THE USE OF GEOGRAPHIC INFORMATION SYSTEMS ANALYSIS TO ESTIMATE GROUNDWATER AVAILABILITY IN WEST CENTRAL GEORGIA

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Abstract. A reconnaissance investigation of five counties in west central Georgia was conducted utilizing capture zone and GIS overlay analysis methods to estimate the general quantity of the ground-water resource and to identify those areas that would be most favorable to explore for high-yielding well sites. The estimated available ground-water resource in the Piedmont portion of the area (1,357 mi^2) is at least 40 million gallons per day (mgd). In the Valley and Ridge portion (257 mi^2), the estimated ground-water resource is at least 19 mgd from wells and springs.

INTRODUCTION

The five county area of west central Georgia (Polk, Carroll, Haralson, Paulding and Douglas Counties) currently faces potential water shortages during drought conditions, and additional water supplies will be required to accommodate the future population growth. In order to meet these water needs, both surface water and ground-water sources should to be considered.

The ground-water resources of the area have not been systematically studied. Previous studies in the 1970's and early 1980's were directed largely at domestic water supplies. High-yielding wells for municipal and industrial uses were not specifically addressed.

The Georgia Geologic Survey conducted a reconnaissance-level investigation to: 1) estimate the general size of the ground-water resource that would be available to potential municipal and industrial users and 2) identify those general areas that would be favorable for exploring for high-yielding well sites. The preliminary results of this study are described by O'Connor, et al. (1993).

BACKGROUND

The west central Georgia area falls within the Piedmont and the Valley and Ridge physiographic provinces (Clark and Zisa, 1976). The Piedmont occupies 3,515 km^2 (1,357 mi^2) in all of Carroll, Douglas and Haralson counties, most of Paulding County and a portion of Polk County. It is characterized by fractured crystalline rock overlain by a clayey/silty residuum of chemically weathered rock. In general, Piedmont aquifers are of limited areal extent, and are restricted to a single drainage basin. Water is mostly stored in the residuum and then transmitted to the wellore via fractures or other geologic discontinuities. The Valley and Ridge Province occupies 666 km^2 (257 mi^2) in most of Polk County and a very small part of Paulding County. The major aquifers in the province are carbonate rocks characterized by solution-enlarged fracture systems.

In 1990, the Georgia Geologic Survey performed a limited two-month study to assess the general ground-water potential of the five county area and concluded that "at least 32 million gallons per day of ground-water are available in the area. Moreover, Polk County has a hydrogeology favorable for the siting of (very) high yielding wells; such wells could be used for industrial water supplies" (Gorday, 1990).

METHODS

The study presented here utilized a combination of two primary methods: 1) GIS overlay analysis and 2) capture zone analysis. GIS overlay analysis was used to delineate areas that have the most favorable ground-water characteristics, and the capture zone analysis was used to estimate the amount of ground-water yield available within these areas. Other methods of approximating ground-water resources were used for comparison with the GIS analysis methods and are described in O'Connor, et al. (1993).

GIS Overlay Analysis.

Several hydrogeologic and environmental GIS coverages (maps) were used to estimate the areas that are most favorable for ground-water exploration in the West Georgia area. The hydrogeologic GIS coverages include: 1) slope, 2) soils, 3) Piedmont alluvial soils with perennial streams, 4) geology, and 5) lineaments. (Only the geology coverage was utilized in the Valley & Ridge Province.) Environmental GIS coverages include: 1) population density, 2) solid waste sites, 3) hazardous waste sites, 4) land application sites (waste water), 5) wastewater treatment plants, and 6) abandoned sulfide mines and heavy metals anomalies. Attributes on each GIS coverage were ranked from least to most favorable on a scale of 0 to 10. Any factor having a 0 ranking was considered to have a fatal flaw and was eliminated from all further consideration.

