

# Section 11

## Sustainable Yield of Aquifers

There have been many definitions over the years of “sustainable, safe, or perennial yield” of an aquifer system. Definitions have ranged from earlier versions that started with the concept of simple aquifer yield, to the more complex idea that the term “sustainability” represents some combination of human use and ecological needs. In Groundwater Hydrology 2<sup>nd</sup> edition (Todd, 1980), *perennial yield* is defined as “the rate at which water can be withdrawn perennially under specified water use conditions without producing an unwanted result.” The United States Geological Survey defined *sustainable yield* as “the development and use of groundwater in a manner that can be maintained for an indefinite time without causing unwanted ecological and social consequences” (Alley et al., 1999). Each definition seems to have two main components: the definition of unwanted results and the element of time.

A reasonable 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.”*

This is a reasonably broad definition that can be used by any state planning agency to set initial guidelines for maximum withdrawals from aquifers. More simply stated, sustainable yield is the amount of groundwater that can be withdrawn without causing unwanted results. These definitions, however, still require that more specific decisions be made regarding how to define what conditions constitute unwanted results and how to measure them for each aquifer under consideration.

### 11.1 Examples of Sustainable Yield Criteria

For this phase of state water resources planning, the focus is on broad scale impacts resulting from the withdrawal of groundwater. Impacts were primarily assessed on an annual basis, with consideration for drought years. Only the limits of aquifer yield were explored, with no comparison to projected water needs. Boundary considerations were addressed to the greatest extent possible for each of the modeling methods applied. An initial set of criteria limiting withdrawals was developed based on broad scientific principles and practical guidelines.

The following criteria 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.

#### 11.1.1 Aquifer Loss of Head/Pressure

A practical limit to avoid impacts to nearby wells is to restrict pumping such that drawdown does not exceed 30 feet below levels representative of current conditions

to avoid substantial losses in yield or the need for pump modifications. This limit is applied between wellfields or between large pumping wells. In this way, it is not likely that drawdown will cause existing wells to go dry.

This seemingly simple rule does, however, require a definition of where the 30-foot rule will apply and how the 30-foot drawdown will be calculated. It also requires decisions on where future pumping is projected to occur, because the location of additional pumping affects the pattern and severity of drawdown. Assumptions made are presented separately for each of the individual modeled areas.

Restricting excessive drawdown can also help to reduce the danger of sinkhole formation. A review of literature (Newton, 1987; Prokopovich, 1985; Jammal & Associates, 1982; Whitman et al., 1999) indicated that sinkhole formation typically occurs when there has been dissolution of carbonate sediments near the top surface of an aquifer, there is an overlying confining unit supporting the weight of the overburden sediments, and there is a large head differences between adjacent aquifers. When these conditions are present, the drawdown limit can be used to avoid head differences which would promote sinkhole formation if other conditions exist within the aquifer.

### **11.1.2 Maintain Opportunities for Surface Water Use**

Lowering of groundwater levels usually results in a reduction in groundwater flowing to streams as baseflow (streamflow that occurs in dry weather and that is totally dependent on groundwater discharge), when the stream has any degree of connection to the pumped aquifer.

The direct ecological responses to changes in stream baseflow are still poorly understood. Many historic in-stream flow methods have been devised to develop criteria limiting groundwater pumping to avoid potential ecological damage. These methods range from very simple approaches based on regional streamflow statistics, suitable for large-scale planning efforts, down to complex approaches that can only be applied to a small watershed with a fairly intensive collection of field data. As the name implies, historic flow methods rely solely on the recorded or estimated flow regime of a river or stream. Many of these methods require either a gage with daily streamflows and a long-term record, or correlation with a nearby gage with a sufficient length of record.

Possible metrics for constraining stream recharge from baseflow discharge, ranging from simple to complex, are listed below.

#### **11.1.2.1 20 Percent of Annual Average Recharge**

This approach requires regional estimates of recharge, then applies the relatively arbitrary limit of restricting pumping to 20 percent of recharge, leaving the rest for discharge to streams and springs.

#### **11.1.2.2 1-in-25 Year Annual Average Baseflow**

This approach assumes that protecting baseflow will protect ecological values associated with the streams. In many areas, groundwater withdrawals are restricted on a watershed basis to 50 percent of the 1-in-25-year annual average baseflow.

