A Statewide Planning Approach to Evaluating Groundwater Availability and Sustainable Yield

John D. Boyer, PE, BCEE, D.WRE[1], Mark Maimone, Ph.D., P.E., BCEE, D.WRE[2]

AUTHORS: [1]CDM Smith, Raleigh, NC 27612, USA, [2]CDM Smith, Woodbury, NY 11797, USA
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ABSTRACT. In support of its' State Water Plan, Georgia recently completed a statewide assessment of prioritized aquifer systems. Georgia's aquifers were prioritized based on the functional characteristics of the aquifer, existing evidence of adverse affects due to withdrawals, and demand forecasts that indicated potentially significant increases in withdrawals from that aquifer in the years ahead. For this early phase of state water resources planning, the focus was on potential regional impacts resulting from the withdrawal of groundwater. Criteria limiting withdrawals were developed based on broad scientific principles and practical guidelines.

A variety of modeling approaches, ranging from a simple water balance to the development and application of numerical models with transient simulation capabilities, were used to estimate a range of sustainable yields for each aquifer selected for the study. The modeling approach depended upon the type of aquifer system and the availability of data, with each approach specifically designed to answer basic questions about the impacts of groundwater withdrawals on surface waters and other users of groundwater.

The results of the assessment indicated there are relatively large quantities of additional groundwater available above existing withdrawals before the sustainable yields of prioritized aquifers in the Coastal Plain are reached, with some exceptions in specific areas due to groundwater-surface water interactions, salt water intrusion, and other concerns. There are smaller amounts of additional groundwater available from the Paleozoic rock aquifer in the northwestern Georgia study basin and from the portion of the crystalline-rock aquifer studied in the Piedmont and Blue Ridge. Because the total range of sustainable yield of prioritized aquifers in the Coastal Plain with simultaneous withdrawals from all prioritized aquifers would be less than the total range with individual aquifer withdrawals, the selection of which aquifers will be utilized for future water supply should be evaluated when planning for use of the sustainable yield from an individual aquifer.

The information, results, and range of sustainable yield estimates developed during the statewide groundwater resource assessment were provided to Georgia's 10 Regional Water Planning Councils to support creation of the Regional Water Plans.

INTRODUCTION

Georgia's 2008 State Water Plan recognized that water resource assessments are one of the foundational building blocks for regional water planning. Beginning in 2009, Georgia undertook statewide assessments of surface water quality, surface water resources, and groundwater resources. The assessments included compilation and analysis of data and modeling to evaluate the capacity of water resources to meet current and future demands for water supply and to receive wastewater discharges without unreasonable impacts.

One of the challenges of conducting water resource assessments on a statewide basis is to apply methods that are accurate enough to provide a reasonable estimate of the sustainable yield for a wide variety of aquifer types, but that can be completed within a limited time frame for a reasonable cost. As South Carolina prepares to update its State Water Plan, it must develop universally accepted methods that efficiently leverage existing tools and information in order to overcome these obstacles. The approach Georgia used to complete the task of evaluating groundwater resources, and the lessons learned, are worth reviewing in light of South Carolina's similar objective.

PROJECT OBJECTIVES

Within the framework of the Georgia State Water Plan, the overall objective of the groundwater assessment (and companion assessments) was to provide information that the 10 Regional Water Planning Councils could use as a starting point for the development of the Regional Water Plans. The specific objectives of Georgia's statewide groundwater resource assessment were as follows:

1. Compile and review data characterizing Georgia's groundwater resources, including the existing models and tools;
2. Prioritize the aquifers and aquifer units for estimating sustainable yields;
3. Develop new and/or employ existing calibrated groundwater flow models and other predictive tools for estimating the sustainable yield in the prioritized units; and
4. Use the models and tools to develop a range of sustainable yield estimates for the prioritized aquifers.

PROJECT DESCRIPTION

Similar to other southeastern states, a wide variety of geologic and hydrogeologic conditions are present in Georgia. The five distinct geologic regions include the Appalachian Plateau and the Valley and Ridge, which consist of indurated and structurally deformed Paleozoic-era sedimentary rock aquifers; the Blue Ridge and the Piedmont, which contain fractured crystalline-rock aquifers; and the Coastal Plain, which consists of Cretaceous and Cenezoic sedimentary rocks and unconsolidated sediments.

