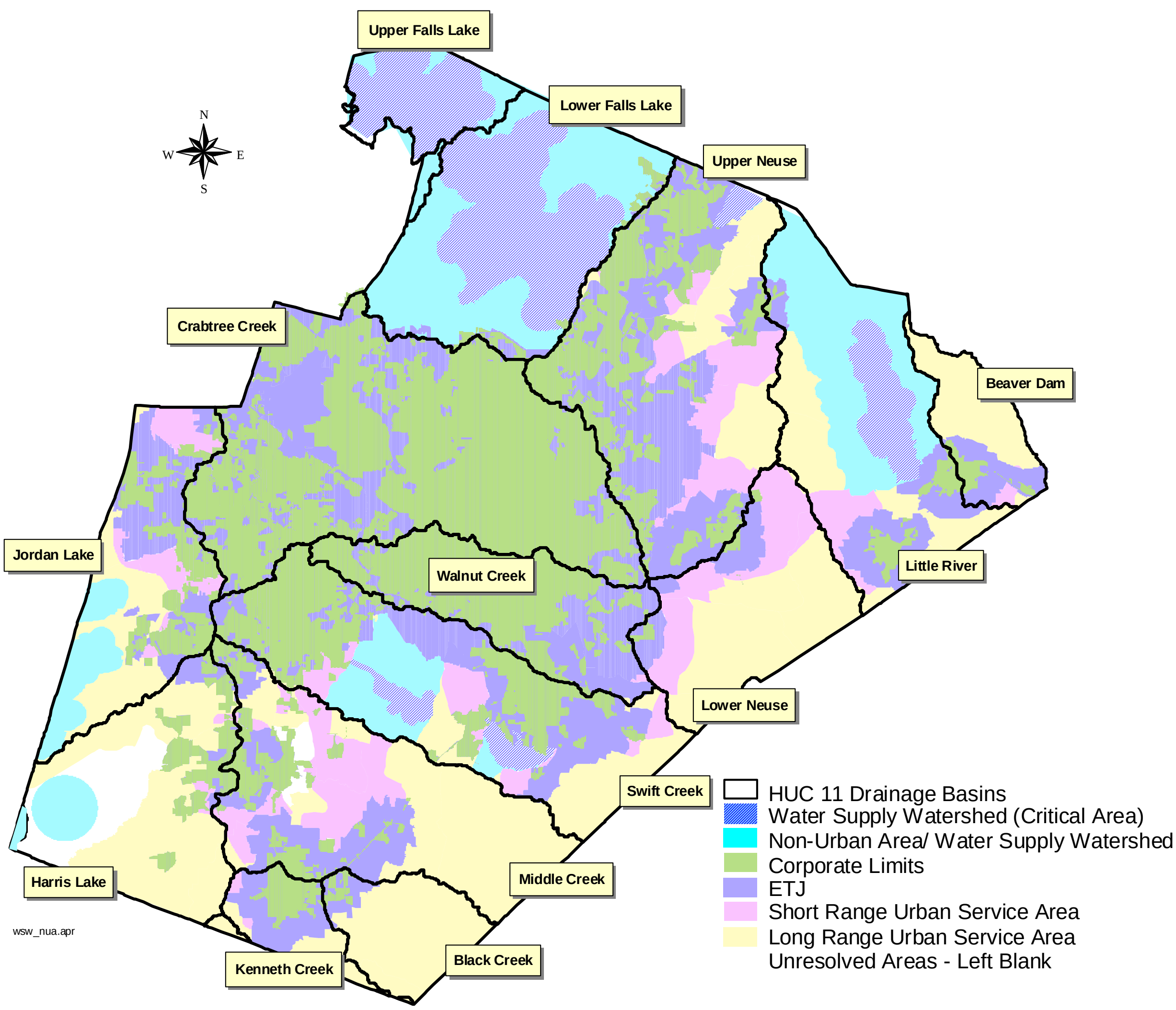



**Figure 5-4**
**Wake County General Classifications**

municipal planning indicates that municipal water and sewer services will continue to be extended to currently undeveloped areas through annexations. Long range planning suggests that the only areas of the County where municipal water and sewer will not be extended are those classified as NUA/WSWs. Of the six WSWs in Wake County, only three – Little River, Swift Creek, and Falls Lake contain non-urban areas of significant size, and/or are expected to be subject to increasing groundwater resource pressures from development. The NUA/WSWs are shown in **Figure 5-4**.

To assess if increased groundwater withdrawals in the NUA/WSWs will reduce the sustainability of groundwater resources, portions of the water budgets for the NUA/WSWs of the Upper Falls Lake, Lower Falls Lake, Little River, and Swift Creek drainage basins were re-calculated assuming fully developed conditions (**Table 5-4**). Except for a small number of Non-Urban Neighborhood Activity Centers, the Wake County Land Use Classifications Map classifies all of the NUA/WSWs as residential, with a density range of 0-0.5 residential units per acre in the WSW critical areas and 0-1.0 residential units per acre in the priority areas. These zoning limits were applied to the NUA/WSW critical and priority areas to determine the number of residential units under fully developed conditions. Areas within 100-feet of streams or surface water supplies were not included as developable area in the calculations.[2]

The calculations were conservative for the following reasons:

- They did not account for ancillary features that accompany residential development such as roads or already designated open space.

- All land outside of the 100-foot riparian buffer was considered developable, regardless of conditions such as steep slopes, soil permeability, the presence of Federally owned land (such as around Falls Lake), or other factors that would prevent residential development. For instance, in the Little River WSW, the thin regolith often precludes lot sizes as small as one acre. It is highly unlikely that any of the NUA/WSWs will be completely developed at the current allowable densities, as assumed in this conservative approach.

The number of residential units under fully developed conditions was calculated, and the population of each area was estimated based on the average number of persons per household from representative census tracts, which generally varies between two and three (US Census, 2000). The average daily groundwater withdrawal for each area was determined using the same water usage data as were previously calculated from year 2000 and 2001 HUI billing record data. Similarly, the return through onsite wastewater treatment systems was calculated using previously estimated rates. The estimated total withdrawals and net groundwater withdrawals were converted to inches per year by dividing the total withdrawals by the area of each NUA/WSW.

For this assessment, all withdrawals were considered to be from domestic wells scattered evenly throughout the developable area, as opposed to concentrated withdrawals from CWS wells. In reality, future total withdrawals from CWS wells may be significantly higher than total domestic withdrawals, especially in the Lower Falls Lake drainage basin where several large HUI-owned systems exist and continue to expand. From a practical standpoint, total withdrawals would be expected to be nearly the same, regardless of the mix of domestic versus CWS wells. If CWS wells are prevalent, and located in only select areas of the NUA/WSW, then potential localized impacts such as decreased water levels and reduced baseflow to streams may be more severe around those systems.

**Table 5-4** shows how net groundwater withdrawals under fully developed conditions compare to average annual baseflow (recharge). As previously demonstrated, recharge from

[2] Wake County ordinances do not prohibit lots within the 100-foot riparian buffer, only structures.

**Table 5-4**
**"Fully Developed" Future Net Groundwater Consumption in the Non Urban Area/Water Supply Watersheds**

| | Under Fully Developed Conditions: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Drainage Basin** | **Residential Units (RU) in NUA/WSW [1]** | **Population in NUA/WSW [2]** | **Average Daily Groundwater Use [3] (gal/day)** | **Estimated Total Withdrawal (in/yr)** | **Estimated Maximum Total Return [4] (in/yr)** | **Net Groundwater Consumption Range [5] (in/yr)** | **Average Annual Baseflow [6] (in/yr)** | **Estimated Recharge Lost Through Increased Impervious Surface [7] (in/yr)** | **Adjusted Average Annual Baseflow [8] (in/yr)** | **Range of Net Groundwater Consumption as a Percentage of Adjusted Average Annual Baseflow** |
| Upper Falls Lake | 6,723 | 20,168 | 1,048,710 | 1.21 | 1.02 | 0.19 to 1.21 | 3.78 | 0.69 | 3.09 | 6.0% to 39.1% |
| Lower Falls Lake | 35,228 | 105,684 | 10,568,400 | 3.07 | 1.87 | 1.20 to 3.07 | 7.11 | 0.64 | 6.47 | 18.5% to 47.5% |
| Little River | 22,741 | 68,222 | 4,366,176 | 2.27 | 1.92 | 0.36 to 2.27 | 8.33 | 0.84 | 7.49 | 4.7% to 30.4% |
| Swift Creek | 8,859 | 26,578 | 1,541,503 | 2.08 | 1.65 | 0.43 to 2.08 | 4.80 | 0.43 | 4.37 | 9.9% to 47.7% |

[1] - Assumptions: 0.5 RUs per acre in the WSW critical areas; one RU per acre in the WSW priority areas; Development cannot occur within the 100-foot riparian buffer.
[2] - Based on 2000 Census reported residents per household (by census tract).
[3] - Based on the following water usage statistics for year 2000 and 2001 (Source: Heater Utilities, Inc. billing records):
Upper Falls Lake = 52 gallons per day per person (gpd/person)
Lower Falls Lake = 100 gpd/person
Little River = 64 gpd/person
Swift Creek = 58 gpd/person
[4] - Based on an assumed maximum 90 percent return rate (of non-growing season withdrawals) through on-site wastewater treatment systems.
[5] - A range is shown to account for the fact that return through onsite wastewater treatment systems may vary, depending on many factors. The range assumes zero return, to a maximum return rate of 90 percent of non-growing season withdrawals.
[6] - Average annual baseflow under fully developed conditions not adjusted for potential loss of recharge associated with increased area of impervious surface.
[7] - Impervious surface estimates under fully developed conditions (for NUA/WSW portion only):
Upper Falls Lake = 11.3%
Lower Falls Lake = 14.4%
Little River = 16.5%
Swift Creek = 16.7%
[8] - Adjusted average annual baseflow under fully developed conditions is calculated by subtracting the estimated loss of recharge associated with increased area of impervious surface.

*wsw_huc11_wake.xls Table 4*

precipitation is expected to decline as a result of increased area of impervious surface associated with development. The Wake County Land Use Plan limits new nonresidential development to a maximum impervious surface coverage of six percent (of the development site) in the WSW critical areas, and a maximum impervious surface coverage of 24 percent in the WSW priority areas. Impervious surface limits are not directly applied to residential development in the WSWs; however, the 0-0.5 and 0-1.0 residential units per acre maximum densities are indirectly intended to limit the amount of impervious surface to 6 percent in the critical areas and 12 percent in the balance of the WSW. The relatively recent practice of constructing homes with a large footprint on 0.5 and 1.0 acre lots in the WSWs has likely resulted in more impervious surface on individual lots than was intended. The Neuse Nutrient Sensitive Waters (NSW) Rules limit development to 15 percent imperviousness, unless stormwater controls are used.

The formula relating population density to the amount of impervious surface was used to estimate the amount of impervious surface in each of the four NUA/WSWs under fully developed conditions. Using this formula, the percent imperviousness in the Little River and Swift Creek WSWs was estimated to be between 16 and 17 percent. Since these watersheds are covered by the Neuse River NSW rules, the fully developed percent imperviousness was adjusted downward to 15 percent.

Accounting for increased runoff, the amount of "lost recharge" was estimated. The "lost recharge" was subtracted from the average annual baseflow and compared to a range of net groundwater consumption, as shown in **Table 5-4**. A range of net groundwater consumption was used to provide a conservative estimate accounting for the fact that returns through onsite wastewater treatment systems may vary significantly, depending on the type of system and local soil conditions. The range used assumes that anywhere from zero to 90 percent of non-growing season withdrawals are returned.

Under current conditions, net groundwater consumption in the Lower Falls lake drainage basin is 5.8 to 12.1 percent of baseflow (assuming the same range of possible onsite wastewater treatment system returns). Under fully developed conditions, the range increases to 18.5 to 47.5 percent. Similarly, net groundwater consumption in the Swift Creek drainage basin is estimated to increase from 2.2 to 7.8 percent of baseflow, to 9.6 to 46.6 percent in the NUA/WSW portion, under fully developed conditions.

The range of net groundwater withdrawals can also be compared to drought condition recharge rates to further define potential groundwater resource impacts of increased future withdrawals. **Table 5-5** shows the range of net groundwater consumption compared to the 7Q10 and 30Q2 flows. The 7Q10 and 30Q2 flows were not adjusted to account for the estimated loss of recharge resulting from increased impervious surface. Recharge under a drought condition is already low; therefore, the loss of recharge from increased impervious surface is only a minor component, and is not easily estimated.

The less extreme low flow condition is the 30Q2 flow. The table indicates that estimated future groundwater consumption does exceed the 30Q2, assuming no return of water through onsite wastewater treatment systems. If the assumption is made that 68 percent of withdrawn water is returned (or 90 percent of non-growing season withdrawals), then estimated net future groundwater consumption remains near or below 50 percent of the 30Q2.

For the more extreme low flow condition, the 7Q10, net groundwater consumption is higher than the 7Q10 flow in all NUA/WSWs except Lower Falls Lake (under the maximum return range). This indicates that consumption under fully developed conditions may result in dry streambeds during periods of low precipitation.

