*Proposal for the*

# Groundwater Resource Assessment in Wake County, North Carolina

*Submitted to*

**Wake County Environmental Services**

*prepared by*

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# INTRODUCTION

Wake County is located in central North Carolina within the Piedmont Physiographic Province, excluding the southeastern corner, located on the edge of the Coastal Plain. Most of the County belongs to the Neuse River Basin, with the southwestern portions found within the Cape Fear River Basin. Groundwater occurs in regolith and fractured-bedrock aquifers, primarily flowing through a complex network of interconnected openings along joints and faults. Wake County is the second-largest county in the state and one of the fastest growing counties in the country, with a population that exceeds one million people in 2015 (State of North Carolina, 2016). The population is projected to double within the next 40 years which will increase demand for drinking-water resources. In 2010, groundwater withdrawals from domestic wells in the County were estimated to be 18.9 million gallons per day (U.S. Geological Survey, 2010). A comprehensive groundwater investigation was conducted by CDM (2003) to create a baseline snapshot of groundwater resources within Wake County.

Wake County regulates private wells, as that is the source of drinking water for most rural residents. State legislation (N.C.G.S.143-355 (I)) requires "all units of local government and large community water systems that regularly serve 1,000 or more service connections or serve more than 3,000 people that provide or plan to provide public water service to prepare a Local Water Supply Plan." Although counties are not required to comply with these mandates, Wake County supports the development of a Water Supply Plan in accordance with the 50-year planning window utilized by the North Carolina Division of Water Resources for residents in unincorporated areas of the county. To develop this plan, Wake County is interested in assessing and characterizing the sustainability of its groundwater resources.

With increasing development within Wake County over the next several decades, impacts to the groundwater system involve potential changes in recharge and withdrawal rates in high-capacity community wells. During periods of drought, less groundwater may be available for consumptive use. Competition for groundwater resources may induce well interference and reduced well yields at a local scale (Chapman and others, 2011). Changes in land use, including increased urbanization, has been shown to impact groundwater recharge rates (Hardison and others, 2009; Price, 2011), which may lead to more surface runoff and less infiltration to the groundwater system.

# PROBLEM

Water resource planning within the County, with respect to groundwater specifically, requires the compilation of locally available data and acquisition of additional high-resolution spatial datasets. Data compilation and interpretation will provide decision makers with the necessary information needed to address current and projected groundwater withdrawal and land-use change issues. Assessments will need to be in the form of practical tools, such as digital maps and web-based archives, that can translate easily for planning purposes.

