WELLHEAD PROTECTION AREA DELINEATION IN FRACTURED BEDROCK AQUIFER, FAYETTEVILLE, GEORGIA

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REFERENCE: Proceedings of the 1993 Georgia Water Resources Conference, held April 20 and 21, 1993, at The University of Georgia, Kathryn J. Hatcher, Editor, Institute of Natural Resources, The University of Georgia, Athens, Georgia.

INTRODUCTION

The City of Fayetteville, about 30 miles south of Atlanta, Georgia, in Fayette County, has developed groundwater from fractured bedrock aquifers between 1988 and 1992. In the summer of 1991, the U.S. Environmental Protection Agency (EPA) awarded a Wellhead Protection Program (WHPP) Demonstration Grant to the City of Fayetteville to delineate a wellhead protection area (WHPA) for a bedrock wellfield and to develop a technical approach to defining a WHPA in fractured crystalline rock.

The WHPP, mandated by 1986 amendments to the Safe Drinking Water Act, is designed to protect public groundwater supplies from contamination. The U.S. EPA (1987) identifies four criteria for WHPA delineations: distance, time of travel, drawdown and physical features (flow boundaries). Six methods of WHPA delineation are outlined by the U.S. EPA (1987): arbitrary fixed radii, calculated fixed radii, simplified variable shapes, analytical methods, hydrogeologic mapping, and numerical flow transport modeling.

The current Georgia wellhead protection standards for wells in the Piedmont physiographic province are based on calculated fixed radii which vary with the pumping rate of the production well. It was the goal of this study to refine the fixed radii method by applying hydrogeologic mapping techniques. WHPA delineation in fractured crystalline bedrock aquifers presents a challenge because flow is partially or entirely controlled by fractures and is highly directional. Thus, a circular WHPA may over or under-protect a well; moreover, appropriate WHPAs may be irregular or highly elongated in shape. A technically-based WHPA delineation appropriate to the hydrogeologic environment significantly reduces the risk of losing a well to contamination.

The Fayetteville groundwater exploration program offered a unique opportunity for a pilot study of WHPA delineation to be performed simultaneously with a groundwater exploration project. The WHPA delineation study could take advantage of an existing data base and conceptual model developed as part of a scientifically-based exploration study.

SITE DESCRIPTION

The approximately 6-acre study site in the Georgia Piedmont physiographic province includes a high-yielding bedrock well drilled in April, 1992, as part of an exploration program. This new well (not yet in production) and site were selected for conducting the WHPA delineation study because certain borehole surveys could be conducted prior to installation of permanent pumps. Also, pumping tests required for State certification could be used as part of the delineation process. The study site is on seasonally-drained floodplain along Ginger Cake Creek near Fayetteville, Georgia (see Figure). The area is primarily rural and has few contaminant threats.

Bedrock consists of fractured metamorphic rocks and granite plutons, and is covered by approximately 40 feet of saprolite and/or alluvium. Projection from the nearest bedrock outcrop suggests that the site is likely underlain by steeply dipping gneisses and amphibolites of the Big Cotton Indian Formation striking approximately east to west. Reconnaissance geophysics and test drilling confirm these observations. Based on outcrop observations and photolineament analysis, the area is characterized by approximately east/west-trending metamorphic layering and approximately north/south (and other) cross-cutting fractures.

GEOPHYSICAL SURVEYS AND RESULTS

A total of 10,410 linear feet of magnetic data and very low frequency electromagnetic (EM) data was collected using an EDA Omni Plus Magnetometer with a magnetic base station. Magnetic data is very effective in defining the foliation direction, which may be a preferred direction for groundwater flow in gneissic terrain. EM data is useful in delineating weathered (and therefore conductive), inclined fracture zones. EM and magnetic data showed distinct anomalies parallel to the east/west foliation direction of the gneissic bedrock as projected from outcrop. Foliation in the gneiss was expected to dip almost vertically in this area, based on projections from outcrop to the east of the site. The magnetic low anoma-

lies also indicated near-vertical dip in features which were later determined by test drilling to be amphibolite bodies. The EM data showed a strong east/west conductive zone parallel to and 60 feet north of one of the east/west magnetic zones.

TEST AND MONITORING WELLS

The bedrock well was sited on the EM anomaly and was drilled to a depth of 501.5 feet. Several water-bearing zones were encountered during drilling; however, while drilling, it was impossible to determine the dip of these zones. Consequently, a video camera was lowered into the well and showed the presence of both flat lying and steeply dipping fractures. The most common fracture strike is east/west; however northwest/southeast and due north fracture strikes were also observed in the well. Most fractures identified during drilling as major fractures or water-bearing fractures were visible with the video camera. It is difficult to determine the dip of these zones from the camera survey, but generally they appear to be low-angle or horizontal. Most of the steeply-dipping fractures are associated with lithologic boundaries (i.e., between gneiss and amphibolite bodies) and tend to be parallel to foliation, which strikes approximately east/west.