#### **11.1.2.3 Aquatic Baseflow Method**

This area-specific approach utilizes the median of all mean August stream flows for a stream as the target for the “summer instantaneous streamflow” because August is viewed as the month of greatest stress to aquatic organisms. In Georgia, September is the month of lowest baseflow and greatest stress. In the absence of adequate flow data from the specific stream, Aquatic Baseflow has a default flow release target of 0.5 cubic feet per second per square mile ( $\text{ft}^3/\text{s}/\text{mi}^2$ ), needed to protect native aquatic organisms during the low flow summer months; 1.0 and 4.0  $\text{ft}^3/\text{s}/\text{mi}^2$  is needed during the fall/winter and spring, respectively. Pumping is restricted to allow these minimum flows.

#### **11.1.2.4 Low Flow Margin**

This approach uses two streamflow statistics. The first is the September median flow, representative of the month with the lowest median flow of the year. The other is the 7Q10, or the lowest average weekly flow that occurs under drought conditions with a recurrence interval of once every 10 years. This method asserts that the critical flow regime for aquatic ecosystems is the lowest monthly flow minus the 7Q10 flow. Pumping is restricted to some percentage of this margin, thus, leaving a significant portion of the recharge for maintenance of stream baseflow.

#### **11.1.2.5 The Tennant Method**

The Tennant method (1976) is perhaps the most widely known of these methods. It is the second most popular method in the USA and is used or recognized by 16 states (Reiser et al., 1989). The Tennant method assumes that some percentage of the mean flow is needed to maintain a healthy stream environment (Jowett, 1997). Tennant examined cross-section data from 11 streams in Montana, Nebraska and Wyoming. He found that stream width, water velocity and depth all increased rapidly from zero flow to 10% of the mean flow, and that the rate of increase declined at flows higher than 10%. At less than 10% of the mean flow, he considered that water velocity and depth were degraded and would provide for “short-term” survival of aquatic life. He considered that 30% of the average flow would provide satisfactory stream width, depth and velocity for a “baseflow regime”. Tennant’s assessment of the environmental quality of different levels of flow was based on the quality of the physical habitat that they provided. At 10% of average flow, average depth was 0-3m and velocity 0-25 m/s, and Tennant considered these to be lower limits for aquatic life. He showed that 30% of average flow or higher provided average depths of 0.45–0.6m and velocities of 0.45–0.6 m/s and considered these to be in the good to optimum range for aquatic organisms.

This method is a standard-setting technique that bases its streamflow requirements on the observation that aquatic-habitat conditions are similar in streams carrying the same proportion of the mean annual flow ( $Q_{MA}$ ). To account for seasonal streamflow variability, the Tennant Method established different streamflow requirements for the summer and winter seasons on the basis of different percentages of the  $Q_{MA}$  without the need for further on-site data collection (Parker et al, 2004).

The Tennant method has become popular because it is an easy to apply standard that can be used with very little data and is particularly appropriate for state level planning. This method utilizes only average flow for a stream. The required flow can be set by using a percentage of the average annual flow without the need for onsite data collection. The method has been used since the 1950s and it is considered applicable to the river segment scale.

#### 11.1.2.6 The Wetted Perimeter Approach

This method is more suitable to application on smaller watersheds, and it focuses on submerged stream width in riffles as a critical ecological indicator. By maximizing the wetted perimeter of riffles, enough fish food and habitat is assumed to be available for a healthy aquatic community to survive in the river as a whole.

#### 11.1.2.7 R2Cross Method

Similar to the Wetted Perimeter method, the R2Cross method calculates the minimum flow necessary to maintain acceptable habitat for fish and macro invertebrates in critical areas, such as riffles. Pumping is restricted to allow these minimum flows under drought conditions.

### 11.1.3 Suggested Criterion for Surface Water Impact

At this level of state water resources planning, there is a need for a sufficiently simple method that can make use of readily available streamflow statistics. The most practical method is the Tennant Method, which relies on percentages of mean annual flow in order to recommend seasonally adjusted in-stream flows necessary for maintaining healthy aquatic habitat conditions. A modified version of this method was applied for most of these groundwater assessments in order to provide initial guidance on limits to groundwater withdrawals.