**Table 5-5**
**Drought Condition Impacts of "Fully Developed" Future Net Groundwater Consumption within the NUA/WSWs**

| Drainage Basin | Under Fully Developed Conditions: Net Groundwater Consumption Range[5] (in/yr) | 7Q10 Flow[2] (in/yr) | 30Q2 Flow[3] (in/yr) | Range of Net Groundwater Consumption as a Percentage of 7Q10 Flow | Range of Net Groundwater Consumption as a Percentage of 30Q2 Flow |
|---|---|---|---|---|---|
| Upper Falls Lake | 0.19 to 1.21 | 0.000 | 0.338 | 7Q10 is zero | 55% to 358% |
| Lower Falls Lake | 1.20 to 3.07 | 1.483 | 3.728 | 81% to 207% | 32% to 82% |
| Little River | 0.36 to 2.27 | 0.168 | 1.343 | 211% to 1353% | 26% to 169% |
| Swift Creek | 0.43 to 2.08 | 0.032 | 1.002 | 1346% to 6506% | 43% to 208% |

[1] - A range is shown to account for the fact that return through onsite wastewater treatment systems may vary, depending on many factors. The range assumes zero return, to a maximum return rate of 90 percent of non-growing season withdrawals.

[2] - 7Q10 flows are based on available low-flow data (Weaver, 1998; Weaver and Pope, 2001) for streams within the same drainage basin.

[3] - 30Q2 flows are based on available low-flow data (Weaver, 1998; Weaver and Pope, 2001) for streams within the same drainage basin.

*wsw_huc11_wake.xls Table 5*

Groundwater consumption under fully developed conditions will undoubtedly result in a decrease in stream baseflow in periods of average precipitation, and likely cause some streams to go dry during extended periods of low precipitation. Because groundwater will begin to be mined (withdrawn at a rate greater than is entering as recharge) under certain drought conditions, impacts to pumping wells may also be expected as the already low water table is further lowered by withdrawals.

It should be stressed that the ranges of net groundwater consumption as a percentage of adjusted average annual baseflow, 7Q10 flow, and 30Q2 flow are overly conservative given the fact that, except for a 100-foot riparian buffer, all the land within the NUA/WSW are assumed to be developed at the current allowable maximum densities.

## 5.3 Water Quality Factors Affecting Groundwater Sustainability

### 5.3.1 Urbanization

The continued, sustainable use of groundwater in Wake County not only depends on its availability and accessibility, but also on its quality. In most areas of the County served by CWSs, groundwater is void of contaminants that would restrict its use for drinking water or other purposes. As the population of Wake County grows, increasing pressures from development may degrade groundwater quality. Contaminants may enter groundwater from a variety of sources, as shown in **Figure 5-5**.

Groundwater quality has been impacted in areas across the country that have already experienced the same rapid growth that currently exists in Wake County. In Nassau County New York (located on Long Island), the population grew rapidly beginning in the 1960s to the present day total of nearly 1.3 million. Accompanying this growth were impacts to the quality of groundwater, which is the County's sole source water supply. Presently, 26 percent of shallow CWS wells in Nassau County must treat to remove VOCs that are present in groundwater above drinking water standards. The use of onsite wastewater treatment systems in densely populated areas of Nassau County also resulted in nitrate contamination to the aquifers. Prior to sewering, nitrate levels in the shallow aquifer averaged nearly 10 mg/l, which is the current drinking water standard. As sanitary sewers were installed, and onsite wastewater treatment systems were no longer used, nitrate concentrations slowly declined over a period of decades, to between 2 mg/l and 3 mg/l.

Current policies and practices regulating chemical and waste transport, handling and disposal are designed to prevent many of the problems that occurred prior to such regulations, and which resulted in groundwater quality degradation. Still, rapid urbanization will undoubtedly result in impacts to water quality from sources such as accidental spills, intentional dumping of chemicals, runoff from paved surfaces, leaking sanitary sewers, and incorrect or over-application of pesticides and herbicides.

Wake County's municipal ETJs, shown in **Figures 5-1 and 5-4**, represent the areas where urbanization will likely occur in the next 10 years. As previously stated, approximately 80 of the 275 CWSs have wells within an ETJ. If the current trend of municipalities annexing around the areas served by CWSs continues, the majority of these 80 CWSs will remain operational. Because of the changing land use, and the associated pressures accompanying growth, some of these CWSs may begin to experience a decline in groundwater quality from urban-related contaminants.

Information resulting from North Carolina's SWAP program can be used to help protect the groundwater supply in these future urban areas. The SWAP process is intended to allow the state to systematically address issues of potential contamination of public water supplies using existing data from established environmental programs. Source water assessments are currently being finalized for the 275 CWSs that rely solely on groundwater. Once completed, the assessments

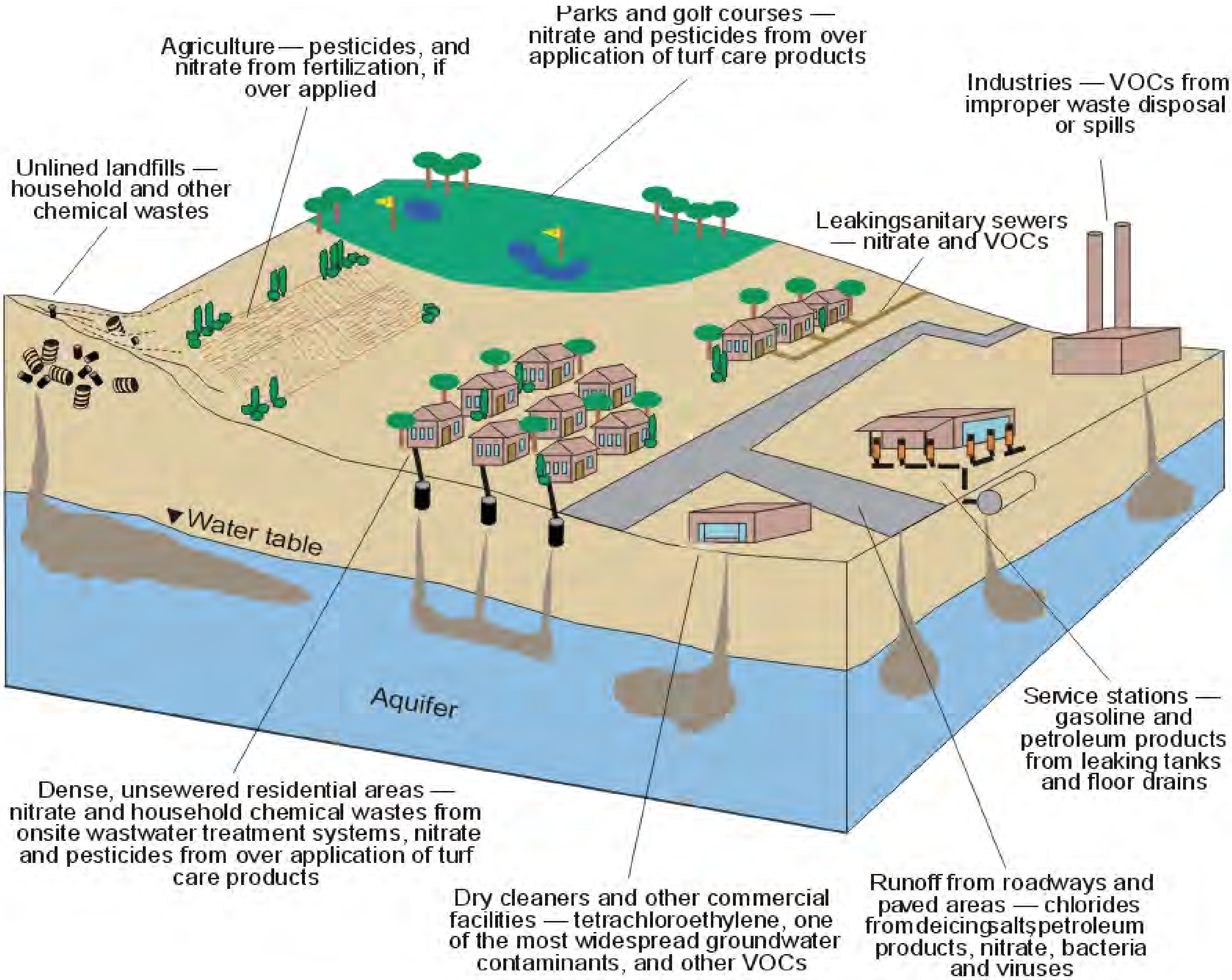



**Figure 5-5**
**Possible Sources of Groundwater Contamination**

should result in an increased understanding of the susceptibility of CWS wells to various types of contaminants within the different major hydrogeologic regions of the County.

### 5.3.2 Agricultural Land

Arsenic, EDB, and 1,2-dichloropropane have historically been detected at concentrations above drinking water standards in CWS wells in Wake County. All three are known constituents of soil fumigants previously used in tobacco farming. At the time fumigants containing these constituents were used, tobacco farming was most intensive in the eastern and southeastern portions of the County, generally coinciding with the areas where EDB and 1,2-dichloropropane have been detected in groundwater. Elevated levels of arsenic have also been detected in these areas. However, unlike EDB and 1,2-dichloropropane, elevated levels of arsenic have been found in other areas of the County, suggesting that additional sources may be responsible for its appearance. Arsenic may be naturally present in groundwater due to the dissolution of rocks containing metal arsenides and arsenates, arsenopyrite, or arsenite.

Although treatment systems have been, and can continue to be used to remove these contaminants from groundwater, future use of groundwater resources in eastern Wake County should proceed with the understanding that these, and other contaminants may be present in groundwater. CWS data dating back to the early 1980s suggest that these contaminants are rarely detected in groundwater and found above drinking water standards in even fewer instances. However, relatively few CWS wells are located in some of the eastern drainage basins, including Black Creek, Kenneth Creek, Little River, and Beaver Dam. As a result there is a lack of current data to fully characterize their prevalence in all areas of the County.

CWS wells are tested for a wide range of potential contaminants, including those mentioned above, prior to becoming operational. Additional testing is done once every three years or more frequently in some instances. Water quality testing of domestic wells for constituents other than bacteriologicals is not routinely performed unless requested or initiated by the homeowner. To determine the quality of groundwater resources in the portions of eastern Wake County not served by CWSs, additional testing for potential agricultural-related contaminants should be conducted.

## 5.3.3 Geology

### 5.3.3.1 Iron and Manganese

Natural factors, such as the type of aquifer or materials that come in contact with groundwater, may also impact groundwater resource sustainability. In Wake County, naturally high levels of dissolved minerals, such as iron and manganese, are present in objectionable quantities due to the natural dissolution of rocks. Elevated iron and manganese concentrations may occur throughout the County although the levels found in different hydrogeologic units vary. Approximately one-half of HUI-owned CWSs add a sequestering agent to prevent these minerals from forming insoluble precipitates that result in taste and odor complaints (Strickler, 2003). Since treatment is relatively inexpensive, the presence of iron and manganese will not significantly impede further development of the groundwater resource.

### 5.3.3.2 Radon and Radionuclides

The studies of radon in groundwater discussed in Section 4 indicated a relationship between geology and radon concentration. The highest concentrations were found in younger granites, biotite gneiss, and schist units, and lower concentrations are associated with the older metamorphosed volcanic units.

The available information on radon in Wake County groundwater suggests that radon concentrations in a large portion of northeastern Wake County may exceed the proposed drinking water standard of 300 pCi/L and potentially exceed the alternative drinking water standard of 4,000 pCi/L. The uranium-rich Rolesville granite underlies this portion of the County. Approximately 25,500 to 27,500 residents use domestic wells in this area. An additional 7,500 residents are served by a CWS well located in the Rolesville granite. Some of these CWS wells have been modified or use treatment to reduce the levels of radionuclides such as gross alpha, uranium and radium.

Since the Rolesville Granite underlies the NUA of the Little River WSW, elevated levels of radon and other radionuclides may impact groundwater resource availability. Insufficient information is currently available to characterize adequately radon and radionuclide concentrations in Wake County. Further substantial development of groundwater resources in northeastern Wake County should be preceded by additional investigation of radon and radionuclides in groundwater.

# Section 6
# Conclusions and Recommendations

The *Comprehensive Groundwater Investigation* represents the conclusion of a yearlong effort to gain a better understanding of Wake County's groundwater resources. Herein are presented the most significant conclusions and recommendations organized according to the two major areas of concern – water quantity and water quality.

## 6.1 Conclusions

The investigation produced new insights into the present condition and future of Wake County's groundwater resources. These findings can be used to shape future policy affecting the resources, whether carried out by County agencies, municipalities, State agencies, or individual water suppliers.

***Groundwater Quantity***

1. Approximately 141,000 County residents rely on groundwater for drinking and other everyday uses. Two-thirds of that total (93,000) obtain water from domestic wells. The remaining 48,000 are served by one of 275 CWSs.

2. The largest total groundwater withdrawal occurs in the Lower Falls Lake drainage basin, which also has the highest per capita withdrawals. Eighty percent of all groundwater withdrawals occur in the Lower Falls Lake, Upper Neuse, Crabtree Creek, Middle Creek, and Swift Creek basins.

3. Groundwater use from CWSs currently range from a low of about 50 gallons per day per person to a high of about 100 gallons per person per day, with an average of approximately 70.

4. Groundwater withdrawals in the County (for all uses) currently total nearly 14 mgd. Up to 8 mgd of water is estimated to return to the groundwater system through onsite wastewater treatment systems. The total net groundwater consumption is estimated to be approximately 6 mgd.