Given the diversity and complexity of the various aquifer systems across the state (Figure 1), and recognizing that a comprehensive accounting of the sustainable yield of all of the aquifers in Georgia would have been expensive and time consuming, the aquifers for which a range of sustainable yield estimates would be developed were prioritized based on the following criteria:

1. Functional characteristics of the aquifer;
2. Existing evidence of adverse effects due to withdrawals from the aquifer;

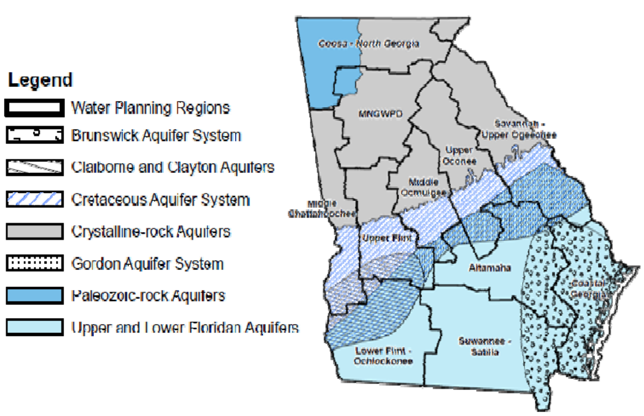

Figure 1. Georgia's Aquifers and Water Planning Regions

(Note: the MNGWPD is not a water planning region under the State Water Plan)

3. Forecasts suggesting significant increases in demands placed on the aquifer;
4. Acceptability of impacts due to increased groundwater withdrawals; and
5. Aquifers where it will not be possible to determine sustainable yield within a reasonable time period.

The prioritized aquifers include an example of each aquifer type found in Georgia. Estimates of ranges of sustainable yield were made for portions of the Upper Floridan aquifer, the Cretaceous aquifer, the Clayton aquifer, and the Claiborne aquifer in the Coastal Plain; a portion of the Paleozoic-rock aquifers in northwestern Georgia; and portions of the crystalline-rock aquifers of the Piedmont and Blue Ridge. The specific approaches used to develop the range of sustainable yield estimates in each aquifer are described in the Methods section.

Defining Sustainable Yield

Before the ranges of estimated sustainable yields were developed, a workable and agreed-upon draft definition of aquifer sustainable yield and means of quantifying sustainable yield had to be developed. There have been many definitions over the years of "sustainable, safe, or perennial yield" of an aquifer system. A reasonable and well accepted definition of sustainability that seems to encompass most ideas was proposed in 1998 by a Task Force of the American Society of Civil Engineers (ASCE, 1998). Their definition of sustainability is as follows:

> "*Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity*."

For the assessment phase of a statewide water resources planning effort, the focus on metrics of unwanted results tends to be on a broad scale of potential impacts resulting from the withdrawal of groundwater. In Georgia, an initial set of metrics to constrain withdrawals to ranges of sustainable yields was developed based on broad scientific principles and, above all, practical guidelines. These metrics included those that have been applied in comparable circumstances elsewhere and tested for their applicability in Georgia. These criteria served as general guidelines, to be addressed in greater detail and adjusted as the regional water plans were developed and stakeholder input was solicited. The overarching concept evaluated was whether increased withdrawal of groundwater, resulting in the removal of water stored in the system and decreased discharge to surface waters, would cause unwanted results. The following metrics were applied, with variations developed appropriate to each of the aquifers being studied and to the level of detail provided by the models used to assess sustainable yield.

1. Drawdowns of groundwater levels in the pumped aquifer do not exceed 30 feet between pumping wells;
2. Reductions in baseflow were constrained to 40 percent of present day average baseflow in order to maintain opportunities for surface water use (modified to 10 percent of baseflow in the Paleozoic rock aquifer);
3. Reduction in aquifer storage does not go beyond a new base level;
4. Groundwater levels are not lowered below the top of a confined aquifer; and
5. The ability of the aquifer to recover to baseline groundwater levels between periods of higher pumping during droughts is not exceeded.

With these metrics in mind, the impacts of groundwater withdrawals were primarily assessed on an annual basis, with consideration for drought years. In this assessment, only the limits of aquifer yield were explored, with no comparison to projected water needs. The assessment of projected water needs and comparison to yield was relegated to the development of the more local, 10 Regional Water Plans.

METHODS

The modeling approach used to estimate the sustainable yield of an aquifer depended on the availability of data and the level of detail required to answer basic questions about the potential impacts of groundwater withdrawals on aquifers. For the assessment phase of Georgia's planning process, three modeling approaches were used, ranging from a simple water budget to the development of fully calibrated numerical models with transient simulation capabilities. The exact metrics used to make a preliminary assessment of sustainability varied according to the modeling approach. In all cases, the models were run with stepped increases of groundwater withdrawal until one of the sustainable yield metrics was reached, and then that level of withdrawals was determined to be part of the range of sustainable yield.

Coastal Plain

Estimates of ranges of sustainable yield were made for portions of the Upper Floridan aquifer, the Cretaceous aquifer, the Claiborne aquifer, and the Clayton aquifer in the Coastal Plain of Georgia using calibrated numerical models. The use of calibrated, three dimensional flow models increased the confidence level of the sustainability estimate. The model's transient flow capabilities were used to assess the timing and spatial distribution of withdrawals.