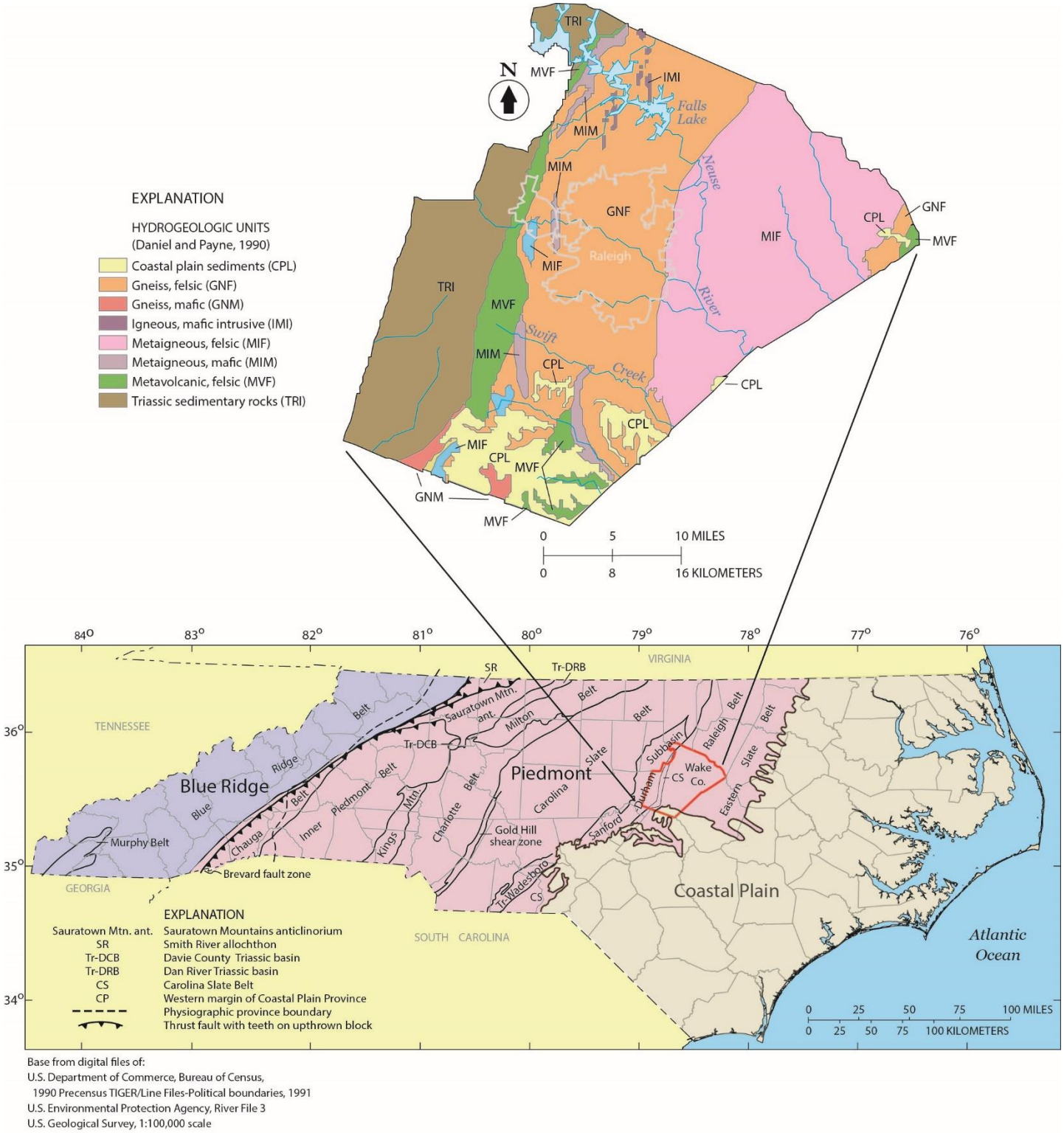


**Figure 1.** Locations of hydrogeologic units in Wake County and geologic belts delineated in the Piedmont Physiographic Province of North Carolina (modified from North Carolina Geological Survey, 1985 and Daniel and Payne, 1990).

## OBJECTIVE

The objective of this proposed study is to develop a County-wide assessment of groundwater availability within the regolith and fractured-rock aquifer system in Wake County. Specific tasks to accomplish the objective are as follows:

1. Implement a groundwater-level monitoring network for Wake County.
2. Inventory wells with adequate location, hydrogeologic, and construction information derived from GW-1 forms supplied by the County.
3. Compile existing borehole geophysical logs from previous studies in order to determine dominant fracture orientations across the county, with additional logs to be collected in those areas lacking geophysical log information.
4. Develop a county-wide map showing the distribution of maximum well-yields and general fracture orientation across the county.
5. Develop a Soil and Water Balance (SWB) model to resolve the spatial distribution of natural recharge to the groundwater system (historic and future).
6. Check/calibrate the Soil and Water Balance and MODFLOW models using hydrograph separation of streamflow.
7. Refine existing land-use and water-demand modeling for the county.
8. Develop a three-dimensional MODFLOW model to simulate groundwater flow throughout the county.
9. Summarize all data collected and assess the County's groundwater resources in USGS Scientific Investigations Reports.

This 4-year, 6-month study (January 2019 – June 2023) will include the compilation of available hydrologic data for the fractured-rock aquifers in and around the Wake County area. The proposed study will assist Wake County in the management of their groundwater resources by providing information on sustainable quantity and areas susceptible to contamination. Sustainable quantity will be based on water-budget components including potential recharge, regolith thickness, and distribution of well yields. Areas more susceptible to contamination will likely correlate with areas of higher recharge and those known to have naturally occurring contaminants. The areas of higher recharge will be delineated with results from the Soil and Water Balance (SWB) model. The potential of contamination from natural and anthropogenic sources will be investigated by relating water-quality data, with regional hydrogeology, geologic information, and land use.