5. On an average annual basis, approximately 15 percent of precipitation in Wake County recharges the groundwater system. In the western part of the County, the clayey soil of the Triassic basin limits recharge to around six percent (or lower) of precipitation. Elsewhere, more permeable soils and rocks may locally permit up to 19 or 20 percent of recharge from precipitation.

6. Baseflow, the component of streamflow that comes from discharging groundwater, typically accounts for between 34 and 55 percent of total streamflow in Wake County, with an average of approximately 45 percent. In naturally flowing streams baseflow accounts for nearly all of streamflow during a drought.

7. The natural components of the hydrologic cycle (i.e. precipitation, ET, runoff from pervious surfaces, and baseflow) are clearly dominant in Wake County, accounting for over 90 percent of the water on both sides of the water budget equation. The artificial components (i.e. surface water and groundwater withdrawals, surface water discharges, and runoff from impervious surfaces) are still relatively minor.

***Groundwater Quantity (continued)***

**8.** Groundwater withdrawals represent a relatively small percentage of the water budget on an average annual basis, but increase in degree during a prolonged drought, such as which occurred in Wake County between 1999 and 2002.

**9.** In the Lower Falls Lake drainage basin, where groundwater withdrawals are the highest in the County, current net groundwater consumption is less than six percent of average annual recharge. In 8 of the remaining 13 basins, current net groundwater consumption is less than 1 percent of average annual recharge.

**10.** In the Swift Creek and Middle Creek drainage basins, and to a lesser extent in the Crabtree Creek, Kenneth Creek and Beaver Dam drainage basins, current net groundwater consumption is contributing to the loss of the already low baseflow during dry periods that occur relatively infrequently and for short durations. In the Upper Falls Lake, Jordan Lake, Harris Lake, and Black Creek drainage basins net groundwater consumption, although low, is probably extending the period during which streams are already dry.

**11.** The thickness of the regolith – the part of the groundwater system where most of the water is stored – is the lowest in the area of the County underlain by the Triassic basin in the west and the Rolesville granite in the northeast, making these areas the most susceptible to problems such as reduced well yields and dry wells during droughts.

**12.** Groundwater availability is also a function of how much water can actually be extracted from the ground. In the Triassic basin, low yielding wells naturally limit the use of the resource. Maximum well yields are typically no greater than 25 gpm in this area, and average well yields are typically well below 10 gpm. In other areas, including the southeastern part of the County where Coastal Plain sediments overlie bedrock, well yields are more favorable to larger groundwater withdrawals. Maximum well yields above 100 gpm have been reported. Variations in well yield are primarily a result of the hydrogeologic characteristic of the water-bearing rocks.

**13.** Recharge rates in the Upper Falls Lake, Lower Falls Lake, Little River, and Swift Creek NUA/WSWs are sufficient to sustain additional water supply withdrawals, if development continues at current allowable residential zoning densities. However, increased groundwater consumption in these areas may result in a decrease in stream baseflow in periods of average precipitation, and cause some streams to go dry during extended periods of low precipitation.

**14.** The future trend in the development of groundwater resources in Wake County remains unclear. Water supply plans prepared by the municipalities of Wake County suggest that fewer residents will rely on groundwater as their water supply in 2020. Yet, over the last several years, the number of people connected to a CWS plus the number of people served by a new domestic well has increased by approximately 4,000 per year. The rate at which municipalities extend public water (and sewer) to areas formerly served by groundwater will play a significant role in determining this trend.

***Groundwater Quality***

**15.** In most areas of Wake County served by CWSs, groundwater is void of contaminants that would prevent or restrict its use as drinking water. Disinfection, pH adjustment and sequestration to remove iron and manganese are the only treatment methods used in the majority of the systems. Infrequently, additional treatment methods are used to bring the water in compliance with drinking water standards. Several CWSs in Wake County treat groundwater to reduce the level of nitrates, radionuclides, and/or organic compounds to drinking water standards.

**16.** Arsenic was detected above drinking water standards in one percent of recent samples from CWS and domestic wells. Occurrences of arsenic in Wake County groundwater may result from natural sources, including minerals dissolved from rocks or from man-made sources including fumigants formerly used in tobacco farming and treated lumber.

**17.** Nutrients (i.e., nitrate) are generally not found in groundwater or are found at levels below drinking water standards. However, there is some evidence that nitrate derived from onsite wastewater treatment systems has impacted groundwater in selected residential developments.

**18.** Chlorinated solvents and petroleum products, most often associated with leaking underground storage tanks, were detected in less than one percent of recent samples from CWSs. These compounds are more likely to occur in groundwater in the urban areas, where CWSs are generally absent. These compounds were not analyzed in samples from domestic wells that were reviewed in this investigation.

**19.** Two compounds formerly used as soil fumigants in tobacco farming continue to be detected in a small percentage of samples from CWSs. 1,2-dichloropropane was detected in 14 of 695 recent samples from CWSs. Three of the detections were above the drinking water standard. EDB was detected in only one of 629 recent samples but has in the past resulted in the abandonment of CWS wells. Historical detections of these compounds in CWS wells have generally been limited to the eastern parts of Wake County. These compounds were not analyzed in samples from domestic wells that were reviewed in this investigation.

**20.** Radionuclide concentrations in groundwater are highest in the northeast portion of the County, and coincide with the Rolesville granite geologic unit. Limited data is available to characterize radon in groundwater in Wake County. Testing for radon is not yet required under the rules of the Safe Drinking Water Act. The limited available data suggests that radon in groundwater is likely to exceed the proposed standard of 300 pCi/L and the proposed alternate standard of 4,000 pCi/L in many areas of the County.

**21.** As the population of Wake County grows, increasing pressures from development may degrade groundwater quality. Contaminants common to urban environments may include nitrates (in unsewered areas or where fertilizers are used), petroleum products (from leaking underground storage tanks), or volatile organic compounds (from spills or improper disposal), to name a few.

## 6.2 Recommendations

Recommendations to address identified data gaps or areas of additional study have been developed in response to the findings of this investigation. The recommendations are aimed at furthering the understanding of aspects related to groundwater quantity and quality.

One specific action that was identified prior to this investigation was the development of a network of wells to monitor changes over time to groundwater levels and quality. Guidance and recommendations for establishing a long-term monitoring well network are presented separately in Section 6.3.

***Recommendations***

**1.** The local governments and citizens of Wake County have demonstrated a commitment to protecting, preserving and restoring the quality and quantity of the County's water resources through their support of recent environmental initiatives, which include the *Comprehensive Watershed Management Plan*, the *Consolidated Open Space Plan*, *Growth Management Strategies*, and the *Comprehensive Groundwater Investigation*. Based on the findings and recommendations of these environmental initiatives it is recommended that Wake County take a leadership role in planning and developing an Environmental Monitoring Program for Wake County. The Environmental Monitoring Program would be used by the local governments and citizens of Wake County to closely monitor trends in the health and condition of water resources in Wake County, and establish benchmarks and performance metrics to monitor the effectiveness of strategies recommended in the various environmental initiatives for protecting, preserving and restoring the quality and quality of water resources in Wake County. It is further recommended that the Environmental Monitoring be implemented, managed and funded as a multi-jurisdictional project, involving local, state and federal governments, departments and agencies, respectively.

**2.** Specific to groundwater resources, it is recommended that the Environmental Monitoring Program include a Long-Term Monitoring Well Network, which would include the installation of monitoring wells and stream gaging stations throughout Wake County. The Long-Term Monitoring Well Network will focus specifically on monitoring groundwater resource conditions (quality and quantity) in Wake County on a long-term basis.

**3.** The purpose of the *Comprehensive Groundwater Investigation* was to conduct a thorough assessment of current groundwater conditions in Wake County with regard to quality and quantity, and to also conduct an assessment of future groundwater conditions under currently adopted growth and development policies and regulations. To develop recommendations as to "how" groundwater resources should be used and managed in the future, it is recommended that the County implement a community-based process to develop principles and policies for groundwater resource sustainability. As an initial step in this process, groundwater resource sustainability should be defined as it pertains specifically to Wake County. Once the principles and policies for groundwater resource sustainability have been developed, then Wake County can initiate efforts to prepare strategies that can be implemented to ensure that the agreed upon definition of groundwater resource sustainability can be met.

***Recommendations (continued)***

**4.** The results of the water budget suggest that at the HUC-11 drainage basin scale, the groundwater system is not stressed at current residential densities. However, insufficient data exist to quantify potential impacts from development projects at a smaller, more localized scale. Therefore, it is recommended that Wake County work with the NCDENR DWQ Groundwater Section to assess the water quantity and quality impacts to both surface and groundwater resources from development projects. The NCDENR DWQ Groundwater Section has proposed such a study to Wake County as part of the Piedmont and Mountains Resource Evaluation Program (PMREP).

**5.** As part of Wake County's *Environmental Stewardship Agenda*, it is recommended that Wake County launch a public education campaign to provide basic information about groundwater, wells, and the risks and responsibilities of well ownership. The campaign should be implemented to accomplish the following goals:

a. Provide information that will assist citizens in performing appropriate due diligence when considering housing choices that rely upon private wells or community wells;

b. Educate well owners as to the importance of proper groundwater well maintenance and wellhead protection; and

c. Encourage groundwater well owners to conduct periodic water quality testing.

**6.** While there appears to be sufficient data to characterize the quality of community water supply wells in the County, there is an acknowledged lack of groundwater quality data for domestic wells. Therefore, it is not possible to characterize the quality of domestic wells in Wake County. To address this data gap in water quality, it is recommended that Wake County undertake the following activities:

a. *Conduct a domestic well testing program*. Recognizing that only a small fraction of the approximately 37,000 domestic wells can be feasibly and economically tested, the program should identify and target priority areas including eastern parts of the County where constituents formerly used in soil fumigants (e.g., EDB, 1,2-dichloropropane, and arsenic) have been detected in CWS wells. A thorough review of historical aerial photographs to identify former locations of tobacco farming should be performed to assist in identifying priority areas for sampling related to these constituents. Other priority areas should include those where domestic wells are located in urban areas. As a component of the testing program, a domestic well water quality database should be created.

b. *Implement a process to collect water quality data associated with new construction*. Wake County's current well regulations require testing for coliform bacteria. Under this recommendation, the list of potential water quality parameters would be expanded to include inorganics and nutrients, and in certain areas, organic compounds, radon, and radionuclides. All water quality data from new wells should be incorporated into the domestic well water quality database.

***Recommendations (continued)***

**7.** It is recommended that Wake County conduct a countywide groundwater quality assessment focused on radon and radionuclides. Groundwater sampling and analysis should be from existing domestic wells, especially in the areas not served by CWSs. Radon in indoor air should also be investigated, since the majority of health concerns associated with radon are from inhalation of radon gas.

**8.** It is recommended that Wake County implement a process that would require well drillers to report to the Wake County Department of Environmental Services the location and depth of attempted new wells that do not yield sufficient water. The data would be used by Wake County staff to identify additional areas that may be unfavorable for groundwater development.

## 6.3 Long-Term Monitoring Well Network

Much like streamflow gaging stations, groundwater monitoring wells provide information on how changes in both the natural and artificial components of the hydrologic cycle impact the flow or volume of water in the ground. They can also be used to determine changes to groundwater quality over time and provide insight into local geologic and hydrogeologic characteristics.

The objectives of the Long-Term Monitoring Well Network in Wake County are to:

- Provide a long-term record of data to assess the impact of sustained groundwater withdrawals on the aquifer, especially in the NUA/WSWs.
- Provide data to monitor water level declines due to groundwater withdrawals, drought, and/or reduced recharge resulting from changing land use.
- Provide information to understand better the impacts of urbanization on groundwater quantity and quality.
- Provide defensible data to support potential groundwater resource management decisions.
- Provide a mechanism to monitor changes in raw groundwater quality over time.

### 6.3.1 Monitoring Well Network Design

#### 6.3.1.1 Well Locations

An effective monitoring well network requires careful thought and consideration when locating the wells. To meet the objectives, a monitoring well network should:

- Be representative of groundwater conditions for the major hydrogeologic units and land uses of Wake County.
- Be compatible with other Wake County environmental monitoring initiatives.
- Be accessible to and/or established with the cooperation of other entities including, but not limited to NCDENR, universities, USGS, and NCGS.
- Include the placement of wells in representative healthy, impacted and degraded watersheds.
- Include the placement of wells in both the critical and priority areas of the NUA/WSWs.
- Include the placement of wells in areas of both high and low imperviousness.
- Include the placement of wells in areas of varying recharge rates and soil types.
- Include the placement of wells in areas served primarily by CWS wells and areas served by domestic wells.



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- Include the placement of wells in areas of varying residential density.
- Include the placement of wells in areas underlain by varying thickness of regolith (i.e., varying amounts of groundwater storage capacity).
- Include the placement of wells in areas where water quality has not been fully investigated or water quality may be expected to change in the future.
- Include the placement of wells in both recharge and discharge areas.
- Include the placement of wells in areas with low or no streamflow during droughts.
- Include the placement of wells in areas having a history of well failures.
- To the extent possible, utilize public lands for locating wells so that future development will not compromise their integrity and functionality.
- Be protected and maintained.