Slope. In the Piedmont Province, ground-water recharge is influenced by slope. Generally, areas with gentler slope have greater recharge, and runoff increases as slopes steepen. The following rankings for three slope categories are: 0-2% = 8; 2-6% = 5 and +6% = 3. A slope coverage was not used for the Valley and Ridge portion of the study. This province is largely underlain by carbonate rocks which tend to have very low slopes, so a separate slope coverage is not meaningful.

Soils. The soils coverage utilized the Georgia Department of Natural Resources (DNR) soil maps compiled from the U.S. Soil Conservation Service (SCS) county soil association maps. The Piedmont soils data were used to estimate the depth to bedrock. Soil series characterized by shallow bedrock (thin soils) were ranked as relatively unfavorable, whereas soil series characterized by deeper bedrock (thick soils) were ranked as relatively favorable. Four groups of soils were identified as follows: shallow, hard bedrock (Louisburg, Musella & Wilkes soils) = 2; shallow, soft bedrock (Louisa & Tallapoosa soils) = 4; shallow bedrock (Appling, Helena & Mecklenberg soils) = 4; and all other Piedmont soils = 7.

Piedmont Alluvial Soils. A separate GIS coverage was prepared for those Piedmont alluvial soils which are accompanied by perennial streams, because these are zones of potentially significant ground-water recharge and storage in the Piedmont. This comprises the Groups 1 and 10 soils designated on the DNR soils maps.

Soils coverages were not prepared for the Valley and Ridge portion of the study area. Ground-water flows through extensive solution-enlarged fractures in carbonate bedrock units so that recharge and storage by the soil and residuum is probably relatively less significant.

Piedmont Geology. The following ranking of geologic units is based on the work in the North Carolina Piedmont (Daniel, 1989 & 1990) where well yield was statistically correlated with rock type: Felsic gneiss, felsic metaigneous rocks, quartzite, and interlayered felsic gneiss & schist = 4; Intermediate gneiss, mafic gneiss, mafic metaigneous rocks, interlayered phyllite & metasandstone, interlayered schist & quartzite, and interlayered quartzite, schist & amphibolite = 5; Phyllite, schist and cataclastic rocks = 6.

Valley and Ridge Geology. Ground-water in the Valley and Ridge is controlled primarily by the carbonate rock units. A simple two-fold division of the geology was based on the well yield summary in Cressler (1970): 1) dominantly carbonate rocks (limestone and/or dolostone); and 2) dominantly non-carbonate rocks (shale, slate, chert and sandstone). Only the areas dominantly underlain by carbonate rocks were subjected to the capture zone analysis.

Lineaments. Topographic lineaments were used to infer the density of fractures and other discontinuities in the Piedmont bedrock. In general, the more fractures that a well encounters, the greater will be its yield. The Valley and Ridge Province was not evaluated for lineaments, because it is dominated by weathered carbonate bedrock units which do not readily show strong linear topographic features in the study area.

Lineament intersections and lineament lengths were determined using: 1:24,000 (7.5') topographic quadrangle maps; high-altitude color infrared photographs (CIR); and Side Looking Airborne Radar (SLAR) imagery. The number of lineament intersections as well as the sum of the lineament lengths within each 1 km^2 grid cell were counted and given relative scores. Because of the variable quality of the three sets of imagery, the data from these images were weighted according to image quality as follows: 7.5' = 5; CIR = 3; SLAR = 2.

Population Density. Population density in the entire five county study area ranges from zero persons/census tract to 2,518 persons/census tract (1990 census). The average population density in the study area is about 57.5 persons/km^2 ($\sim$149/mi^2). Population density was used as a surrogate for non-point source pollution potential. Areas having lower population were considered more favorable for ground-water exploration as the non-point source pollution potential would be less. The following divisions and rankings are based on a review of the population distribution data, by census tract, as contained in the U.S. Census Bureau's 1990 census: 1) $>$1,000 (/km^2) = 0 (Fatal Flaw); 2) $>$100 - 1,000 = 2.5; 3) $>$10 - 100 = 5; 4) $>$0 - 10 = 7.5; 5) 0 = 10.