Eight shallow monitoring wells were installed in the study area. Three of these wells were sited along a magnetic anomaly; five wells were sited off anomalies. A six-inch outer-diameter, hollow-stem auger was used to penetrate the overlying alluvium and saprolite. Drilling stopped at auger refusal, which usually was within the saprolite-competent bedrock interface zone. The most conductive zones above bedrock were screened. The monitoring wells provided water level data during the pumping test; this was the primary data for determining the WHPA.

The preceding investigations allowed development of a conceptual model of the aquifer system at the site. According to this model, bedrock fractures and foliation are the most prominent structural features influencing groundwater flow in the Fayetteville area. Geophysical surveys indicate that the primary structural fabric is related and parallel to foliation. Drilling and borehole video camera surveys showed that a majority of the fractures have horizontal to low-dips. Some of the major water-producing fractures were developed along lithologic boundaries between gneiss and amphibolite bodies which were often steeply dipping. The steeply-dipping foliations, lithologic boundaries and associated fractures probably provide avenues for water flow from alluvium and saprolite above to horizontal fractures below.

PUMPING TEST

The well was pumped at 200 gallons per minute (gpm) for four days as part of the water supply exploration program. Water levels were measured in the monitoring wells prior to the pumping test, during the pumping test, and during recovery.

Contoured water level data (and drawdowns) gathered during constant rate pumping show an east-southeast/west-northwest- (ESE/WNW) trending zone of influence that is a result of relatively greater drawdowns in monitoring wells 1, 5 and 6. These are the closest monitoring wells to the magnetic (low) anomaly, thus reinforcing the hypothesis that the primary vertical "connection" to the overburden is an amphibolite bed parallel to foliation. Within precision of the data, the zone of influence trends in the same ESE/WNW direction as foliation and associated fractures and amphibolite bodies.

WELLHEAD PROTECTION AREA DELINEATION

The WHPA was delineated by using a combination of the drawdown, physical features, and Georgia Department of Natural Resources calculated fixed radii criteria. The approach is based on the assumption that the bedrock well receives its recharge from overlying unconsolidated deposits (alluvium and saprolite). Drawdown contouring for the overburden monitoring wells resulting from constant rate pumping showed an elliptical shape with an ESE/WNW-trending long axis (parallel to geologic and geophysical features). The Georgia calculated fixed radii criterion indicated the size of the area to be protected (based on pumping rate). Physical features such as drainage divides and groundwater gradients modified the final WHPA.

According to new Georgia WHPA delineation guidelines, a bedrock well in the Piedmont Province has a WHPA whose Outer Management Zone (OMZ) is a circle with radius determined by its pumping rate. For example, for a well pumped at 210 gpm, the fixed radius for the Outer Management Zone would be 2,950 feet. (The well in this study will be pumped at 210 gpm, slightly higher than the aquifer test rate, because another nearby bedrock well which could be pumped simultaneously will not be put into production.) The results of the geophysics and the pumping test indicate that the Zone of Influence for the pumping well can best be described as an ellipse rather than a circle. The OMZ was designed to have the same elliptical shape as drawdown contours observed during the aquifer test, but with an area equal to that of a circle with radius 2,950 feet. In this way, the same amount of area would be protected, but that shape would reflect site-specific hydrogeologic conditions. Knowing the area and the long/short axis ratio of the ellipse, the long and short axis lengths were calculated. The resulting ellipse was

then transferred to the base map (Figure) with the center located at the pumping well and the long axis oriented parallel to the drawdown contours' long axis.

The regional groundwater table in the study area was mapped by assuming that the elevation of all surface water bodies, including intermittent streams and ponds, from a 7.5 minute topographic map, represents the groundwater surface elevation. This map was used to modify the extent of the WHPA at drainage divides and some surface water bodies.

The OMZ was extended using flow lines perpendicular to contours on the water table map. These flow lines indicate that several small areas beyond the original ellipse also may contribute water to the well. These areas encompass hills that contribute groundwater into the OMZ. Also, a thin slice of the extreme western end of the ellipse was truncated at a watershed divide (Figure).

CONCLUSIONS

A conceptual hydrogeologic model for a bedrock aquifer in Fayetteville, Georgia, was developed using airphoto analysis, bedrock and overburden geologic mapping, surface geophysics, aquifer testing, and video camera surveys. Installation of a monitoring network in saprolite (with the aid of surface geophysical surveys) provided subsurface information to refine the conceptual model and allowed water level monitoring during aquifer testing at the site. Aquifer testing showed an elliptical cone of depression oriented parallel to major geologic features inferred to be water-bearing in the conceptual model. The pumping test combined with the monitoring well network comprised the single most important technical element of our wellhead protection area delineation. An elliptical Outer Management Zone having an area equal to that proposed by the new Georgia guidelines was defined based on geological, geophysical, and aquifer information. Modifications of the Outer Management Zone are based on drainage divides and groundwater flow lines.