Based on these criteria, 16 locations were selected for monitoring well placement. The locations with respect to major land use type are shown in **Figure 6-1**. The locations with respect to some of the other major criteria are shown in **Figure 6-2**. **Table 6-1** provides a summary of the well locations with respect to most of the criteria listed above.

The proposed well locations do not represent a single, unique solution. Potential current and future access problems to wells proposed on privately owned land might require that some wells be moved to a nearby, publicly-owned parcel. In this instance, the usefulness of the monitoring well network is not likely to be lessened, assuming the same thought and consideration is put into selecting new well locations.

As part of the PMREP study, the USGS and NCDENR DWQ Groundwater Section have installed a network of 12 monitoring wells at the 30-acre Lake Wheeler Research Station in south-central Wake County. The stated objectives for the site include (1) its use as a training site for Groundwater Section Staff and (2); to provide educational outreach to the legislative and educational community.

The site includes wells set in the regolith, transition zone and bedrock. Real-time, continuous data recorders have been installed in one well of each zone. Real-time water level, water temperature, dissolved oxygen, pH, and specific conductance data are available on the USGS water resources web site.

As part of the Statewide Active DWR Network, the NCDENR DWR maintains a monitoring well in Wake County, just south of Fuquay-Varina. Water level measurements are available dating back to 1982. Daily water level measurements are available since October of 2002, and should continue to be available through the DWR Groundwater Branch Database Access web site.

These sites, and information obtained from them, should be included as part of the Wake County monitoring well network.

#### 6.3.1.2 Well Design

Initially, one bedrock monitoring well is recommended for each location. Bedrock monitoring wells should be 6.25-inches in diameter and have a galvanized-steel casing. Bedrock monitoring wells would be expected to average approximately 300 feet in depth (which is the average domestic well depth). Dedicated water level recorders (transducers) should be used to automatically record and store water level information on a daily basis.

Additional wells screened in the regolith and transition zone might provide additional useful information, and could be added in subsequent phases. The USGS may provide well construction services for shallow wells (up to 50 feet) in the regolith.

#### 6.3.1.3 Water Quality Sampling

By using the network of wells as water quality monitoring points, they could provide a better understanding of how groundwater quality changes in response to changing land use. A baseline set of water quality samples should collected and analyzed from each well for inorganics, VOCs, SOCs, radionuclides, bacteriologicals, and conventionals. Subsequent sampling should occur at yearly intervals for the first three to five years, followed by every two to three years thereafter. More frequent sampling may be warranted in particular instances.

#### 6.3.1.4 Cost

A budgetary capital cost estimate for a network of 16 bedrock monitoring wells and water level transducers is $70,000 to $80,000. This cost does not include oversight during well installation or potential costs associated with land acquisition or access.

Baseline water quality sampling and analysis costs would be range from $40,000 to $50,000, assuming the sampling and analysis is conducted by the private sector.

Wake County could realize significant cost savings during the establishment, operation and maintenance of the monitoring well network through cooperation with State and Federal agencies. Potential roles and contributions of interested agencies are presented in the following section.

### 6.3.2 Stream Gaging Stations

As discussed in Section 3, streamflow records provide a method to estimate recharge rates. Streamflow records are also crucial in the evaluation of water-supply potential and reservoir release requirements, the determination and regulation of wastewater discharges to streams, and the maintenance of aquatic habitats in streams (Weaver and Pope, 2001).

Continuous-record gaging stations are currently operational in only 6 of the 14 HUC-11 drainage basins in Wake County. This includes the Middle Creek gage near Clayton, in Johnston County. Locating monitoring wells in sub basins that contain stream gages provides a way to examine the relationship of groundwater levels to streamflow and recharge. **Figure 6-3** shows the location of current stream gages in relation to the proposed monitoring wells.

Additional stream gaging stations located in the Lower Falls Lake and Little River drainage basins are recommended to monitor flow characteristics as these NUA/WSWs continue to be developed. Lower Barton Creek (in Lower Falls Lake) and Buffalo Creek (in Little River) may provide suitable locations for new stream gages, as shown in **Figure 6-3**. The proposed gaging station on Buffalo Creek is located in a watershed classified as degraded. Smith Creek and Poplar Creek may be suitable locations for gages in the Upper and Lower Neuse drainage basins, respectively. The proposed gaging station on Smith Creek is located downstream of watersheds classified as impacted and degraded. An additional stream gaging station is recommended in the Black Creek or Kenneth Creek basins. A possible location on Little Black Creek, nearby proposed monitoring well WC-13, is shown on **Figure 6-3**.

Stream gaging stations that provide an automated record of stream stage and are correlated to stream flow can be relatively expensive, compared to groundwater monitoring wells. Significant thought and consideration beyond the initial recommendations provided above should precede decisions on locating stream gaging stations in Wake County. The USGS is the recognized local authority on establishing and maintaining stream gaging stations and should play an integral role in the process.

### 6.3.3 Establishing a Cooperative Monitoring Well Network

To get the most benefit from a groundwater monitoring well network, Wake County should work in cooperation with the USGS, NCDENR DWR and DWQ, State Climate Office, and local universities for its establishment and operation. Establishment of a cooperative network offers such obvious benefits as shared responsibility, shared cost, and increased education outreach.

The USGS, NCDENR DWQ and DWR, and State Climate Office have expressed interest in working with Wake County to develop, maintain, and/or otherwise contribute to some aspect of the proposed monitoring well network. Potential roles and contributions offered by these agencies include:

- ***USGS and DWQ*** - 1) Collect borehole geophysical logs to aid in well characterization; 2) delineate and characterize fractures and production zones (depth, flow, orientation), and; 3) provide a description of lithology, including foliation orientation. Collected data would be published as part of the ongoing PMREP.

- ***USGS and DWQ*** – Collect baseline groundwater quality samples including major ions, nutrients, and trace metals for correlation with the geologic unit. Data would be published as part of the ongoing PMREP.

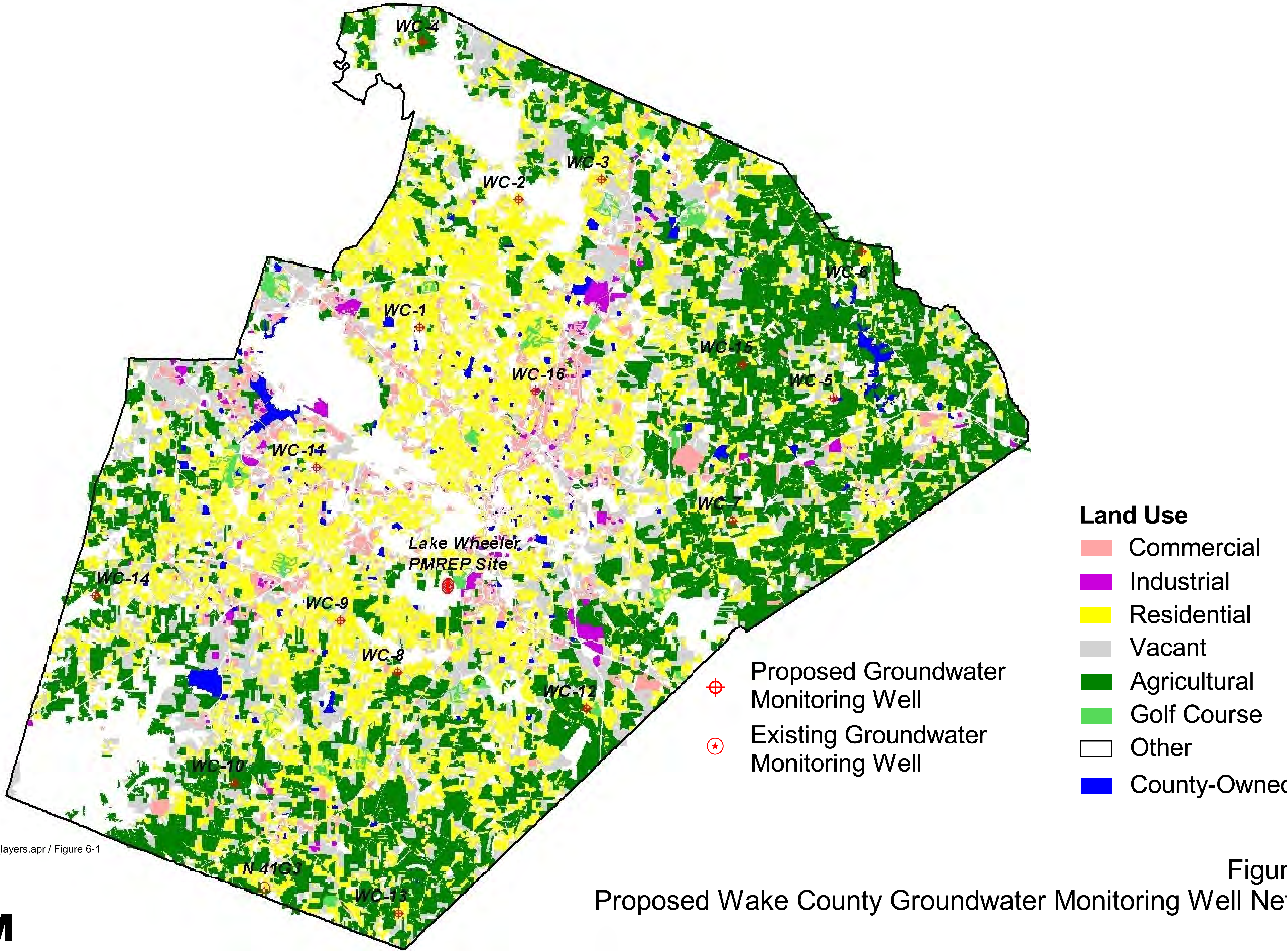
- ***USGS, DWQ, and DWR*** - Train County personnel on well inventory and groundwater level data collection procedures.

- ***USGS and DWR*** - Compile all well characterization and water level data collected by County personnel and other agencies, including quality assurance. Water level data would be served up on the Web, and permanently stored in USGS and/or DWR databases, retrievable by the County and other agencies on a daily basis. Hydrographs displaying data trends would be produced as data are incoming and have been reviewed. Maps showing areal water levels could be produced. Data would be published annually in the USGS ground-water records in cooperation with DWR, DWQ, and other agencies.

- ***USGS -*** Drill shallow (up to 50 ft) 2-inch PVC wells in the regolith.

- ***State Climate Office –*** Co-locate and operate a North Carolina Environment and Climate Observing Network (ECONet) station near one of the rural groundwater monitoring wells. The State Climate office already operates three ECONet stations located in Raleigh. Standard ECONet stations provide real-time information on precipitation, humidity, wind, temperature, atmospheric pressure, and soil moisture. An additional capability at select stations is the measurement of ET rates. Co-location of a monitoring well and ECONet station would enable direct comparison of precipitation and evapotranspiration to groundwater levels. The correlation of these measurements would significantly further the understanding of the amount and timing of recharge, as it varies by storm event, season, and year.

- ***North Carolina State Lab –*** The North Carolina State Lab may provide groundwater sample analysis for organics, inorganics, nutrients, bacteriologicals, and radionuclides.




mw_network _layers.apr / Figure 6-1

Figure 6-1
Proposed Wake County Groundwater Monitoring Well Network

CDM

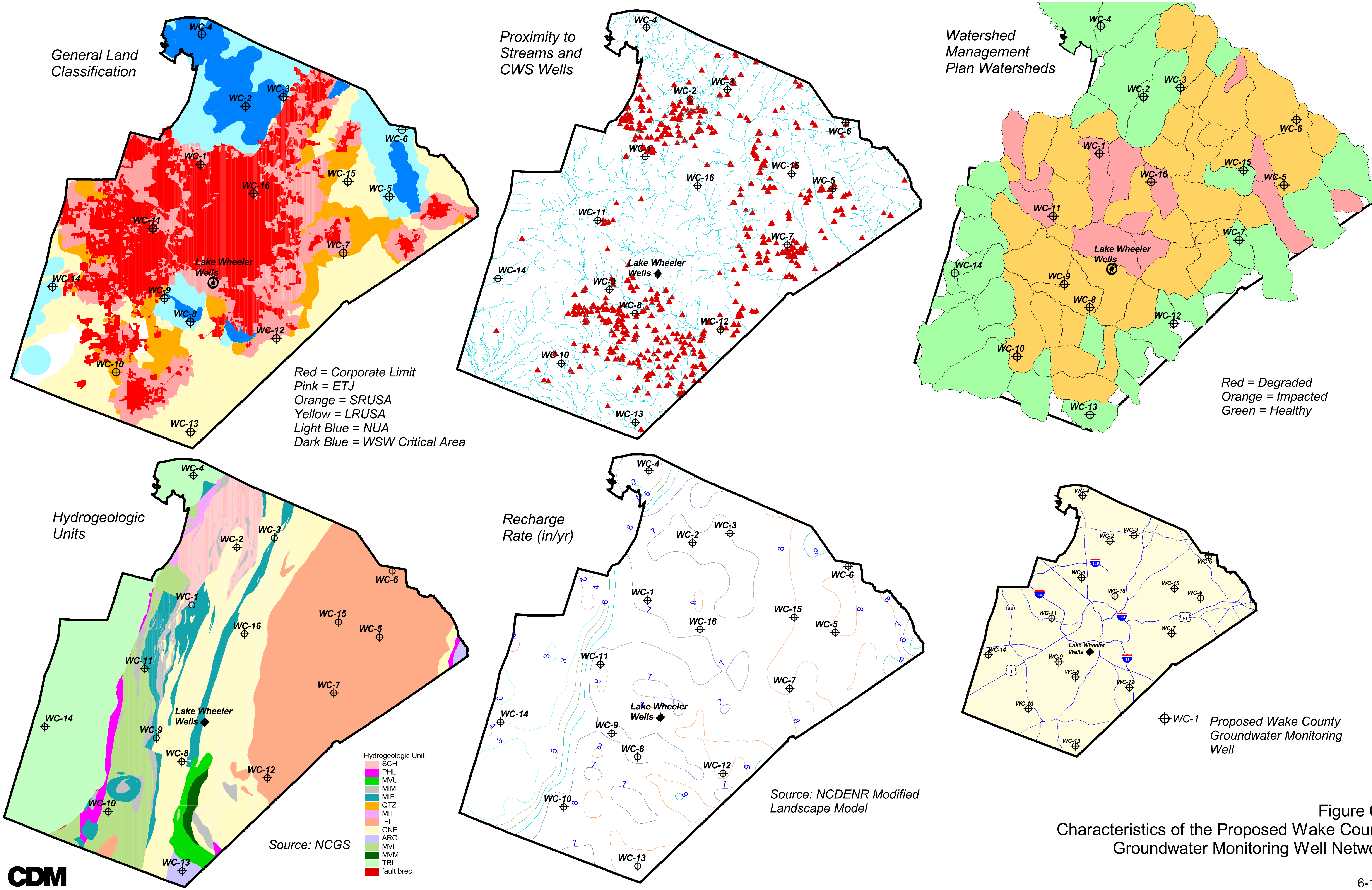



Figure 6-2
Characteristics of the Proposed Wake County Groundwater Monitoring Well Network