## PURPOSE

This proposal is written to formally address the approach to investigating groundwater resources throughout Wake County, North Carolina. The proposal documents plans, methods, timeline, and funding needed to compile an inventory of existing bedrock wells; estimate major components of the water budget including recharge, groundwater use, and discharge of groundwater to streams; collect and interpret available data to assess groundwater resources; develop tools to simulate groundwater recharge and flow; and publish a map and reports of results.

## RELEVANCE AND BENEFITS

The proposed groundwater recharge and modeling study of Wake County, North Carolina supports the USGS Strategic Plan *Facing Tomorrow's Challenges—U.S. Geological Survey Science in*

*the Decade 2007-2017* (U.S. Geological Survey, 2007) under the goal of "A Water Census of the United States: Quantifying, Forecasting, and Securing Freshwater for America's Future." This study aligns with the 2016 priorities for the Cooperative Water Program, including "data collection--enhance hydrologic-data networks for improved hazards protection and forecasting and to support assessments of water sustainability for human and ecological needs" and "assessments and tracking of water use, consumptive use, and water availability (Water Availability and Use Science)." The data collected as part of this study will supply important groundwater and surface-water data to the USGS NWIS database that will further the understanding of water resources in the Nation.

Completion of the proposed work will provide the USGS with higher-resolution recharge data in a common setting like the Piedmont geologic province than what is currently available for use in local and regional groundwater models. This study will build on previous studies (Chapman and others, 2005 and 2011; McSwain and others, 2013) and further research within the region. Providing County planners with recharge delineation maps that are linked to county land-use data will help to inform future zoning decisions locally that protect vulnerable recharge areas and reduce possible aquifer contamination. If the identified approaches herein prove successful, federal, state, and municipal agencies, along with private consulting firms, will benefit greatly by having access to defensible maps, reliable data, and scientifically-based models for future water-management decisions in the study region.

# APPROACH

The proposed study will seek to address county-wide groundwater availability characterization to provide information for future, more local-scale investigations involving specific groundwater-related issues. The regional county-wide approach will include identifying the major components within the water budget and impacts to the aquifer system due to land-use changes.

Phase 1 – Groundwater data collection

***Task 1a*** *– Implement a county-wide groundwater-level network*

USGS will work with Wake County to identify a network of existing wells to include in a groundwater-level monitoring network. Selection of wells and their location will include consideration of major hydrogeologic units, land use type, proximity to community water systems, zones of groundwater recharge/discharge, and areas of known drought-affected streamflow (high baseflow index streams). If an adequate number of wells (15 – 20) are not available to characterize water-levels across the various land-use, geologic, and hydrogeologic settings, USGS will work with Wake County to contract the installation of new monitoring wells by another party. Wells within the network will be instrumented with continuous recorders that transmit data in near real-time to the USGS NWIS-web site. Installation of equipment (pressure transducer, data collection platform, antenna, solar panel and charging setup, and shelter) will cost $13,000 per well and annual operation and maintenance of the site will cost $6,600 (at FY19 costs).

***Task 1b*** *– Develop existing wells in monitoring network*

Well development will be conducted in each of the wells selected for monitoring to ensure adequate connection between the well and aquifer is restored. The USGS will evacuate a large volume of groundwater from each well to remove sediment build-up from the open fractures

or well screens within the wells. The development procedure will continue until the turbidity and field parameters stabilize. Development will cost $2,000 per well based on the time and equipment necessary to bring each well to optimal monitoring conditions, with the exclusion of any repairs to well construction.

***Task 1c*** *– Water-quality data analysis and collection*

Water-quality sampling will be conducted at 15 wells sites in the groundwater-level network. Sites will be sampled once for groundwater-age dating tracers, such as tritium, helium, chlorofluorocarbons, sulfur hexafluoride, as well as water isotopes. Age-dating has been used in previous USGS studies involving fractured-rock aquifers, including those in Wake County (Nelms and others, 2003; Chapman and others, 2005; McSwain and others, 2013) and can be used to estimate recharge rates, aquifer vulnerability, and provide useful information for the SWB and groundwater-flow models. The use of water isotopes along with other geochemical tracers within groundwater, surface water, and rainfall can yield information on distinguishing signatures for each hydrologic component to define groundwater recharge sources (Hopkins, 2013).

