Fiscal Year 2010 Challenge

Estimating groundwater withdrawals for selected principal aquifers in the Southeastern United States: Floridan aquifer system and Biscayne aquifer
Study period FY09-11

Principal investigators: Richard Marella and Jack Grubbs, FISC and Susan Hutson, Tennessee WSC

Problem Statement: Detailed accounting of the Nation's water use is a costly and labor intensive effort. Statistical sampling and indirect methods are needed to estimate aggregate water use. Annual site specific public-supply and self-supplied industrial water withdrawal records exist for the past twenty-five years in Florida and for several other states in the southeastern United States for various lengths of time. In Florida, irrigation water use has also been estimated for 25 years by application of various statistical approaches for each of the water management districts. This rich body of data provides an ideal situation for developing a rigorously formulated approach for estimating water use.

Background: Detailed estimates of the water withdrawals from the Floridan aquifer system and the Biscayne aquifer have been made for the year 2000. The Floridan aquifer system underlies an area of about 100,000 square miles in southeastern Alabama, eastern and southern Georgia, southern South Carolina, and all of Florida, and is one of the most productive aquifers in the world. Total groundwater withdrawals from the Floridan aquifer system in 2000 were 4,020 Mgal/d, which constituted about 5 percent of withdrawals from all aquifers in the United States. The majority (78 percent) of water withdrawn from the Floridan aquifer system occurred in Florida (3,125 Mgal/d). In 2000, about 33 percent was withdrawn for public supply (1,329 Mgal/d) and 14 percent (576 Mgal/d) for industrial self-supplied. The Biscayne aquifer underlies an area of approximately 4,000 square miles in four counties in southeastern and southernmost Florida. In 2000, about 812 Mgal/d was withdrawn from the Biscayne aquifer, and about 86 percent (698 Mgal/d) is used for public supply.

Objectives: The main objective of the study is to design a rigorously formulated approach to develop consistent water-use estimates for the Floridan and Biscayne aquifers that can be scaled-up to other local and regional aquifers in the Nation. The estimates would be calculated with uniform accuracy and reliability characteristics, emphasizing standard error and confidence limits. The accuracy of estimates based on a stratified random sampling approach (see for example chapter 5 in Committee on USGS Water Resources Research (2002) would be tested against the results of the groundwater public supply and self-supplied industrial inventory for 2000 and 2005. The sampling design would integrate the already extensive local expertise. In addition, the study will also evaluate the accuracy of computing site-specific withdrawals for water-use categories in which withdrawals are typically aggregated at a county-level. The site-specific groundwater withdrawals compiled for the challenge study will be critical information for the upcoming Groundwater Availability of the Floridan aquifer system study (FY10 GWRP start).

Approach: The proposed study will adopt the stratified-sampling approach described by the Committee on USGS Water Resources Research (2002, chapter 5) to estimate total ground-water withdrawals from the Floridan Aquifer system for public supplies, commercial supplies, industrial supplies, once-through thermoelectric, closed-loop thermoelectric, and mining supplies. A census approach has typically been used to estimate ground-water withdrawals for these categories, whereby the withdrawals of all users in these categories is completely inventoried for a given time period. In the proposed study, withdrawals rates of users will instead be randomly sampled within these categories (strata). The value of total ground-water withdrawals for all of these strata is then estimated by (1) computing a mean withdrawal rate for each sampled stratum, (2) estimating the total withdrawals for each stratum by multiplying the mean withdrawal rate for each stratum by the total number of users in the stratum, and (3) summing these estimated stratum withdrawal totals:

$$\hat{Y} = \sum_{h=1}^{L} N_h \hat{\mu}_h \tag{1}$$

where $\hat{Y}$ is the estimated value of total ground-water withdrawals for all of the sampled strata; N_h is the total number of users in a given stratum, h; L is the total number of strata, and $\hat{\mu}_h$ is the estimated value of the mean withdrawal for stratum h.