CDM

**Table 6-1**

**Characteristics of the Proposed Wake County Groundwater Monitoring Well Network**

| Proposed Monitoring Well ID | Major Land Use[1] | Hydrogeologic Unit[2] | Watershed No. (H)ealthy, (D)egraded, or (I)mpacted | Percentage of Impervious Surface[3] | General Land Classification | WSW (P)riority or (C)ritical | Recharge Rate[4] (in/yr) | Hydrologic Soil Type | Proximity to Stream (feet) | Area Served by CWS or Domestic Well | Residential Density (lots/acre) | Sewered Area? | Estimated Depth of Saprolite | Current Water Quality Concerns | Subdivision Name | County-Owned Property | Located on a Diabase Dike? | Primary Justification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WC-1** | RES | SCH | 15-03 (D) | 19.4% | Corp (Raleigh) | -- | 7 | B | 750 | CWS | 1.6 | No | 80 | None | Stonehenge | No | No | Area of current, high residential groundwater use (CWSs) and degraded watershed. |
| **WC-2** | RES | GNF | 20-01 (H) | 9.4% | NUA/WSW | C | 7 | B | 2,000 | CWS | 0.7 | No | 50 | None | Pointe at Falls Lake | No | No | Monitor impact of growth in Falls Lake NUA/WSW (CWS well area). |
| **WC-3** | RES | MIF | 20-01 (H) | 9.4% | NUA/WSW | C | 7 | B | 2,500 | Domestic | 0.4 | No | 80 | None | Grayson Creek | No | No | Monitor impact of growth in Falls Lake NUA/WSW (domestic well area). |
| **WC-4** | AGR | TRI | 17-01 (H) | 4.1% | NUA/WSW | C | 3 - 4 | C | 2,000 | Domestic | -- | No | 30 | None | -- | No | No | Monitor impact of growth in Falls Lake NUA/WSW (Triassic). |
| **WC-5** | RES/AGR | IFI | 33-02 (I) | 5.8% | NUA/WSW | P | 8 | B | 6,000 | CWS | 1.1 | No | 40 | Rad | Ponderosa | Yes | No | Monitor impact of growth in Little River NUA/WSW (Triassic). |
| **WC-6** | RES/AGR | IFI | 33-02 (I) | 5.8% | NUA/WSW | C | 8 | B | 100 | CWS | 0.3 | No | 50 | Rad | Little River Run | No | No | Monitor impact of growth in Little River NUA/WSW (Triassic). |
| **WC-7** | AGR | IFI | 30-01 (H) | 8.2% | SRUSA (Knightdale) | -- | 8 | B | 1,500 | CWS (nearby) | 0.8 | No | 60 | Rad | Oakdale Mobile Estates[5] | No | Yes | Monitor impact of growth in predominately agricultural area. |
| **WC-8** | RES/AGR | GNF | 09-02 ( I) | 11.4% | NUA/WSW | C | 6 - 7 | B | 1,500 | CWS (nearby) | 0.6 | No | 100 | None | Whippoorwill Downs[5] | No | No | Monitor impact of growth in Swift Creek NUA/WSW (CWS well area). |
| **WC-9** | RES/AGR | MIF | 09-02 ( I) | 11.4% | NUA/WSW | P | 6 - 7 | B | 2,000 | Domestic | 0.4 | No | 140 | None | Bluffs East | No | No | Monitor impact of growth in Swift Creek NUA/WSW (domestic well area). |
| **WC-10** | AGR | MVF (CP) | 07-01 (I) | 10.1% | SRUSA (Fuquay-Var.) | -- | 7 - 8 | B/D | 1,000 | Domestic | -- | No | 80 | None | -- | No | No | Monitor impact of growth in Holly Springs & Fuquay-Varina area. |
| **WC-11** | RES | MVF | 14-03 (D) | 17.5% | ETJ (Cary) | -- | 7 - 8 | B/D | 1,400 | CWS (nearby) | 2.7 | No (Nearby) | 80 | None | Royal Oaks[5] | No | No | Isolated area of groundwater use between Raleigh/Cary and degraded watershed. |
| **WC-12** | RES/AGR/ GOLF | IFI | 11-01 (H) | 6.7% | LRUSA (Garner) | -- | 8 | B | 7,000 | CWS (nearby) | 0.9 | No | 50 | Nitrate/Pest | Village of White Oak[5] | No | No | Monitor impact of growth in area with historical water quality problems. |
| **WC-13** | RES/AGR | ARG (CP) | 06-02 (H) | 8.0% | LRUSA (Fuquay-Var.) | -- | 8 | A | 300 | Domestic | 0.3 | No | 100 | None | Black Creek | No | No | Monitor impact of growth in southern, coastal plain setting. |
| **WC-14** | RES/AGR | TRI | 03-02 (H) | 5.2% | NUA/WSW | C | 3 - 4 | C | 800 | Domestic | < 0.5 | No | 130 | None | -- | Yes | No | Monitor impact of growth in Jordan Lake WSW critical area (Triassic). |
| **WC-15** | AGR | IFI | 26-02 (H) | 7.2% | LRUSA (Raleigh) | -- | 8 | B/D | 5,000 | Domestic | -- | No | 30 | Rad/Pest | -- | No | No | Monitor impact of growth in northwest Raleigh LRUSA. |
| **WC-16** | COM/RES | GNF | 15-07 (D) | 25.7% | Corp (Raleigh) | -- | 7 | B | 2,700 | Neither | 9.8 | Yes | 70 | Unknown | Brook Forest Townhomes[5] | Yes | No | Highly developed area. Serve as a baseline when comparing to growth areas. |

[1] - RES = Residential; AGR = Agriculture; COM = Commercial

[2] - SCH = Schist; GNF = Gneiss, felsic; MIF = Metaigneous, felsic; TRI = Triassic sedimentary; IFI = Igneous, felsic intrusive; MVF = Metavolcanic, felsic; ARG = Argillite; (CP) = overlying coastal plain sediments.

[3] - Percentage of impervious surface based on Watershed Management Plan estimate for the respective watershed.

[4] - Area recharge rate based on NCDENR Groundwater Section Modified Landscape Model.

[5] - Located nearby

WSW = Water supply watershed; CWS = Community water system

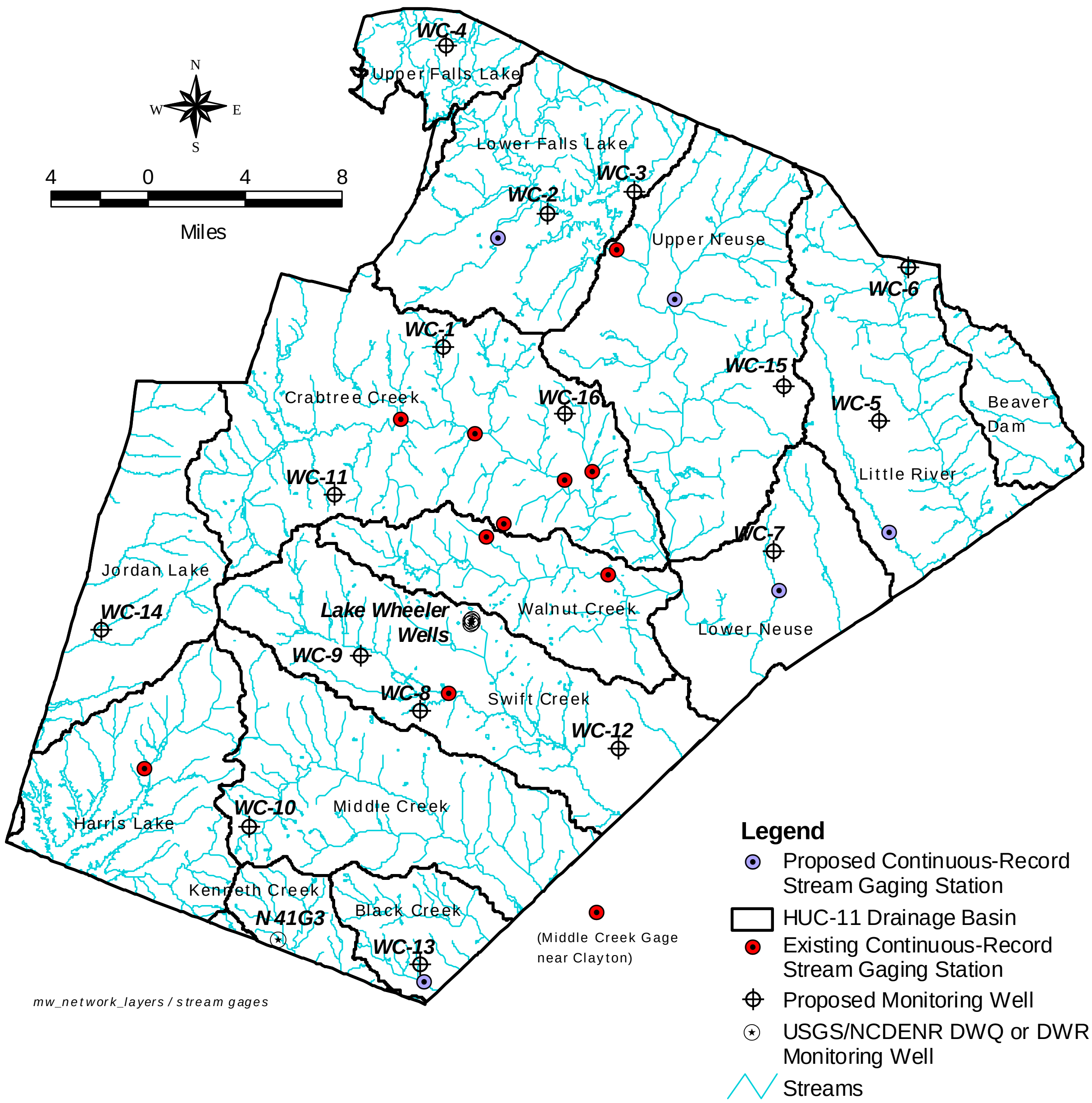



**Figure 6-3**
**Proposed Long-Term Monitoring Well Network and Existing and Proposed Stream Gaging Stations**

# Section 7
# References


Alley, W. M. , T.E. Reilly and O.L. Franke. 1999. *Sustainability of Ground-Water Resources.* USGS Circular 1186.

Amoozegar, A., 2002. Personal communication.

Bachman, L., 1984. *Nitrate in the Columbia Aquifer, central Delmarva Peninsula, Maryland.* USGS Water-Resources Investigations Report 84-4322.

Bolich, R., 2002. Personal communication.

Briel, L., 1997. *Water quality in the Appalachian Valley and Ridge, Blue Ridge, and the Piedmont physiographic provinces, Eastern United States*. USGS Professional Paper 1422-D.

Carpenter, R. H. and J. Reid. 1993. Listing of concentrations of variables of stream sediment, stream water, and groundwater for the Raleigh 30 x 60-minute quadrangle. Open-file report 93-21. North Carolina Geological Survey: Raleigh.

CH2M Hill, 2001. *OWASA Water and Sewer Master Plan Water Demand Forecasts.* Technical Memorandum 3.1.

CH2M Hill, 2003. *Comprehensive Watershed Management Plan.* Prepared for Wake County.

Chemerys, J. C., 1967. *Effect of Urban Development on Quality of Ground Water, Raleigh, North Carolina*. Professional Paper 575B. Geological Survey Research 1967.

Clark, T., 2003. Personal communication.

Cunningham, W. and C. Daniel, 2001. *Investigation of Ground-Water Availability and Quality in Orange County, North Carolina.* USGS Water-Resources Investigations Report 00-4286.