Phase 2 – Groundwater data analysis

***Task 2a*** *– Well-yield distribution and dominant fracture orientation map*

A well inventory will be derived from compiled GW-1 Forms provided by Wake County Department of Environmental Services. These forms provide location information with drilling logs, casing depth, well depth, well-yield and basic water-quality data collected at time of well installation. Well-yields will be compared with regional lithologic and hydrogeologic information to assess patterns that could be used to estimate well-yields in areas of the county where there are few data points. To supplement existing hydrogeologic information, borehole geophysical logging within several existing unused wells will be conducted to assess the general depth of water bearing zones and general orientation of fractures within the fractured-bedrock. The spatial distribution of well-yields and major fracture orientations across the county will be summarized and illustrated in a digital map.

***Task 2b*** *– Soil and Water Balance modeling and groundwater recharge map*

Recharge estimation is a primary component of the water budget and provides an upper limit of measure to much of the water entering the groundwater system. The USGS will estimate natural recharge using a Soil-Water-Balance model (Westenbroek and others, 2010). The model compiles climatological data and soil and landscape properties to create a water budget of the hydrologic system. The model output is a gridded distribution of recharge, run-off, and evapotranspiration through a specified period of time that is in downloadable GIS format. The proposed time period will cover the past 15 years of climatological data. Forecast scenarios will be run using future land use projections and a range (i.e. dry, median, wet) of downscaled global climate change model projections in order to predict changes to groundwater recharge. Plans for the implementation of green infrastructure in future development will also be considered, with additional recharge being incorporated into the output of the model.

***Task 2c*** *– Hydrograph Separation of Streamflow*

Watersheds within and surrounding Wake County will be analyzed for groundwater and runoff contributions to stream flow. Direct results of the hydrograph separation will estimate these two components of the water budget using the graphing interface techniques in the USGS

Groundwater Toolbox (Barlow and others, 2015). Groundwater Toolbox allows for robust analysis for large amounts of hydrologic data that can be retrieved from the USGS National Water Information System (NWIS) database. The results of these analyses will be compared with the output estimates from the SWB model to evaluate the uncertainty in the model.

***Task 2d*** – *Refine existing land-use and water-demand modeling*

Future water demand is related to growing populations, expanding cities and changing climate and directly influence groundwater withdrawals in Wake County. This research will analyze alternative futures of continued urbanization and estimate the associated development-related water demand (a combination of public supply, domestic self-supply and industrial self-supply) across the county. We will integrate site-specific long-term development plans and additional land conservation measures to refine an existing land-use and water-demand modeling framework by Sanchez and others (2018) and project urbanization and water demand to 2070. The final projected output will be incorporated into the SWB and MODFLOW models, which help local entities to better understand the implications of their planning and development choices on future water demand.

***Task 2e*** – *Publication of a USGS-Series Scientific Investigations Report*

The results of Phase 2 will be published in a USGS Scientific Investigations Report. The report will include a summary of the data collected in the previous tasks, as well as a discussion of the regional water-budget and factors that may impact groundwater sustainability.

Phase 3 –MODFLOW modeling

***Task 3a*** – *Develop a MODFLOW groundwater-flow model*

A MODFLOW (Harbaugh, 2005) groundwater flow model will be created to assist in managing the resources of Wake County. This three-dimensional finite-difference model will simulate the water movement throughout the fractured-rock aquifer to give a better understanding of the groundwater flow throughout the County. The model will simulate water levels and groundwater withdrawals over the past 20 years to predict results of future stresses on the groundwater system. The hydrologic data collection and compilation efforts, along with the SWB modeling completed in Phases 1 and 2 of this project will be used to build the groundwater-flow model.

***Task 3b*** – *MODFLOW model calibration*

The model will be calibrated by adjusting input parameters (e.g. hydraulic conductivity, specific storage, etc.) until simulated aquifer heads match historical and recent records of measured heads in groundwater monitoring wells.