For a given stratum, the optimal number of samples is defined by the following equation (Committee on USGS Water Resources Research, 2002; Cochran, 1977, Equation 5.26):

$$n_h = n \frac{N_h \hat{\sigma}_h}{\sum_{h=1}^{L} N_h \hat{\sigma}_h} \tag{2}$$

where n_h is the number of samples in stratum, h; n is the total number of samples needed to estimate $\hat{Y}$ with the desired level of accuracy; and $\hat{\sigma}_h$ is estimated value of the standard deviation of withdrawals in the stratum. The term, n, in equation (2) is computed as follows:

$$n = \frac{\sum_{h=1}^{L} N_h \hat{\sigma}_h^2}{\sigma_T^2 + \sum_{h=1}^{L} N_h \hat{\sigma}_h^2} \tag{3}$$

The term, σ_T^2, in equation (3) is the error variance of the total withdrawal estimate arising from sampling, and is computed as follows:

$$\sigma_T^2 = \sum_{h=1}^{L} \frac{N_h^2 \sigma_h^2}{n_h} - \sum_{h=1}^{L} N_h \sigma_h^2 \tag{4}$$

For the proposed study, values of n, and n_h will be computed for values of $\sqrt{\sigma_T^2}$ equal to 1, 2, 5, and 10 percent of the "known" value of total water use that is obtained from a complete census of ground-water use for calendar year 2005. As stated above, the strata within which ground-water withdrawal rates will be sampled to correspond to categories of freshwater use employed by the National Water Use Information Program (public supplies, commercial supplies, industrial supplies, once-through thermoelectric, closed-loop thermoelectric, and mining supplies). The proposed study will also quantify the benefits of further subdividing some or all of these strata. Examples of possible subdivisions include climate zone (or some suitable surrogate for climate zone), season, population density, and commercial density. Values of $\hat{\mu}_h$ and $\hat{\sigma}_h$ will be determined by computing the arithmetic means and sample standard deviations from the random samples obtained from each stratum.

In addition to the “pure” sampling approach described above, a hybrid approach will also be evaluated. In this approach, a given stratum may be further subdivided into a “top” substratum, in which a census approach is applied to a limited number of major users, and a “bottom substratum”, in which the remaining, more numerous minor users are randomly sampled. The total water withdrawal is then computed as:

$$\hat{Y}_h = \hat{Y}_{h,top} + n_{h,bottom}\hat{\mu}_{h,bottom} \tag{5}$$

where $\hat{Y}_h$ is the estimated withdrawal total for the stratum, $\hat{Y}_{h,top}$ is the sum of the withdrawal rates of users in the top substratum, $n_{h,bottom}$ is the number of samples in the bottom substratum, and $\hat{\mu}_{h,bottom}$ is the arithmetic mean of the withdrawal rates of the sample of users in the bottom substratum.

An example of this approach is described by the Committee on USGS Water Resources Research (2002, chapter 5, p. 92-95) and the results are illustrated below, in figure 1. In this example, the total number of samples required to estimate irrigation from surface-water withdrawals was reduced by a factor of nearly 10 (from 1,789 to 163) using the hybrid approach. Although the hybrid approach did not produce similar efficiencies for sampling ground-water withdrawals in this example, successful application of this approach to ground-water withdrawals from the Floridan Aquifer System and the Biscayne Aquifer appears promising because the distribution of withdrawal rates appear to be quite different from those in the example data set. For example, the 1995 data for the state of Florida indicate that withdrawal rates for public supplies from the Floridan Aquifer System are highly skewed (not symmetrically distributed about the mean), with 50 percent of the withdrawals accounted for by the top 3 percent of the users, and 75 percent accounted for by the top 9 percent of the users. Thus, it is quite likely that sampling could be optimized (for at least some of the strata in the proposed study) by including a small fraction of the users in the top substratum and randomly sampling a fairly small number of the remaining users in the bottom substratum.

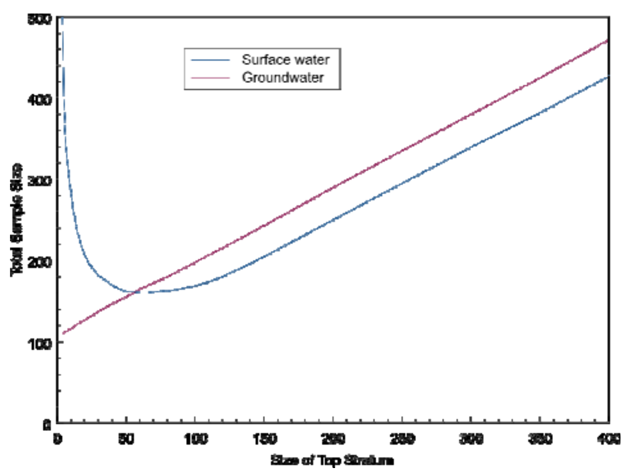

Figure 1. An example of determining optimal sample size using a hybrid approach that combines a census of the largest users (top stratum) with random sampling of the remaining users. This figure is reproduced from the Committee on USGS Water Resources Research (2002, chapter 5, p. 94) and based on data from irrigation withdrawals in Arkansas during 1997, which were obtained from the USGS Arkansas District Office.