Daniel, C.D. and Paul R. Dahlen. 2002. *Preliminary Hydrogeologic Assessment and Study Plan for a Regional Ground-Water Resource Investigation of the Blue Ridge and Piedmont Provinces of North Carolina*. USGS Water-Resources Investigation Report 02-4105.

Daniel, C.D. and R.A. Payne. 1990. *Hydrogeologic Unit Map of the Piedmont and Blue Ridge Provinces of North Carolina*. USGS Water Resources Investigation Report 90-4035.

Daniel, C.D., 1996. *Ground-Water Recharge to the Regolith-Fractured Crystalline Rock Aquifer System, Orange County, North Carolina.* USGS Water-Resources Investigation Report 96-4220.

Dano, K.E., E. Porter and G. Thyme. 2002. *Geochemical and Geophysical determination of the fate of septic tank effluent in a mountain watershed, Colorado:* Geol. Soc. of America Abstracts with Programs, V34, No. 6, P. 261.

Dusenbury Jr., B.D. 1992. *A Compilation of Measurements of Radon in North Carolina Groundwater and a Study of Sample Collection Methods.* University of North Carolina Masters Thesis 92-68.

Godfrey, J.E., 1978. *Some Studies Relating Water Well Yields to the Geology and Geomorphology of the Triassic Basin in Wake, Chatham, and Durham Counties, North Carolina.* Unpublished report submitted to the Wake County Health Department.

Hardy, A., 2003. Personal communication.

Hardy, A.V. and J.D. Hardy, 1975. *Weather and Climate in North Carolina*. Raleigh, NC. North Carolina Agricultural Extension Service.

Heath, R. C, 1980. *Basic Elements of Ground-Water Hydrology With Reference to Conditions in North Carolina.* USGS Water-Resources Investigations Open-File Report 80-44

Loomis, D.P., 1985. *An Investigation of Radon in North Carolina Groundwater and its Relationship to Rock Type*. University North Carolina, Chapel Hill Masters Thesis.

May, V and J.D. Thomas, 1968. *Geology and Ground-Water Resources in the Raleigh Area, North Carolina*. North Carolina Department of Water and Air Resources, Bulletin 15.

Mew, H.E. Jr., D.V. Lewis, D.K. Hirth, A.J. Keyworth, R.B. Daniels. 2002. *Methodology for Compiling Ground Water Recharge Maps in the Piedmont and Coastal Plain Provinces of the North Carolina. Ground Water Bulletin No. 25.* North Carolina Department of Environment and Natural Resources, Raleigh, North Carolina.

Musgrave, G.W. and H.N. Holtan. 1964. *Infiltration: Section 12 in Handbook of Applied Hydrology*. (ed. by Ven te Chow), McGraw Hill, NY.

North Carolina Geological Survey. 1985. *Geologic Map of North Carolina.*

North Carolina Geological Survey. 2003. *Geologic and Hydrogeologic Map of the Raleigh Quadrangle.* Unpublished (GIS layers).

Northern Virginia Planning District Commission, 1979. *Guidebook for Screening Urban Nonpoint Pollution Management Strategies.* Final Report Prepared for Metropolitan Washington Council of Governments.

Powell, J. and J. Abe, 1985. *Availability and quality of ground water in the Piedmont Province of Virginia.* USGS Water Resources-Investigations Report 85-4235.

Spruill, T., J. Williams, D. Galeone and D. Harned. 1997. *Radon in Guilford County, North Carolina*. USGS Survey Fact Sheet FS-147-97.

Strickler, J., 2002. Personal communication.

Strickler, J., 2003. Personal communication.

Thornthwaite, C.W. and R.R. Mather, 1957. *Instructions and Tables for Computing Potential Evapo-transpiration and the Water Balance.* Drexel Institute of Technology, Centerton, New Jersey Publications in Climatology 10: 185-311.

United State Environmental Protection Agency, 2000. *Arsenic Occurrence in Public Drinking Water Supplies.* EPA-815-R-00-023.

Wade, H., C. Bailey, J. Padmore, K. Rudo, B. Williams, and A. York, 1997. The Interagency Study of the Impact of Pesticide Use on Ground Water in North Carolina. Prepared for the North Carolina Pesticide Board.

Weaver, C.J., 1998. *Low-Flow Characteristics and Discharge Profiles for Selected Streams in the Neuse River Basin, North Carolina.* USGS Water-Resources Investigation Report 98-4135.

Weaver, C.J. and B.F. Pope, 2001. *Low-Flow Characteristics and Discharge Profiles for Selected Streams in the Cape Fear River Basin, North Carolina, through 1998.* USGS Water-Resources Investigation Report 01-4094.

Welby, Charles. 1967. *Groundwater Yields in the Raleigh Quadrangle.* WRRI Report No. 8.

Welby, C.W. 1983. *Wake County Ground Water Study "Risk Level" Areas.* Department of Marine, Earth and Atmospheric Sciences, North Carolina State University.

Welby, C.W., 2000. *A study of nitrate movement to groundwater at the Neuse River Waste Water Treatment Plant.* WRRI of the University of North Carolina.

Welby, C.W. and T. M. Wilson. 1982. *Use of Geologic and Water Yield Data from Ground Water Systems as a Guide for Ground Water Planning and Management*. Water Resources Research Institute of the University of North Carolina. Report No. 184.

## Instructions for Installing the Wake County Incident Management Database

The Wake County Incident Management Incident database is intended to allow for easy viewing and querying of data pertaining to soil/groundwater contamination incidents in the County. The NCDENR UST and Groundwater Sections maintain the database for reported incidents throughout the State. Only those occurring in Wake County are provided in this version of the database. The locations of incidents with available latitude/longitude information can be mapped using the "incident_database" GIS shapefile.

To load the incident management database onto your computer, complete the following steps:

1. Create a directory called "Wake Incidents" on your C: drive.
2. Copy the file "WakeIncidents.mdb to that directory. The update feature contained in the database will not work if it is not placed in this directory.
3. Click on the file or open it in MS Access 2000 to view, query and update the database.

For questions pertaining to installing, viewing, querying or updating the database please contact John Boyer: boyerjd@cdm.com / 919-787-5620.

For questions pertaining to the information contained within the database, please contact the NCDENR Groundwater Section.

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## Instructions for Installing the Wake County Community Water System Water Quality Database

You can copy and access the Community Water System (CWS) Database to any location on your computer, or simply run it from the enclosed CD. The database allows for simple querying of water quality results based on PWS identification number and date range. The data contained in the CWS database was provided by the NCDENR PWS Section and is provided "as is" without guarantee of any kind.

For questions pertaining to viewing or querying the database please contact John Boyer: boyerjd@cdm.com / 919-787-5620.

For questions pertaining to the information contained within the database, please contact the NCDENR Public Water Supply Section.

# THE PIRF INCIDENT MANAGEMENT DATABASE

NCDENR-DWQ GROUNDWATER SECTION

## INTRODUCTION

On average, DEM/Groundwater Section can expect in excess of 700 reports of groundwater and/or soil contamination per year. Given the number of contamination incidents taking place, it became necessary to develop a computerized system by which this data might be easily managed. This data is now available on the DWQ\GW webpage in two formats: Paradox 4.0 and Ascii Delimited Text.

## DATA STORAGE

Data is submitted to the Groundwater Section Central Office from the Regional Offices along with the current status of the site. Data is stored in two primary tables as follows:

1) PIRF - (table contains data obtained from PIRF forms submitted by the Regional Offices).
2) Status - (table contains the dates in which the site was issued a Notice of Violation and/or was Closed Out).

## CODES USED BY THE PIRF DATABASE

The database uses a variety of numeric codes in order to simplify data entry and search and retreival activities. The codes used by the system are as follow:

### Codes found in the PIRF Database

| Ownership | Operation Type | Pollution Source |
|---|---|---|
| 0. N/A | 0. N/A | 1. Intential Dump |
| 1. Municipal | 1. Public Service | 2. Pit, Pond, Lagoon |
| 2. Military | 2. Agricultural | 3. Leak, UST |
| 3. Unknown | 3. Residential | 4. Spray Irrigation |
| 4. Private | 4. Educational/Religious | 5. Land Appication |
| 5. Federal | 5. Industrial | 6. Animal Feedlot |
| 6. County | 6. Commercial | 7. Source Unknown |
| 7. State | 7. Mining | 8. Septic Tank |
| | | 9. Sewer Line |
| | | 10. Stockpile |
| | | 11. Landfill |
| | | 12. Spill-surface |
| | | 13. Well |
| | | 14 Dredge Spoil |
| | | 15. Non-Point Source |

| Pollutant Type | Location | Setting |
| --- | --- | --- |
| 1. Pesticide/herbicide | 1. Facility | 1. Residential |
| 2. Radioactive waste | 2. Railroad | 2. Industrial |
| 3. Gasoline/diesel | 3. Waterway | 3. Urban |
| 4. Heating Oil | 4. Pipeline | 4. Rural |
| 5. Other petroleum prod. | 5. Dumpsite | |
| 6. Sewage/septage | 6. Highway | |
| 7. Fertilizers | 7. Residence | |
| 8. Sludge | 8. Other | |
| 9. Solid Waste Management | | |
| 10. Metals | | |
| 11. Other inorganics | | |
| 12. Other organics | | |

## Codes used in the Status Table

The status of a particular groundwater or minor_soil incident is recorded in the Status Table in the Incident Phase field. Three codes are currently being used to indicate the status of a particular incident.

Incident Phase

1. CO – Closed Out
2. FU – Follow Up
3. RA – Remedial Action Implemented.

## RELIABILITY AND ACCURACY OF PIRF DATA

The PIRF Incident Management Database is a working database. It was created to facilitate the ongoing daily activities of the Division of Water Quality-Groundwater Section in its efforts to protect the environment. Keeping the database updated is a monumental task, with a number of people entering, checking, and manipulating its data all day every day. Because of this constant activity, errors do take place. Therefore, the Groundwater Section, although pleased to provide this data to the public, does not warranty or assure this data in any way. The Incident Management Database is provided "as is" without guarantee of any kind.

## ArcView Shapefile Catalog and Descriptions
## Wake County Comprehensive Groundwater Investigation

| *Directory* | *Shapefile Name* | *Description* | *Source* |
|---|---|---|---|
| **Quality** | gross_alpha | Locations of CWS wells where gross alpha was detected above drinking water standards, 1979 - 2001. | PWS Section, 2002 |
| | metals | Locations of CWS wells where select heavy metals were detected above drinking water standards, 1979 - 2001. | PWS Section, 2002 |
| | nitrates | Locations of CWS wells where nitrate was detected above drinking water standards, 1979 - 2001. | PWS Section, 2002 |
| | organics | Locations of CWS wells where select volatile and synthetic organic constituents were detected above drinking water standards, 1979 - 2001. | PWS Section, 2002 |
| | mhp_radon | Radon concentrations from mobile home park wells. | Dusenbury, 1992 |
| | subdivisions_radon | Radon concentrations from CWS wells (subdivisions). | Dusenbury, 1992 |
| | all_arsenic_detects | Locations of CWS wells with arsenic detections, 1979 -2001. | PWS Section, 2002 |
| | all_12dcp_detects | Locations of CWS wells with 1,2-dichloropropane detections, 1979 - 2001. | PWS Section, 2002 |
| | all_edb_detects | Locations of CWS wells with ethylene dibromide detections, 1979 - 2001. | PWS Section, 2002 |
| | fe_by_hydrounit | Iron concentrations at CWS wells from the most recent sample set. Hydrogeologic unit code in which the CWS well is located is included. | PWS Section, 2002 |
| | mn_by_hydrounit | Manganese concentrations at CWS wells from the most recent sample set. Hydrogeologic unit code in which the CWS well is located is included. | PWS Section, 2002 |
| **Geology and Hydrogeology** | creed_hydrounit | Hydrogeologic units in the Creedmor area of Wake County. This coverage should be used as a "topping" to the wake_hydrounit coverage. | NCGS, 2003 |
| | wake_hydrounit | Hydrogeologic units in Wake County. | NCGS, 2003 |
| | wake_rockunit | Geologic units in Wake County. Rock unit descriptions are included in the file "wake_rockunit.doc". | NCGS, 2003 |
| | diabase_dikes | Observed or inferred diabase dikes in Wake County. | NCGS, 2003 |
| **Wellhead Protection** | hazsites_polygons | Locations (polygons of properties) of uncontrolled and unregulated hazardous sites. Includes sites from the CERCLIS National Priorities List, the State Inactive Hazardous Sites List and the Sites Priority List. | NCBasinPro |
| | hazsites_points | Locations (centroids) of uncontrolled and unregulated hazardous sites. Includes sites from the CERCLIS National Priorities List, the State Inactive Hazardous Sites List and the Sites Priority List. | NCBasinPro |
| | animal_sites | Unverified locations of intensive livestock operations registered with DWQ. | NCBasinPro |
| | incident_database | Point theme showing locations of incidents possibly resulting in soil or groundwater contamination, as contained in the DWQ Incident Management Database (a.k.a PIRF database). It is important to note that the point coverage includes only 715 of the approximately 1,210 reported incidents in Wake County. This is a result of missing, incomplete or incorrect lat/long information for many incidents reported in the PIRF Database. [incident_database.avl is the associated legend file. incident_database.doc is a description of the database provided by DWQ]. | DWQ / DWM |
| | usts | Point them showing locations of operational, permanently closed, or temporarily closed underground storage tanks (USTs), as contained in the DWM Regional UST Database. It is important to note that the point coverage includes only 2,353 of the approximately 4,725 reported USTs in Wake County. This is a result of missing, incomplete or incorrect lat/long information for many USTs reported in the Database. [usts.avl is the associated legend file]. | DWM Regional UST Section |
| **Monitoring Well Network** | mw_network-draft | Proposed locations for Wake County monitoring wells | CDM |
| | lake_wheeler_wells | USGS-DWQ Lake Wheeler monitoring wells. | USGS |
| | dwr_well_n41g3 | DWR monitoring well (south of Fuquay-Varina). | DWR |