**Table 11-1** summarizes the primary recommendations of the Tennant Method. For this project, the method was modified to be somewhat more conservative in a number of ways:

- pumping was limited to levels that would result in groundwater discharge to rivers that would preserve the “outstanding” category in order to maintain opportunities for surface water use;
- pumping was limited to levels that would not decrease mean annual stream *baseflow* by more than 40 percent (as opposed to mean annual discharge, which includes baseflow and surface runoff, as in the original Tennant Method); and

- the 40% reduction limit for baseflow was applied all year, and not just between October through March.

These values should be considered as initial targets, to be refined as Regional Plans are developed and more data become available.

**Table 11-1 Tennant Method Showing Percentage of Mean Annual Discharge and Associated Aquatic Ecosystem Health**

Description of Aquatic Ecosystem Health	Percentage of Mean Annual Discharge (QMA), in percent	
	October to March	April to September
Outstanding	40	60
Excellent	30	50
Good	20	40
Fair or Degrading	10	30
Poor or Minimum	10	10
Severe Degradation	<10	<10

## 11.2 Sustainability Measures by Modeling Approach

During this phase of the state water resources planning process, 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 impacts of pumping on the ecosystem and other users of groundwater. Three modeling approaches were used for the State of Georgia Groundwater Assessment Project, as follows:

- Simple streamflow-based water balances;
- Numerical groundwater flow model-based water balances; and
- Numerical groundwater flow models.

Each approach provides a different level of information, and thus a different approach to providing initial estimates of the sustainable yield of the aquifer in question. The exact criterion used to make a preliminary assessment of sustainability will vary according to the modeling approach. The simple streamflow-based water balance approach was used to provide a planning level assessment of groundwater resource sustainability in the Piedmont and Blue Ridge physiographic provinces of Georgia. The numerical groundwater flow model-based water balance approach was used to provide a planning level assessment of groundwater resource sustainability in the Paleozoic rock aquifer in northwest, Georgia. The numerical groundwater flow

model approach was used to evaluate sustainable yields in the Coastal Plain Aquifer System including the Dougherty Plain. Details about how the numerical groundwater flow model approach was used for the Coastal Plain Aquifer System, including sustainable yield metrics are presented in section 11.3.1. Details about the application of the how the modeling approaches and sustainable yield metrics were developed and applied for the Piedmont and Blue Ridge, the Paleozoic rock aquifer in northwest Georgia and the Dougherty Plain are presented in separate memorandums appended to this report and will not be discussed further herein.

## **11.3 Numerical Flow Models**

Calibrated three-dimensional groundwater flow models of the Coastal Plain Aquifer system were developed for existing baseline pumping with both steady-state and transient flow capabilities. The steady-state models were used to assess the impacts of pumping on heads and baseflow, thus accounting for the spatial distribution of pumping, timing of pumping, and impacts of pumping in underlying and overlying aquifers. Transient models were used to evaluate the effects of existing and increased seasonal pumping under both average and drought conditions on heads and baseflow.

### **11.3.1 Evaluating Groundwater Availability**

Before the sustainable yield criteria were evaluated with the models, a quick review of the relationship between recharge, groundwater storage, baseflow, and pumping was needed. Under predevelopment conditions, there is no pumping and recharge, baseflow and groundwater storage are in equilibrium. When pumping is introduced, there is an increase in recharge, a decrease in groundwater storage and a reduction in baseflow. A new equilibrium is established. The primary question that must be answered with the models is: 'does an increase in recharge, removal of groundwater stored in the system, or a decrease in baseflow (groundwater discharge) cause unwanted results?' The following sections present metrics that were used by the groundwater flow models to evaluate sustainable yield.

### **11.3.2 Sustainable Yield Criteria**

The sustainable yield definition requires that the pumping be done in such a way that the aquifer maintains its ecological integrity into the future. If withdrawals are to be considered sustainable, simulations should be done in steady-state to estimate the ultimate drawdown due to increased pumping once the aquifer has had time to reach a new equilibrium. For this reason, criteria for assessing sustainable yield were assessed using a steady-state mode representative of long-term equilibrium.