The stratified-sampling approaches (hybrid and nonhybrid) will initially be implemented with the 2005 ground-water inventory data. This process will be repeated with the 2010 groundwater inventory data to test and adjust, if necessary, the sampling design developed from the analysis of the 2005 inventory data. The consistency between the accuracy-versus-sample size relations developed from the 2005 and 2010 data will also be evaluated.

The proposed project will evaluate the accuracy of estimating site-specific ground-water withdrawals from withdrawal totals that have been aggregated at the county level. This will be accomplished in two steps. First, site-specific withdrawals will be estimated for a selected set of counties in the study area for which metered data exist at individual wells that withdraw water for a water-use (such as agricultural irrigation) that is typically accounted for at a county level. Examples of such data include the Benchmark Farms Program of the St. Johns River Water Management District. Site-specific estimates for such wells will be computed as follows:

$$w_j = W \frac{p_j}{\sum_{i=1}^{m} p_i} \quad (6)$$

where w_j is the site-specific estimate of the withdrawal at well j in the set of all wells in the county that have metered data for the category of water use withdrawn by well w_j; W is the total ground-water withdrawal for the county for the same category of water use withdrawn by well w_j; p_j is the permitted withdrawal rate for well w_j; and p_i is the permitted withdrawal rate for all of the wells in a given county for the category of water use withdrawn by well w_j. For sites with multiple wells falling under a single permit, the above equation will be used to compute a site-specific rate for the permit, and then divided among the individual wells using the ratio of the squared diameter of the casing of an individual well divided by the sum of the squared diameters of all of the wells in the permit. Once the site-specific estimates have been computed for individual wells in the selected counties, the differences between the site-specific estimates (based on the aggregated, county data) and the metered values will be computed for each well. Summary statistics and plots of these differences will be computed to assess the statistical properties of the site-specific differences (for example, bias and precision). Maps of the differences will also be constructed to help assess the degree to which the accuracy of the site-specific estimates vary geographically. It is expected that these assessments of the accuracy of site-specific estimates computed from aggregated data will directly benefit efforts at revising existing ground-water flow models of the Floridan Aquifer System.

References:

Committee on USGS Water Resources Research, 2002, Estimating water use in the United States: A new paradigm for the National Water-Use Information Program, National Research Council, 176 p.

Maupin, M.A., and Barber, N.L., 2005, Estimated withdrawals from principal aquifers in the United States, 2000: U.S. Geological Survey Circular 1279, 46 p.

Products:

1. Scientific Investigations Report
2. Storage of site-specific groundwater withdrawals in the USGS Site-Specific Water Use Database, SWUDS

Timeline: abbreviated

FY2010
1. Collect, quality assure, and process the 2000 and 2005 data for the Floridan and Biscayne aquifers: Data preprocessing (formatting and data import)
a. Site-specific public-supply data b. Site-specific self-supplied industrial data c. Other category site-specific data d. County aggregated irrigation data
2. Enter site-specific groundwater data for the Floridan model into SWUDS
3. Compute statistics
a. Stratified sampling i. Compute summary statistics for strata ii. Evaluation of substrata b. Hybrid sampling evaluation i. Assemble and preprocess permit data c. Site-specific estimates from aggregated data i. Assemble and preprocess metered data ii. Compute site-specific estimates iii. Compute differences between estimated and metered values
2011
1. Create maps of residuals and statistics 2. Scientific Investigations Report written, reviewed, printed

Personnel and Budget:

	2010		2011	
Richard Marella, GS-12				
Salary	1 pay period	$4,262.40	1 pay period	$4,262.40
Overhead		$2,088.80		$2,088.80
Jack Grubbs, GS-12				
Salary	8 pay periods	$32,403.20	8 pay periods	$32,403.20
Overhead		$15,878.40		$15,878.40
Susan Hutson, GS-12				
Salary	8 pay periods	$34,859.09	7 pay periods	$29,383.14
Overhead		$9,168.85		$8,515.44
Publication costs				$5,000.00
Travel to Tallahassee	1 trip	$1,200	1 trip	$1,200
Total		$99,860.74		$98,731.38