## ArcView Shapefile Catalog and Descriptions
## Wake County Comprehensive Groundwater Investigation

| *Directory* | *Shapefile Name* | *Description* | *Source* |
|---|---|---|---|
| **Miscellaneous** | recharge_contours | Line theme (contours) representing estimated average annual groundwater recharge rates in inches per year, derived from the NCDENR Groundwater Section Modified Landscape Model. [recharge_contours is associated legend file] | NCDENR DWQ |
| | wake_stdev_spft | NCDENR Groundwater Section modified Landscape Model polygons for Wake County. "Recharge_c" field denotes estimated recharge rate in cm/year, under average annual conditions [recharge_c.avl is associated legend file]. | DWQ |
| | soil_groups | Polygons representing soil group classifications and hydrologic soil types. | Wake County |
| | npdes_maj | Location of major NPDES discharges in Wake County | DWQ |
| | npdes_min | Location of minorr NPDES discharges in Wake County | DWQ |
| | usgs_gaging_stations | Current, continuous USGS stream gaging stations in Wake County. Also included is the Middle Creek gaging station in Johnston County, near the Wake County line. | |
| | cws_yield_hydrogeo_unit | CWS well locations with associated well yield and hydrogeologic unit data. | PWS Section and NCGS |
| **Supply** | CWS_wells | Community water system wells in Wake County. Both "active" and "inactive" wells are included. Where available, well yield is included. | PWS Section, 2002 |
| | CWS_wells_ep | Community water system wells in Wake County. Both "active" and "inactive" wells are included. Where available, well yield is included. A field with the combined PWSID and entry point is included (e.g., 392091-3). | PWS Section, 2002 |
| | Heater_wells | Heater Utilities CWS wells. Locations are approximate. "CWS_wells", provided by the PWS Section is considered a more accurate representation of CWS wells, including Heater wells. | Heater Utilities |
| | parcels_domestic_wells | Developed parcels not connected to a municipal water system, Heater Utilities system, or Carolina Water Service system. | Wake County Tax parcel file & municipal water line coverages |
| | parcels_septic | Developed parcels not connected to a municipal sewer system or other system with a surface water discharge. | Wake County Tax parcel file & municipal water line coverages |
| | streets | Wake County streets. | Tiger Files (ESRI) |
| | wake co outline | Wake County limits. | Wake County |
| | subdiv_cws | Subdivisions served by Heater Utilities or Carolina Water Service. | Wake County Subdivison coverage |
| **Wake Well Permit Database** | well_data_parcels | Well information from the Wake Co. well permit database located spatially by parcel. Well data includes permit number, driller name, depth, casing, yield and static water level. Includes wells entered into the Wake Co. well permit database through 8/1/02. | Wake County |
| | well_data_centroids | Same as "well_data_parcel" but as a point theme (centroids of parcel polygons). | Wake County |
| | casing_depth | Line theme (contours) representing depth of casing of wells in the Wake Co. permit database. [casing_depth is associated legend file]. | Wake County |
| | max_yield_contours | Line theme (contours) representing maximum well yield within 5,000 ft by 5,000 ft grid units. Well yield data from the Wake Co. well permit database. [max_yield_contours.avl is associated legend file]. | Wake County |
| | max_yieldperfoot_contours | Line theme (contours) representing maximum well yield per foot of well depth within 5,000 ft by 5,000 ft grid units. Well yield and depth data from the Wake Co. well permit database. [max_yield_contours.avl is associated legend file]. | Wake County |

Note: All coverages are in North Carolina State Plane feet (1983) coordinate system.

**Appendix D**
**Rock Unit Descriptions**

*Note: Rock unit descriptions provided by the North Carolina Geological Survey, 2003.*
*All rock unit descriptions are considered preliminary (DRAFT).*
*Rock unit codes correspond to those shown on Figure 2-2.*

## SEDIMENTARY/SURFICIAL UNITS

**Late Triassic**
*Lithofacies Assoc. III*
Trcc - conglomerate: reddish-brown to dark brown, irregularly bedded, poorly sorted, cobble to boulder conglomerate. (CA)

Trcs/c - sandstone w/interbedded conglomerate: reddish-brown to dark brown, irregularly bedded, poorly sorted, coarse-grained to pebbly, muddy lithic sandstones with interbedded pebble to cobble conglomerate. (CA)

Trcsc - pebbly sandstone: reddish-brown, pebbly, poorly sorted, coarse-grained, lithic, feldspathic sandstone; locally contains laterally discontinuous pebble and cobble trains and conglomeratic channel lags. (SED)

Trcs - interbedded sandstone and pebbly sandstone: reddish-brown to dark brown, irregularly bedded to massive, poorly to moderately sorted, medium- to coarse-grained, muddy lithic sandstones with occasional matrix-supported granules and pebbles and 1-5 cm thick basal gravel layers. (CA)

*Lithofacies Assoc. II*
Trcs/si2 - sandstone w/interbedded siltstone: whitish-yellow to grayish-pink to pale red, coarse- to very coarse-grained, cross-bedded, lithic arkose that fines upwards through yellow to reddish-brown, medium- to fine-grained sandstone, to reddish-brown, burrowed and rooted siltstone. (CA)

Trcsi/s - siltstone w/interbedded sandstone: reddish-brown, extensively bioturbated, siltstone interbedded with tan to brown, fine- to medium-grained, arkosic sandstone. Locally contains zones of calcareous stringers and nodules. (SED)

*Lithofacies Assoc. I*
Trcs/si1 - sandstone with interbedded siltstone: pinkish-gray to light-olive-gray, fine- to medium-grained, micaceous, feldspathic, crossbedded sandstone; fine- to very fine-grained biotite is a distinctive accessory mineral; unit includes inter-bedded reddish-brown, bioturbated siltstone and muddy, fine-grained sandstone. (CA)

## IGNEOUS UNITS

**Late Paleozoic**
Pacg - granite of the Avents Creeks type: Light gray to pinkish gray, fine- to medium-grained granite composed mainly of quartz, microcline perthite, and granophyre, with accessory biotite, garnet, magnetite, and muscovite; generally massive, but locally foliated near contacts. The granite is characterized by low color index (percentage of dark-colored minerals, generally less than 2, and ranging fron 1 to 5), and by an abundance of perthitic alkali feldspar. Plagioclase occurs almost entirely as a component of perthite, so the rock is a hypersolvus granite. It occurs mainly in a large pluton exposed along Avents Creek in the southeastern part of the quadrangle and extending into the Fuquay-Varina quadrangle to the east and the Mamers quadrangle to the south. The age is uncertain, but it appears to be younger than the granites listed below and may be middle to late Paleozoic.(Cokes)

Plbg- Lake Benson Pluton:  medium-grained, locally porphyritic biotite granite. May contain white mica, epidote, allanite, and zircon. (LW)

Png - Nottingham granite: (Garner)

Prg - Rolesville granite:  Gray-white to pink-white, medium-grained, locally weakly porphyritic, moderate- to well-foliated, leucocratic (CI<15) biotite granite and pink-white, medium- to coarse-grained, unfoliated to weakly foliated granite. Locally pegmatitic granite. (Grissom)

Pwg - Muscovite-biotite granite of Wyatt pluton (Pennsylvanian):  Very light gray, medium-grained, muscovite-biotite monzogranite and pinkish-gray, medium- to coarse-grained, muscovite-biotite monzogranite.  Presence of muscovite (less abundant than biotite) and accessory garnet are distinctive.  Granite is foliated, and inclusions of Raleigh gneiss are common. (92-269)

## METAMORPHIC UNITS

### *CAROLINA TERRANE*

*META-IGNEOUS UNITS*

**Neoproterozoic – Paleozoic**
Umstead Meta-intrusive Suite
PzZrg - Reedy Creek metagranodiorite:  leucocratic (CI<10) light tannish-gray, medium-grained to porphyritic, foliated and lineated to massive, metagranodiorite. Locally white mica rich and/or contains blue quartz phenocrysts and clots of biotite and epidote. (RW)

PzZuw - White mica granitic gneiss:  leucocratic (CI<5) white to tan, medium-to coarse-grained, moderately to well foliated, white mica metagranite to white mica granitic gneiss. (RW)

PzZug - Biotite metagranite:  Leucocratic (CI<10) pink to tan, medium-grained, weakly to moderately foliated locally porphyritic biotite and quartz metagranite. (RW)

PzZub - Biotite granitic gneiss:  mesocratic (CI<35) gray, medium- to fine-grained, well foliated, biotite granitic gneiss. (RW)

PzZrs - Reedy Lake schist:  dark green, coarse-grained, moderately to well foliated, chlorite + actinolite + talc schist. (RW)

PzZgc - Chalk Level metagranite:  Light gray to pinkish white, fine- to medium-grained biotite.  It generally has a distinct foliation and a color index of 5 to 8.  Biotite is the main accessory mineral.  The granite forms small plutons west of Chalk Level Church on the eastern side of the Cape Fear River valley and the lower valley of Parkers Creek.  (Cokes)

CZbl - metamorphosed leucogranite of the Buckhorn Dam intrusive suite:  Light-colored, medium- to coarse-grained rocks with poorly developed foliation; composed mainly of plagioclase, quartz, and microcline, with minor amounts of chlorite, sericite, epidote, biotite, and opaque minerals.  The color index is usually less than 5. (Cokes)

CZsl - Sunset Lake Pluton:  A distinctive porphyritic rock, containing abundant euhedral phenochrysts of sodic plagioclase, beige where fresh, and sparse roundish quartz phenocrysts in a groundmass of a vermicular intergrowth of feldspar and quartz.  Very leucocratic (CI < 5) with traces of chlorite, epidote, garnet, titanite, zircon, and opaques. (Apex)

CZbg - metamorphosed granitoid rocks of the Buckhorn Dam intrusive suite: Metatonalite, metagranodiorite, and metagranite: Dark-colored, medium- to fine-grained rocks with variably developed foliation; composed mainly of plagioclase, quartz, epidote, microcline, biotite, and opaque minerals, with minor amounts of sericite, sphene, chlorite, and garnet. The color index is generally high, ranging from 15 to 30. The more felsic granitoid rocks are mineralogically and chemically similar to the felsic metavolcanic rocks described below, and are probably the intrusive equivalents. The unit includes a number of small granitoid bodies, probably originally dikes and plugs, intruding felsic metavolcanic rocks northeast of the main outcrops of Buckhorn Dam intrusive suite. (Cokes)

PzZbg1 - ???????: Mixed facies of dark gray to bluish-gray, fine- to medium-grained, weakly to moderately foliated, mesocratic (CI>25) garnet-bearing biotite metagranite and light pinkish-tan, fine- to medium-grained, weakly to moderately foliated, leucocratic (CI<5) magnitite-biotite metagranite. (Fuquay)

PzZbg2 - ???????: Light pinkish-gray, medium-grained, nonfoliated to weakly foliated, leucocratic (CI<10) garnet- and epidote-bearing biotite metagranite. (Fuquay)

PzZgp - Parkers Creek metagranite: Dark gray, generally fine grained, foliated to massive, garnet-biotite metagranite. It is characterized in hand specimen by abundant biotite and conspicuous small garnet crystals, which give it a darker appearance than other nearby granites. The color index is generally 15 to 20. The main minerals are plagioclase, perthitic microcline, quartz, biotite, garnet, and epidote, with small amounts of opaque minerals, muscovite, and sphene. The pluton crops out on both sides of Parkers Creek in its middle reaches. (Cokes)

PzZgr - Reedy Creek metagranodiorite: Light tannish-gray, medium-grained to porphyritic, foliated and lineated to massive, leucocratic (CI<10) metagranodiorite. Locally white mica rich and/or contains blue quartz phenocrysts and clots of biotite + epidote. (Fuquay)

CZbm - metamorphosed mafic rocks: Metagabbro and metadiorite: Dark green, coarse-to fine-grained, variably foliated rocks composed mainly of epidote, chlorite, hornblende (and/or actinolite), plagioclase, opaque minerals and minor quartz. The rocks appear to be gradational into granitoids of the Buckhorn Dam intrusive suite. (Cokes)

CZdi - metadiorite (Cambian and (or) Late Proterozoic?): Metamorphosed biotite- and hornblende-biotite diorite to quartz diorite. (92-269)

## METAVOLCANIC AND METASEDIMENTARY UNITS

**Late Proterozoic-Cambrian**
*Cary Metamorphic Suite*
CZic - undifferentiated crystalline rocks of the Carolina Slate Belt: metamorphosed volcanic, volcaniclastic, and intrusive rocks. (SW Dur)

CZp - Coles Branch phyllite: tan to dark silvery gray, fine-grained, well foliated, leucocratic white mica phyllite locally containing quartz and plagioclase phenocrysts or compositional layering including mesocratic white mica-chlorite-biotite phyllite and greenstone.