***Task 3c*** – *Simulation of scenarios*

The MODFLOW model will be applied to test future withdrawal scenarios from the fractured-rock aquifer and surface-water sources. These scenarios will be used in planning future groundwater withdrawals and development in the county as they determine the potential susceptibility of the aquifer to contamination and simulate the effects that potential supply wells will have on existing wells. The future land-use and water-demand modeling results developed in Task 2e will be simulated as part of this task. Multiple scenarios can and will be run; however, no

more than five scenarios will be summarized in the final report. Wake county will be involved in developing scenarios to be tested.

***Task 3d*** – *Publication of a USGS-Series Scientific Investigations Report*

A USGS Scientific Investigations Report will be published to document the groundwater-flow model. The report will also summarize the results of the scenarios.

## QUALITY-ASSURANCE

All projects are reviewed at least twice per year in the USGS South Atlantic Water Science Center (SAWSC) for technical details, schedule, and budget. Partners are welcome to participate in these reviews. When completed, reports undergo formal USGS colleague review and are approved following procedures according to USGS policies for data and interpretive reports. In addition, the SWB model will be documented and archived according to USGS guidelines and policies. USGS Office of Quality Assurance and SAWSC quality-assurance plans will be followed for all field and office work related to the project. Data compiled as part of this study will be quality assured by USGS personnel and entered into the USGS NWIS database or published in a Data Release on the USGS ScienceBase web portal for access by the general public.

## PRODUCTS

Deliverables will include hydrologic datasets made available on NWIS-web, documentation and gridded output files for the SWB and MODLFOW models, a maximum well-yield distribution map with dominant fracture orientations, and a groundwater recharge map. Data and metadata from the SWB and MODLOW models will be disseminated to the public by means of a data-release. Two associated USGS Scientific Investigations Reports will be published: 1) will include the assessment of groundwater resources and hydrogeologic factors associated with observed well yields, discussion on the Soil and Water Balance model outputs, and water-level and water-quality data and 2) groundwater model documentation including calibration metrics and scenario results.

## PERSONNEL

A hydrologist (GS-11) will serve as the project chief and will conduct most of the project tasks. A senior hydrologist (GS-12) will lead the MODFLOW modeling tasks. A hydrologist (GS-7/9) will assist with the collection of borehole geophysical logs for the project, as well as geographic information system data processing and water-quality sampling.

## TIMELINE

The proposed project duration is 4 years and 6 months, beginning on January 1, 2019, and ending on June 30, 2023. A proposed timeline for the project, based on the Wake County fiscal year, is outlined in table 1.

**Table 1**. Proposed project schedule; Quarter 1 – July-Sept.; Quarter 2 – Oct.-Dec.; Quarter 3 – Jan.-March; Quarter 4 – April-June

| Tasks | Fiscal Year 2019 | | | | Fiscal Year 2020 | | | | Fiscal Year 2021 | | | | Fiscal Year 2022 | | | | Fiscal Year 2023 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quarter | | | | Quarter | | | | Quarter | | | | Quarter | | | | Quarter | | | |
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **Phase 1: Groundwater data collection** | | | | | | | | | | | | | | | | | | | | |
| Task 1a: Implement a county-wide groundwater level network | | | | | | | | | | | | | | | | | | | | |
| Task 1a: Continuous water-level collection for 5 years | | | | | | | | | | | | | | | | | | | | |
| Task 1b: Develop existing wells in monitoring network | | | | | | | | | | | | | | | | | | | | |
| Task 1c: Water-quality data collection (age dating and isotopes) | | | | | | | | | | | | | | | | | | | | |
| **Phase 2: Groundwater data analysis** | | | | | | | | | | | | | | | | | | | | |
| Task 2a: Well Inventory Compilation | | | | | | | | | | | | | | | | | | | | |
| Task 2a: Borehole geophysical logging | | | | | | | | | | | | | | | | | | | | |
| Task 2a: Well-yield and dominant fracture orientation map | | | | | | | | | | | | | | | | | | | | |
| Task 2b: SWB model and recharge map | | | | | | | | | | | | | | | | | | | | |
| Task 2c: Hydrograph separation analysis | | | | | | | | | | | | | | | | | | | | |
| Task 2d: Refine existing land-use and water-demand modeling | | | | | | | | | | | | | | | | | | | | |
| Task 2e: Prepare USGS Scientific Investigations Report | | | | | | | | | | | | | | | | | | | | |
| **Phase 3: MODFLOW Modeling** | | | | | | | | | | | | | | | | | | | | |
| Task 3a: Develop a MODFLOW groundwater-flow model | | | | | | | | | | | | | | | | | | | | |
| Task 3b: MODFLOW model calibration | | | | | | | | | | | | | | | | | | | | |
| Task 3c: Simulation of scenarios | | | | | | | | | | | | | | | | | | | | |
| Task 3d: Publication of USGS-Series Scientific Investigations Report | | | | | | | | | | | | | | | | | | | | |