ACKNOWLEDGMENTS

Don Easterbrook and Rick Eastin of the City of Fayetteville are thanked for their assistance throughout the project. Nathalie Ellington of the U.S. EPA is also thanked for coordinating the project. Melinda Chapman and others of U.S.G.S. Atlanta are thanked for their interest, support, and geophysical well logging at the site. Sandra Jo Robertson and others of the Georgia Geologic Survey are thanked for their interest and support. Joseph Walker, landowner, is thanked for access to the study site. Field and other investigations were performed by the staff of HydroSource Associates, Inc.; all are thanked. Jim Brady was project manager for field investigations, and Christine Worthen prepared the manuscript. Robin Roth, Karla Cashman and Rosemarie de Mars prepared the figure.

Notice. Although the information in this document has been funded wholly or in part by the U.S. Environmental Protection Agency under Wellhead Demonstration Grant S00497791-0 to the City of Fayetteville, Georgia, it does not necessarily reflect the view of the Agency, and no official endorsement should be inferred.

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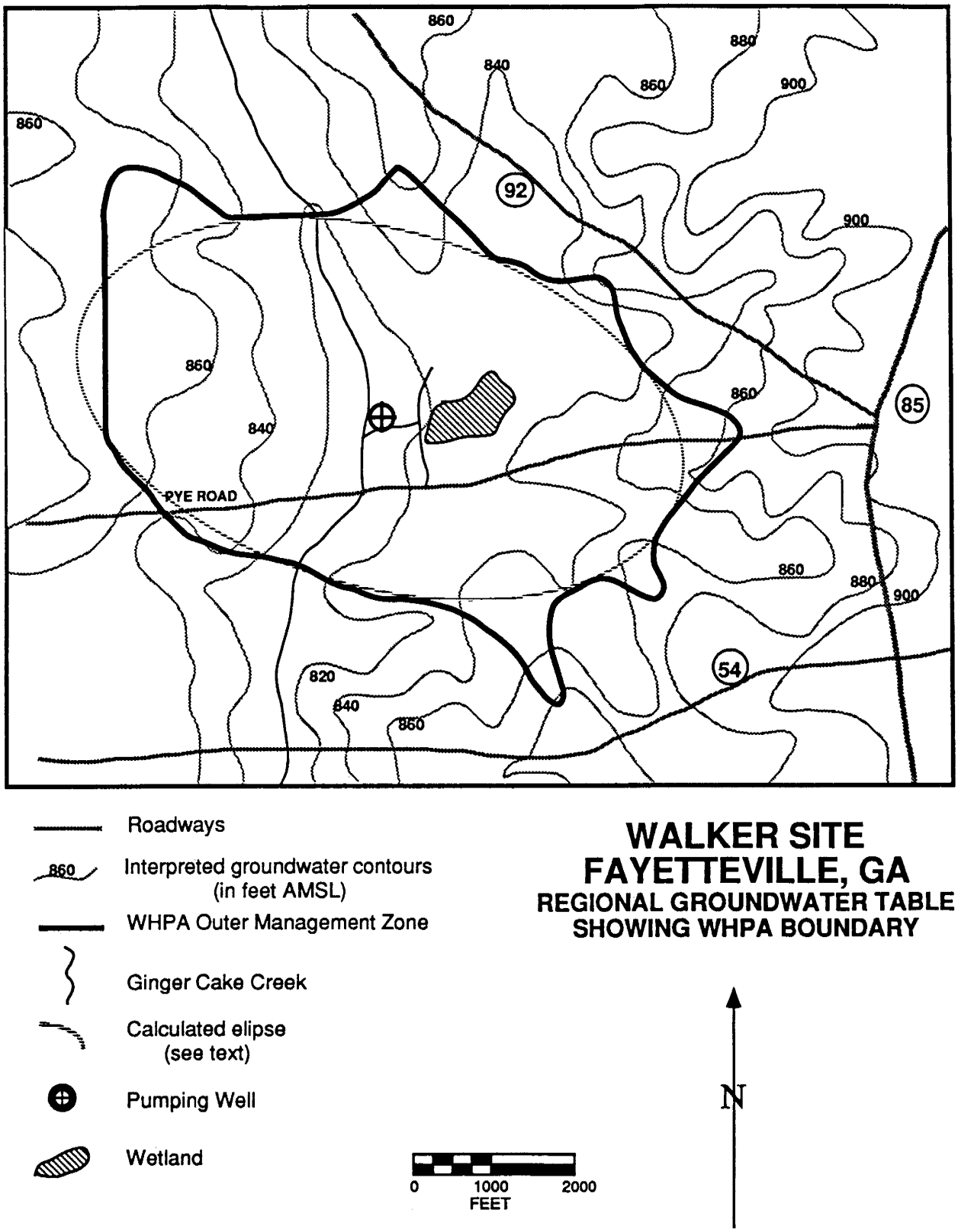

Figure 1. Regional Groundwater Table Showing WHPA Boundary at Walker Site, Fayetteville, GA.