The steady state modeling of ranges of sustainable yield were controlled by the following two criteria:

- A 30-foot groundwater level drawdown is the maximum allowed between wells and wellfields. The drawdown is compared to today's condition.



- Groundwater contributions to stream baseflow and rivers must not be reduced by more than 40 percent of annual average baseflow under equilibrium conditions.

The stream baseflow criterion is a more conservative approach than the original Tennant method because it is not applied to total streamflow reduction but just to stream baseflow. Streams are represented as sources or sinks in groundwater models but total streamflow cannot be simulated. Instead, the groundwater discharge to surface waters (baseflow) under existing conditions and reductions in baseflow due to increases in pumping were simulated by the models. The relationship between a 40 percent reduction in groundwater contributions to stream baseflow and the corresponding percentage reduction in total streamflow for major rivers in the outcrop areas are presented in Section 16.

Sustainability was estimated under equilibrium conditions. The 30-foot drawdown condition caused by increased pumping would occur within a few years in the confined aquifer itself. It is important, however, to understand the length of time it takes for the entire aquifer system with increased withdrawals to reach equilibrium. Impacts to groundwater contributions to stream baseflow may take longer. Delayed reduction of groundwater contributions to stream baseflow should not be misinterpreted to mean that higher levels of withdrawal should be permitted.

Even with increased withdrawals, water levels will recover from drought pumping within a few years. The recovery time is relatively independent of the level of stress (within reasonable bounds such as those implied by the 30-foot drawdown criterion). Thus, recovery time is not a metric that constrains the ranges of sustainable yield estimated by the steady state simulations.

### **11.3.3 Pumping Patterns Affect Sustainable Yield Estimate**

The sustainable rate of aquifer withdrawal is sensitive to the location and intensity of pumping. The same level of pumping in a small area will result in a 30-foot drawdown, whereas the same pumping dispersed over a larger area will not have the same result. Because the distribution of pumping in the future can vary, sustainable yield was assessed as a range, and increased groundwater withdrawals should be established within that range based on a reasonable assumption of the expected pattern and intensity of pumping. Two approaches to future withdrawal patterns were simulated to establish reasonable maximum and minimum values of sustainable yield.

The likely minimum allowable pumping was simulated by concentrating pumping. To do this, a simulation was performed in which no new areas of pumping were added to the model, and existing pumping centers were increased until either the 40 percent stream reduction or the 30-foot drawdown criterion was reached.

The likely maximum allowable withdrawal was simulated by dispersing pumping as widely as possible across the entire area of the aquifer. In the simulation, additional pumping was added to the model dispersed over the rest of the model area, away

from existing pumping centers, and simulated pumping was increased in existing pumping wells until either the 40 percent stream baseflow reduction or the 30-foot drawdown criterion was reached.

#### **11.3.4 Aquifer System Sustainable Yield Simulations**

The ranges of sustainable yield for each of the prioritized aquifers were first estimated in isolation (individual aquifer sustainable yield). This meant that simulations of increased withdrawals were limited to the aquifer being considered, while pumping in overlying or underlying aquifers was held to current rates of pumping. The Upper Floridan, Claiborne, and Cretaceous Aquifers, however, are hydraulically connected. This can be seen in simulations where pumping is increased in one aquifer, and drawdowns are observed in overlying or underlying aquifers. Depending on the degree of hydraulic connection, increasing pumping in an overlying or underlying aquifer could result in a slightly lower estimate of the sustainable yield (aquifer system sustainable yield) than the range calculated under the assumption that increased pumping will only occur in the aquifer being considered (individual aquifer sustainable yield). To assess whether the aquifer system sustainable yield is lower than the sum of the individual aquifer sustainable yields, two simulation scenarios were performed.

In the first group of simulations, pumping from the Upper Floridan Aquifer, Claiborne Aquifer, and Cretaceous Aquifer was uniformly increased in the existing wells until either the groundwater level drawdown criteria of 30 feet was exceeded over a large area or baseflow reduction to rivers was reduced by 40 percent in any of the aquifers (lower end of sustainable yield range). In the second group of simulations, pumping from all three aquifers was non-uniformly increased in the existing wells until either the groundwater level drawdown criteria of 30 feet was exceeded over a large area or baseflow reduction to rivers exceeded 40 percent (upper end of sustainable yield range).