CZbr - Felsic metavolcanic rocks: Mainly white to light gray, fine-grained metavolcanic rocks, with rhyolitic or dacitic composition; generally with well- developed schistosity; composed mainly of quartz, plagioclase, microcline, muscovite, and biotite, commonly with small amounts of garnet. The unit also includes some darker colored rocks of intermediate to mafic composition that are metamorphosed to mica phyllite. (Cokes)

CZbr1 - Big Lake-Raven Rock schist 1: light tan to white, fine- to medium-grained white mica quartzitic schist containing abundant relict phenocrysts of blue quartz and plagioclase or local white to gray lapilli and rock clasts.

CZbr2 - Big Lake-Raven Rock schist 2: light tan to white, fine- to medium-grained, well foliated white mica schist containing fragmental textures including white to gray lapilli tephra and rock clasts.

CZbr3 - Big Lake-Raven Rock schist 3: Light tan to orange-brown, fine- to medium-grained, white mica schist to gneiss. (Fuquay)

CZfv - felsic metavolcanic rock and phyllitic metasiltstone (Cambrian and (or) Late Proterozoic?): Generally fine-grained, almost massive to phyllitic, mainly dacitic metavolcanic rock, and fine-grained phyllitic metasiltstone composed mostly of quartz, muscovite, and plagioclase. (92-269)

CZsg - Sycamore Lake greenstone: variably light green to dark black-green to gray-green, fine- to medium-grained, unfoliated to well foliated, epidote actinolite chlorite greenstone and chlorite + biotite + actinolite phyllite.

CZta - Turkey Creek amphibolite: dark black-green, fine- to medium-grained, moderately to well-foliated and locally lineated, amphibolite, biotite amphibolite, and locally hornblende gneiss and metagabbro. Relict plagioclase phenocrysts are preserved in fine-grained amphibolite.

CZha - hydrothermally altered rocks and mineralized zones, regionally metamorphosed: Quartz granofels, epidosite, muscovite-quartz schist, biotite schist, and iron ore. The rocks contain various combinations of quartz, muscovite, epidote, garnet, biotite, iron oxides, and manganese oxides. The rocks are fine- to medium-grained, and schistose to massive. This unit includes the Buckhorn-type iron ore deposits. Judging from boulders at the Buckhorn iron mine, the main seams of iron ore were as much as 2 meters thick. Protoliths of the altered rocks are probably felsic metavolcanic rocks and granite. The age of alteration and mineralization is uncertain, but the rocks are regionally metamorphosed and appear to be associated with the Avents Creek granitic intrusion or one of the older granites. (Cokes)

CZhb - meta-hornblendite and hornblende metagabbro: Greenish-black, medium- to coarse-grained, massive rocks composed mostly of hornblende, with lesser amounts of plagioclase, epidote, biotite, quartz, and opaque minerals. The rocks occur in four isolated groups of outcrops and residual boulders, on both sides of Avents Creek north of Cokesbury. The largest body is about 250 meters across. The occurrences are interpreted to be intrusive plugs. The rocks are mineralogically similar to some rocks of the Buckhorn Dam intrusive suite but are spatially separated from the main part of the suite and may be unrelated. (Cokes)

CZmv - interlayered mafic, intermediate, and felsic metavolcanic rocks: Mainly dark green to light gray, fine-grained metavolcanic rocks with well-developed schistosity; composed mainly of quartz, feldspar, epidote, chlorite, actinolite, biotite, and muscovite. (Cokes)

Czu - meta-ultramafic rocks: Dark green, coarse- to fine-grained, semi-schistose to massive rocks composed mainly of chlorite, actinolite, talc (?), opaque minerals, and epidote, locally with relict clinopyroxene. Rocks occur in three small areas; two small bodies occur on the western bank of the Cape Fear River and one is associated with (and probably gradational into) metagabbro just south of the Jonesboro fault near Corinth. The age is uncertain, but the rocks are possibly related to the Buckhorn Dam intrusive suite. (Cokes)

***SPRING HOPE TERRANE***

CZss - (meta)siltstone:  Fine-grained, yellowish-gray to greenish-gray metasiltstone. Composed of quartz, plagioclase, muscovite, and chlorite.  Accessory minerals include titanite, epidote, apatite, and magnetite (?).  (Stancils)

CZsa - argillite:  Very fine grained, light-gray to light-olive-gray argillite.  Muscovite-rich layers, generally <1 mm in thickness, alternate with thicker quartz-rich layers. (Middlesex)

CZsu - Metavolcanic rocks and phyllite undivided:  included chlorite phyllite, muscovite phyllite, greenstone, and quartz-feldspar-white mica phyllite. (Lake Wheeler)

CZsp - Muscovite Phyllite:  grayish-green muscovite phyllite and phyllonite, commonly with lesser amounts of chlorite and very rarely garnet. (Lake Wheeler)

CZsm - Mafic metavolcanic rocks:  greenstone, chlorite +/- muscoviet phyllite, and sparse epidote-rich quartzofeldspathic rocks.  Phyllite is the predominant lithology. (Lake Wheeler)

CZspv - Muscovite Phyllite:  grayish-green muscovite phyllite and phyllonite, commonly with lesser amounts of chlorite and very rarely garnet. (Lake Wheeler)

CZsfv - fine-grained felsic volcanic:  Aphanitic, gray, quartzo-feldspathic, volcanic rock interpreted to vitric and vitric-crystal tuff.  (Middlesex 96-1)

***FALLS LAKE TERRANE***

*METASEDIMENTARY UNIT*

CZfs - Falls Lake schist:  variably gray colored, mesocratic, medium- to coarse-grained, biotite-white mica-oligoclase-quartz schist locally having garnet, staurolite, kyanite, and chlorite porphyroblasts.  Pods of talc schist exposed locally. (Raleigh West)

CZfu - ultramafic rocks (undivided):  Variably altered ultramafic rocks including metapyroxenite, actinolite-chlorite schist, and talc schist. (Creedmoor)

CZfut - talc schist:  White to gray talc-tremolite schist, talc-chlorite schist, and soapstone. Rhombohedral cavities suggest former presence of a carbonate mineral (ankerite?). (Creedmoor)

CZfus - serpentinite:  Pale greenish-gray, fine-grained, and massive to moderately-foliated; contains fibrous tremolite, clots of magnetite, and minor amounts of talc and dark green, unfoliated, chlorite actinolite rock.  (Creedmoor)

CZfua - actinolite rock and actinolite-chlorite schist:  Dark green, schistose to almost massive, splintery rock composed of actinolite and varied amounts of chlorite; minor amounts of talc and magnetite octrahedra are common.  (Creedmoor)

CZfa - amphibolite:  Dark gray to black, fine- to coarse-grained, well-foliated dikes generally parallel to foliation within country rock.  (Creedmoor)

CZfp - pebbly paragneiss and schist (Cambrian and (or) Late Proterozoic?):  Biotite-muscovite-oligoclase-quartz paragneiss and schist containing rounded granitoid pebbles.  Pebbles are matrix
supported and typically sparse.  Interpreted as metamorphosed pebbly mudstone or graywacke. (92-269)

CZfq - siliceous rock (Cambrian and (or) Late Proterozoic?):  Mainly chalcedony with drusy quartz crystals; occurs in serpentinite at crest of Adam Mountain.  (92-269)

CZfqz - quartzite (Cambrian and (or) Late Proterozoic?): White, granular, and well foliated. (92-269)

***CRABTREE TERRANE***

*META-PLUTONIC UNITS*

**Proterozoic – Cambrian**
*Crabtree Creek Gneiss*
CZcc1- Crabtree Creek gneiss: leucocratic (CI=5-10) greenish-gray to pink, medium- to coarse-grained, well foliated and lineated, porphyroclastic granitic orthogneiss facies containing elliptical to rod-shaped quartz crystals, and white mica. (RW)

CZcc2 - Crabtree Creek gneiss: leucocratic (CI=0-5) gray-white to white-pink, medium-grained, well foliated and lineated, granitic orthogneiss facies containing mica and feldspar porphyroclasts and elongate quartz aggregates. (RW)

## METASEDIMENTARY AND METAVOLCANIC UNITS

*Crabtree Metamorphic Suite*
CZcrc - Richland Creek schist: mixed unit of silver-gray, fine- to medium-grained, well foliated, pelitic garnet + staurolite + tourmaline + white mica + biotite phyllite schist and tan to white, fine-grained, moderately foliated felsic gneiss. Contains layers of CZcgs. (RW)

CZcfg - Felsic gneiss: pinkish-gray to tan-white, fine- to medium-grained poorly to well foliated, weakly banded microcline-plagioclase-quartz-white mica gneiss and leucogneiss, locally with magnetite. (LW)

CZcwq - White mica-rich and quartz-rich schist: gold-gray to silver-gray, very fine- to fine-grained, moderately well foliated quartz-biotite and/or chlorite-white mica schist containing sparse to abundant garnet interlayered with silver-white, fine- to medium grained, moderately foliated white mica-plagioclase-quartz schist. (LW)

**Late Proterozoic to Early Paleozoic**
CZcbh - Biotite +/- hornblende gneiss and schist: white-gray to black-gray, very fine- to fine-grained, moderately well foliated, unlayered to moderately layered, biotite +/- hornblende-bearing white mica-quartz-microcline-plagioclase gneiss and schist. Interlayered with lesser green-black, fine-grained moderately foliated plagioclase-chlorite-biotite schist and tan, fine-grained, weakly foliated epidote-hornblende-plagioclase rock. (LW)

CZcm - ilmenite-magnetite quartzite (Cambrian and (or) Late Proterozoic?): Occurs near U.S. Highway 70 entrance to Umstead State Park. (92-269)

CZchc - Horse Creek schist: Silvery gray, coarse-grained, well foliated, lineated and layered, white mica + biotite schist containing conspicuous porphyroblasts of garnet, kyanite, and minor staurolites. (RW)

CZcgs, CZcgs - Muscovite schist: fine-grained white mica phyllite and schist containing garnet porphyroblasts. Locally includes fine-grained, slaty graphite schist with garnet porphyroblasts - CZcgs (LW)

***RALEIGH TERRANE***

CZrgn - Raleigh gneiss:  pinkish-gray to tan-gray, medium-grained, weakly to moderately foliated biotite-bearing granitic orthogneiss; black-gray to tan-gray, medium-grained, moderately foliated, variably layered biotite +/- hornblende-bearing quartz-plagioclase gneiss and schist; and lesser gray-black, fine-grained amphibolite and gold-brown, medium-grained biotite schist.

CZqfg - heterogeneous gneiss and schist:  Fine- to medium-grained, white to medium gray quartz-plagioclase +/- biotite-muscovite gneiss and quartz-muscovite schist.  Interlayered with muscovite schist, biotite schist, fine-grained biotite gneiss, and amphibolite.  Local layers contain abundant plagioclase crystals and sparse white lithic fragments elongate parallel to foliation. (Clayton)

CZgn - (Edmondson - CZqfg on Clayton, Powhatan)

CZgn - biotite gneiss:  Medium- to coarse-grained, light-gray to medium-light-gray, well-foliated, quartzofeldspathic gneiss.  Contains interlayers of light-gray to pale-pink felsic gneiss, white to light-gray, fine-grained muscovite schist, and greenish-black to black amphibolite.  Where it is in contact with metamudstone, the gneiss is predominantly fine-grained, white to pale-pink felsic gneiss with scattered biotite flakes.  The felsic gneiss includes metasediment and metavolcanic rock.  Some felsic gneiss is metatuff containing rock fragments parallel to the direction of the foliation and cleavage.  Metamorphic grade increases to the north. (Powhatan)

Felsic Gneiss - Pinkish-gray to tan-white, fine- to medium-grained poorly to well foliated, weakly banded

microcline-plagioclase-quartz-white mica gneiss and leucogneiss, locally with magnetite. (Garner)

CZflg - Falls leucogneiss:  leucocratic (CI<5) pink-gray to orange-tan, medium-grained, weakly to moderately foliated and strongly lineated, biotite magnetite granitic gneiss.

CZra - (Angier)

CZrbg - biotite granitic orthogneiss:  medium-grained, weakly banded, weakly porphyritic well foliated granitic gneiss.  Phenocrysts are alkali feldspar; also contains white mica, epidote, and titanite.

CZrl – fine-grained leucocratic gneiss:  very light gray, fine-grained, leucocratic epidote-plagioclase-quartz gneiss, locally containing darker, hronblende-bearing interlayers.  Composition suggests volcanic origin.

PzZgg - gneissic biotite granitoid (Paleozoic?):  Foliated biotite granitoid and granitoid orthogneiss interlayered with Raleigh gneiss.  Includes Wake Forest pluton and Greshams Lake pluton. (92-269)

## FAULT ROCKS

Trfb - fault breccia:  silicified and/or hematite-stained fault breccia containing angular clasts of Triassic and pre-Triassic rock material along Jonesboro fault.

my - mylonite and mylonite gneiss:  Recrystallized mylonite and thinly banded "ribbon" gneiss along Falls Lake thrust. (92-269)