## FUNDING

The total cost to accomplish all the stated objectives in all 3 phases of the project is $1,565,000. USGS Cooperative Matching funds will be contributed to the project extension in the amount of $569,800; subject to the availability of funds in the Federal budget. The USGS will also contribute more than $100,000 in geophysical tools to accomplish the objectives of this study. The requested Wake County contribution to the project will be $995,200. A detailed breakdown of the project budget and cost sharing is shown in table 2 below. The costs in table 2 associated with the groundwater-level network assumes a network of 15 continuously recording wells and fiscal year 2019 funding includes the equipment installation costs. For long-term monitoring agreements (i.e. 5-years), equipment installation costs ($195,000) can be fully covered by USGS funds. Tables 3 and 4 outline the budget by County fiscal year (July 1 through June 30) based on contributions from Wake County and USGS for 60 and 40 percent of project task costs, respectively. Wake County funds will cover the total annual operation and maintenance costs for the groundwater-level network (see table 3, task 1a). Table 5 outlines the total project contributions for each agency by County fiscal year.

**Table 2.** Project funding by task (FY – County Fiscal Year (July 1 – June 30))

| Project Task | FY 2019 Funding | FY 2020 Funding | FY 2021 Funding | FY 2022 Funding | FY 2023 Funding |
|---|---|---|---|---|---|
| **Task 1a** – Implement a county-wide groundwater level network | $220,000* | $99,000 | $102,000 | $102,000 | $105,000 |
| **Task 1b** - Develop existing wells in monitoring network | $20,000 | $10,000 | -- | -- | -- |
| **Task 1c** - Water-quality data analysis and collection<br>Lab Analysis - $30,000<br>Field Supplies - $3,500<br>Staff (480 hrs) - $43,000 | $32,000 | $45,000 | -- | -- | -- |
| **Task 2a** - Well inventory compilation<br>Staff (680 hrs) | $60,000 | -- | -- | -- | -- |
| **Task 2a** - Borehole Geophysical Logging<br>Staff (380 hrs) | $25,000 | $30,000 | -- | -- | -- |
| **Task 2a** - Well-yield and fracture orientation map<br>Staff (360 hrs) | -- | $29,000 | -- | -- | -- |
| **Task 2b** - Soil & Water Balance (SWB) model<br>Staff (FY20 – 1028 hrs; FY21 – 100 hrs) | -- | $95,000 | $8,000 | -- | -- |
| **Task 2c** - Hydrograph Separation Analysis<br>Staff (540 hrs) | -- | -- | $49,000 | -- | -- |
| **Task 2d** - Refine existing land-use and water-demand modeling<br>Staff (405 hrs) | -- | -- | $38,000 | -- | -- |
| **Task 3a/b** – Develop/calibrate MODFLOW model<br>Staff (2160 hrs) | -- | -- | $100,000 | $95,000 | -- |
| **Task 3c** - MODFLOW model scenarios<br>Staff (440 hrs ) | -- | -- | -- | $52,000 | -- |
| **Task 2e/3d** - Scientific Investigations Report,<br>Data Release, and model archiving<br>Staff (FY20 – 400 hrs;<br>FY21 – 870 hrs; FY22 – 380 hrs; FY23 – 1150 hrs) | -- | $40,000 | $59,000 | $40,000 | $110,000 |
| **TOTAL** | **$357,000** | **$348,000** | **$356,000** | **$289,000** | **$215,000** |