Anthropogenic and Other Point Sources of Pollution. Anthropogenic point sources are human induced sources of ground-water pollution. For the West Georgia study area, the analysis was restricted to known or permitted landfills, hazardous waste sites, waste water treatment facilities and sulfide mines. Existing transportation and large pipeline corridors were not considered. Other anthropogenic point sources such as abandoned waste sites, leaking underground storage tanks, non-domestic septic systems, etc., were not considered, because they are generally undocumented or of a transient nature.

The Ground Water Pollution Susceptibility Map of Georgia (Trent, 1992) demonstrates that, of all the hydrogeologic provinces within Georgia, the Piedmont Province is the least susceptible to human-induced pollution. A graduated scheme was developed for assigning different buffer radii for various types of point sources depending on their pollution potential and geologic location. Abandoned sulfide-bearing mines and heavy metals anomalies were treated in a similar fashion, because they are potential point sources of heavy metals for ground-water pollution. Each type of site and their respective buffer radii, in miles, for Piedmont and Valley & Ridge are: Superfund (NPL) = 1 & 2; RCRA Enforcement Actions = 1 & 2; Other (RCRA, CERCLA, etc.) = 0.5 & 1; Municipal Landfills = 1 & 2; Industrial Landfills = 0.5 & 1; Waste Water Treatment (NPDES) = 0.25 & 0.5; Land Application (LAS) = 0.5 & 1; Abandoned sulfide mines = 0.25 & 0.5. Areas within these buffer zones were rated 0 (ie., fatal flaw), while areas outside the buffers were rated 10.

Overlay Analysis. In the overlay analysis process, all of the GIS coverages described above were overlain on top of each other, and the rank score for each area on each coverage was added to all of the areas on the succeeding coverage layers. Because there is no consensus concerning various possible weighting schemes for overlay analysis, each of the GIS coverages were assigned the same weight. The resulting composite rank scores were compiled onto a final thematic overlay analysis coverage.

To identify broad areas most favorable for ground-water, the composite overlay analysis scores were divided into thirds. In order to select the areas with the greatest ground-water favorability, only those areas having scores in the upper third were subject to capture zone analysis.

RESULTS

Ground-water Resources of the Piedmont Province

For this study a high-yielding Piedmont well is defined as having a yield of 50-150 gallons per minute (gpm). In the Valley and Ridge, a high-yield well is defined as yielding 250-500 gpm. Using capture zone analysis, a 100 gpm well in the Piedmont is calculated to correspond to a capture zone radius of 830 m (2,724 ft.) which equates to a circle of 2.2 km^2 (0.8 mi^2). The radius was determined from a plot of capture zone radius versus pumping rate which was generated using the well-head protection method of Heath (1991). This assumes a high yielding Piedmont well is pumped at 100 gpm, that the recharge is 3.4 inches per year (ie., almost half the state-wide average) and that the area of influence is circular. This relationship was then applied to the areas with favorability scores in the upper third as determined by the GIS overlay analysis. As a first approximation, all of this area was assumed to be available for drilling. The number of 100 gpm wells that could be drilled in these 1,030.8 square kilometers (398 mi^2) was calculated by assuming perfectly circular wellhead capture zones in a closest packing configuration (ie., 74% coverage). This analysis, which assumes that all of the areas with score in the most favorable third are available, indicates that 347.75 such wells could be drilled in the most favorable third of the Piedmont.

Because some of the overlay analysis polygons are quite small, those polygons smaller than 2.2 km^2 (ie., less than one 100 gpm well) were excluded. As a result, at least 279 wells with a total potential yield of 40.2 mgd can be drilled in the Piedmont portion of the study area.

Ground-water Resources of the Valley and Ridge Province

The Valley and Ridge Province lies in the central and northern part of Polk County and a small portion of northwestern Paulding County. The ground-water resources of the Valley and Ridge Province are considered to be relatively large even though it only occupies or about 16 percent of the study area. While wells and springs have been used as sources of municipal and industrial water supply in Polk County for over 100 years, the available ground-water resources have never been estimated.