The existing, USGS MODFLOW regional numerical model of the Coastal Plain Clastic aquifer system and an existing Modular Finite Element (MODFE) of the Floridan Aquifer in the Dougherty Plain area (southwest Georgia) were used, in conjunction with newly developed regional and sub-regional flow models (CDM Smith, 2011; CDM Smith, 2012a). Sub-regional models were developed for the prioritized aquifers by zooming into portions of the calibrated regional model. The calibrated sub-regional model of each prioritized aquifer was used to simulate increased groundwater withdrawals from individual prioritized aquifers to determine the range of sustainable yield for the aquifer. The calibrated regional model was used to simulate increased groundwater withdrawals from all prioritized aquifers to determine the total range of sustainable yield for simultaneous increased withdrawals from all of the prioritized aquifers.

Piedmont and Blue Ridge

A more simple, water budget approach was used to provide a planning level assessment of groundwater resource sustainability in representative basins of the Piedmont and Blue Ridge (CDM Smith, 2012b). Water budgets are appropriate where shallow, water table aquifers are in direct connection with surface water. A water budget is an accounting of water movement within the hydrologic cycle, both natural and artificial. The water budget equation accounts for water "in" to the system (i.e., average precipitation, wastewater and industrial discharge to groundwater systems and streams, and estimated domestic recharge from onsite wastewater treatment systems), and water "out" of the system (i.e, runoff, evapotranspiration, all surface water and groundwater withdrawals, and median baseflow of streams.) The components of the water budget equation which specifically relate to groundwater can be rearranged to develop an estimate of net groundwater consumption. By comparing net groundwater consumption to the sustainable yield criteria, estimates of net groundwater availability can be developed.

Two areas within the Piedmont and Blue Ridge were selected for analysis during the assessment phase. These were the 163 square mile Middle Oconee River Lower Basin in the Piedmont, and the 215 square mile Chattahoochee River-Chickamauga Creek and Soque River basins in the Blue Ridge.

An underlying assumption of the water budget method is that the surface watershed and the groundwater basin cover the same area, making them appropriate for assessments designed for unconfined, surficial aquifers. Because the water budget focuses on streamflow as the primary estimator of recharge and groundwater availability, a practical method to make an initial estimate of sustainable yield is to apply a variant of the Tennant method. The Tennant method offers several categories of streamflow reduction. These were modified into minimum, mid-level, and maximum allowable streamflow reduction categories and were subtracted from the mean monthly flow during the time of lowest streamflow (September). Because of the difficulty of finding fractures in the crystalline-rock aquifers in the Piedmont and Blue Ridge areas to provide water, a conservative estimate of sustainable yield was used. In this case, the streamflow reduction targets were reduced, allowing only 20 percent of the difference between the mean September flow and the Tennant reduction category thresholds to calculate groundwater availability. An even more conservative (minimum) value for sustainable yield was also developed with the same approach, but using stream baseflow instead of total streamflow.

Valley and Ridge

A numerical model of confined and unconfined Paleozoic rock aquifers in the Valley and Ridge of northwestern Georgia was developed using existing, available data on water levels and aquifer heads; aquifer properties; the spatial extents and folding of the aquifers; confining units; and the thickness of each stratigraphic unit, as well as estimates of average annual withdrawals and stream baseflow (CDM Smith, 2012c). The area modeled covered several watersheds within the Valley and Ridge physiographic province in Floyd, Polk, Bartow and Paulding counties, where the largest spatial extent of the Knox Group outcrops. The model was checked against available groundwater head data and streamflows in a qualitative manner, but there were generally insufficient data to develop a quantitatively calibrated model.

Both transient and steady state simulations were conducted to provide an estimated range of sustainable yield. A transient model simulation based on actual drought year data was conducted to represent drought year conditions. Hypothesized groundwater withdrawals were uniformly added to the model, and modified sustainability metrics were assessed by simulating streamflow and drawdown impacts of the withdrawals. The sustainability metrics were modified to account for the very limited storage capacity of the Paleozoic aquifers. For example, the allowable reduction in total streamflow and spring flow due to additional withdrawals was limited to 10 percent of mean annual discharge. The 10 percent criterion was applied to the mean annual discharge of both an average and dry year.

CONCLUSIONS

Sustainable yields of prioritized aquifers in Georgia were determined using carefully selected methods that were supported by available data and existing models and tools, and were deemed appropriate for use in the specific aquifer being assessed. Results of the simulations and analyses indicated a range of sustainable yield for each prioritized aquifer. Table 1 presents the ranges of sustainable yields of Coastal Plain and Paleozoic rock aquifers that were modeled numerically. Table 2 presents the range of sustainable yields of the crystalline-rock aquifer that were assessed analytically. Sustainable yields in Table 2 are presented for the entire basin and are normalized for the area of the basin. Baseline withdrawals were determined for some of the prioritized aquifers and are also presented in Tables 1 and 2. Baseline withdrawals were estimated based on actual current withdrawals, not permitted capacities.