* - This cost includes one-time $195,000 equipment installation costs

**Table 3.** Wake County project funding contributions by task, given a long-term monitoring agreement established (FY – County Fiscal Year (July 1 – June 30).

| WAKE CO | FY 2019 | FY 2020 | FY 2021 | FY 2022 | FY 2023 |
|---|---|---|---|---|---|
| Task 1a | $25,000 | $99,000 | $102,000 | $102,000 | $105,000 |
| Task 1b | $12,000 | $6,000 | -- | -- | -- |
| Task 1c | $19,200 | $27,000 | -- | -- | -- |
| Task 2a | $36,000 | -- | -- | -- | -- |
| Task 2a | $15,000 | $18,000 | -- | -- | -- |
| Task 2a | -- | $17,400 | -- | -- | -- |
| Task 2b | -- | $57,000 | $4,800 | -- | -- |
| Task 2c | -- | -- | $29,400 | -- | -- |
| Task 2d | -- | -- | $22,800 | -- | -- |
| Task 3a/b | -- | -- | $60,000 | $57,000 | -- |
| Task 3c | -- | -- | -- | $31,200 | -- |
| Task 2e/3d | -- | $24,000 | $35,400 | $24,000 | $66,000 |
| **TOTAL** | **$107,200** | **$248,400** | **$254,400** | **$214,200** | **$171,000** |

**Table 4.** USGS project funding contributions by task, given a long-term monitoring agreement established (FY – County Fiscal Year (July 1 – June 30).

| USGS | FY 2019 | FY 2020 | FY 2021 | FY 2022 | FY 2023 |
|---|---|---|---|---|---|
| Task 1a | $195,000* | -- | -- | -- | -- |
| Task 1b | $8,000 | $4,000 | -- | -- | -- |
| Task 1c | $12,800 | $18,000 | -- | -- | -- |
| Task 2a | $24,000 | -- | -- | -- | -- |
| Task 2a | $10,000 | $12,000 | -- | -- | -- |
| Task 2a | -- | $11,600 | -- | -- | -- |
| Task 2b | -- | $38,000 | $3,200 | -- | -- |
| Task 2c | -- | -- | $19,600 | -- | -- |
| Task 2d | -- | -- | $15,200 | -- | -- |
| Task 3a/b | -- | -- | $40,000 | $38,000 | -- |
| Task 3c | -- | -- | -- | $20,800 | -- |
| Task 2e/3d | -- | $16,000 | $23,600 | $16,000 | $44,000 |
| **TOTAL** | **$249,800** | **$99,600** | **$101,600** | **$74,800** | **$44,000** |

*** -** This entails the equipment installation costs for monitoring network

**Table 5.** Project budget by agency, given a long-term monitoring agreement established (FY – County Fiscal Year, July 1 – June 30).

| Agency | County fiscal year | | | | | TOTAL |
|---|---|---|---|---|---|---|
| | **FY 2019** | **FY 2020** | **FY 2021** | **FY 2022** | **FY 2023** | |
| Wake County | $107,200 | $248,400 | $254,400 | $214,200 | $171,000 | $995,200 |
| USGS | $249,800* | $99,600 | $101,600 | $74,800 | $44,000 | $569,800 |
| **Project Total** | **$357,000** | **$348,000** | **$356,000** | **$289,000** | **$215,000** | **$1,565,000** |

***** - This cost includes one-time $195,000 equipment installation costs

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# APPENDIX

Appendix 1. Laboratory analyses and costs for proposed constituents in water-quality sampling

| Parameter Name | Lab Code | Cost | Unit |
|---|---|---|---|
| Stable Isotopes | | | |
| $^{2}H/^{1}H$ and $^{18}O/^{16}O$ | 1142 | $70 | ‰ |
| Age Dating | | | |
| Tritium ($^{3}H$) | 600 | $675 | TU |
| Helium ($^{3}He/^{4}He$) | 610 | $675 | ‰ |
| Dissolved gasses (helium, neon, argon, krypton, and xenon) | 620 | $200 | ug/L |
| Chloroflourocarbons (CFCs-11, -12, -113) | N/A | $220 | ug/L |
| Sulfur hexafluoride ($SF_6$) | N/A | $220 | ug/L |