Unlike the fractured crystalline rocks of the Piedmont, where ground-water is stored in a porous regolith and then transmitted to wells via geologic discontinuities, ground-water in the Valley and Ridge aquifers is both stored in and flows through solution cavities in carbonate rocks. Locally such flows can be quite prolific; Cressler (1970) reports well yields up to 1,500 gallons per minute.

Carbonate rock aquifers of the Valley and Ridge also differ from crystalline rock aquifers of the Piedmont in two other important aspects; namely: (1) lowering of the water table as a result of pumpage can induce sinkhole collapse; and (2) the greater susceptibility to human-induced pollution. Inducement of sinkholes as a result of lowering the water table in the vicinity of pumping wells is a significant limitation on the volume of water that can be pumped. Therefore, carbonate aquifer wells in the Valley and Ridge of northwest Georgia should only be pumped at a rate that will not significantly lower the water table for adjacent properties.

Recharge in the Valley and Ridge portion of Polk County probably exceeds the state average of 6 inches per year. Average annual recharge was estimated to be 18.4 cm (7.25 in.), and 10.8 cm (4.25 in.) during dryer periods.

The GIS overlay analysis for the Valley and Ridge included the following coverages: geology, anthropogenic point sources of pollution, and population density. In order to minimize the potential impact of sinkholes, only those areas with the lowest population density (zero persons/mi^2) were selected. In this way, any sinkholes which might develop due to well pumping would impact the fewest people. The resulting most favorable, lowest population density areas total 44.9 km^2 (17.35 mi^2) which, with a 74% packing factor, will support 9 wells at 500 gpm or 6.5 mgd. This analysis assumes a 1 foot drawdown for a well pumped at 500 gpm and circular capture zone with a radius of 1,093 m (3,585 ft.). The radius was determined from an analysis of ground-water withdrawl and injection data from a limestone quarry associated with sink hole development in the vicinity of Fairmount in Gordon County, Georgia.

As a somewhat less conservative alternative, the most favorable geologic units which coincide with census tracts having less than or equal to the Polk County median population density (18.0/km^2) were evaluated. The resulting favorable, low population density areas total 218.6 km^2 (84.4 mi^2) which will support 38 wells at 500 gpm or 27.4 mgd (well radius=1,093 m; 3,585 ft.).

Springs provide ground-water that naturally discharges at the surface. Cressler (1970) lists 17 springs with flows of greater than 0.1 mgd in Polk County. Four of these very large springs are currently being utilized by the City of Cedartown and the Polk County Water Authority. In addition, the four largest undeveloped springs could augment the ground-water supply in the Valley and Ridge by about 12.5 mgd.

CONCLUSIONS AND RECOMMENDATIONS

An analysis of the west Georgia area using GIS and capture zone analysis indicates that at least 40 mgd of additional ground-water should be available on a sustained yield basis from wells in the Piedmont. Ground-water resources of the Piedmont are dispersed and will probably require approximately 280 wells at widely scattered locations to obtain 40 mgd.

The ground-water resources of the Valley and Ridge are more concentrated than in the Piedmont. Depending on the level of sinkhole risk one is willing to assume, between 6.5 and about 27 mgd of ground-water could be obtained from Valley and Ridge carbonate aquifer wells. In addition to ground-water withdrawals from wells, four significant springs (greater than 0.5 mgd) in the Valley and Ridge could be utilized to provide approximately 12.5 mgd.

The ground-water yields presented here are based on a reconnaissance level study and should be considered estimates only. Further investigations are needed to substantiate the various assumptions regarding ground-water favorability in the GIS overlays. The ground-water recharge estimates and capture zone radii also need to be verified. And, perhaps most importantly, the sinkhole risk assessment for the Valley and Ridge carbonate aquifers requires much more study.

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