Table 1
Sustainable yield ranges for the Coastal Plain and Paleozoic rock aquifers

Aquifer	Modeled Sustainable Yield (mgd)		Baseline Groundwater Withdrawal (mgd)
	Min	Max	
Upper Floridan Aquifer in Dougherty Plain	237	328	587
Upper Floridan Aquifer in South-Central Georgia	622	836	329
Upper Floridan Aquifer in South-Central Georgia and Eastern Coastal Plain	868	982	475
Claiborne Aquifer	140	635	93
Cretaceous Aquifer	347	445	219
Clayton Aquifer	37	67	30
Paleozoic-Rock Aquifer in Northwest Georgia Valley & Ridge	27	70	15

Table 2
Sustainable yield ranges for the crystalline-rock aquifer of the Piedmont and Blue Ridge

Crystalline-rock Aquifer	Basin Sustainable Yield (mgd)		Area Normalized Sustainable Yield (mgd/mi^2)		Current Groundwater Consumption (mgd)
	Min	Max	Min	Max	
Piedmont	0.6	2.1	0.004	0.013	1.2
Blue Ridge	10.3	19.1	0.033	0.061	2.4

In addition to the estimated ranges of sustainable yield, a number of other observations were drawn from the results of the groundwater resources assessment:

1. Except in the Upper Floridan aquifer of the Dougherty Plain of southwestern Georgia, there are relatively large quantities of additional groundwater available above existing withdrawals before the ranges of sustainable yield of prioritized aquifers in the Coastal Plain are reached (based on the selected sustainable yield criteria of allowable groundwater drawdown from current conditions of 30 feet or less and streamflow reductions from current conditions of 40 percent or less.)
2. There are smaller amounts of additional groundwater available from the Paleozoic rock aquifer in the northwestern Georgia study basin and from the crystalline-rock aquifer in the Piedmont and Blue Ridge.
3. A combination of increasing withdrawals from existing and hypothetical new wells to spread the impacts over a larger area results in the highest range of sustainable yield in the Upper Floridan aquifer, the Cretaceous aquifer, and the Claiborne aquifer.
4. Because the total range of sustainable yield of prioritized aquifers in the regional Coastal Plain model with simultaneous withdrawals from all prioritized aquifers would be less than the total range with individual aquifer withdrawals, the selection of which aquifers will be utilized for future water supply, and in what order, needs to be re-evaluated when planning for use of the sustainable yield from an individual aquifer.
5. As withdrawals are increased, groundwater will initially come from storage until steady state conditions are reached at a new equilibrium of recharge, withdrawals, and natural discharges. Sources of recharge can include leakage from other aquifers and geologic units, recharge from surface waters, and rainfall. Transient modeling indicated that it may take up to 40 years of withdrawals within the ranges of sustainable yields for aquifers to reach new equilibriums.

DISCUSSION

The broad-scale planning level data, observations, and conclusions generated during completion of Georgia's state-wide groundwater resources assessment served as the building blocks for each of the 10 Regional Councils to develop region-specific plans. Each council used the information from this groundwater assessment to understand current withdrawals, the relationship and magnitude between groundwater withdrawals and surface water withdrawals, and what level of future withdrawals, given projected population growth and expected water use, is sustainable. The broad-scale data and results were considered carefully with region and basin specific issues, prior to identifying, evaluating, and selecting one or more approaches to meet future water needs.

As one example, the Coastal Council (covering nine counties in southeast Georgia), to accommodate both the regional planning process and bi-state discussions between Georgia and South Carolina, used the assessment results to develop a flexible and adaptive approach for meeting regional groundwater needs. For planning purposes, the Coastal Council evaluated several different scenarios to meet regional water needs, with a range of assumed allowable Upper Floridan withdrawals. While the groundwater resources assessment indicated that the sustainable yield for the portions of the region's aquifers that were modeled is greater than the forecasted demands, the Coastal Council additionally considered the fact that groundwater withdrawals in a coastal region could lead to salt water intrusion, and therefore refined the sustainability metrics.

As South Carolina prepares to update its State Water Plan, it must develop universally accepted methods that leverage existing tools and information to efficiently and effectively assess its' water resources. Because the information, results, and conclusions of the assessments must be readily accepted, understood, and capable of supporting region-specific water management plans, a proven and reliable approach is necessary. The state water planning effort in Georgia, and similar recent efforts in such states as Colorado, Oklahoma, and Texas can serve as examples to consider.

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