GEOLOGICAL SURVEY OF ALABAMA

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Potential for Impacts of Regional Ground-Water Movement and Quality on Redstone Arsenal

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INTRODUCTION

Redstone Arsenal is a historically important site for the development of missile and rocket technology. However, it is also known in the environmental community for biological habitat and species including the endangered Alabama cave shrimp (*Palaemonias alabamae*) in Bobcat Cave and the Tuscumbia Darter (*Etheostaoma tuscumbia*), a species of High Conservation Concern, in Williams Spring (McGregor and others, 2004).

Redstone arsenal is bounded on the south by the Tennessee River and on the west, north, and east by expanding urban areas of the cities of Madison and Huntsville. Urbanization of areas hydrologically upgradient from the arsenal cause changes in runoff and water quality. Previous investigators (Rheams and others, 1992, McGregor and others, 1996-2008, McGregor and others, 2004, Campbell and others, Campbell, 1997) addressed effects of water quality and water movement on wildlife on the arsenal. This investigation employs previously unused data and evaluation techniques to characterize pathways of ground-water movement, surface- and ground-water interactions, and sources and pathways of contaminant movement.

HYDROGEOLOGY

Much of the surface and shallow subsurface of Madison County is composed of the Fort Payne Chert and Tuscumbia Limestone. The geology of the Redstone Arsenal area is characterized by Tuscumbia Limestone at the surface, underlain by Fort Payne Chert. Fort Payne Chert is composed of very light gray to light-gray, thin- to thick-bedded, fossiliferous or bioclastic limestone, siliceous and dolomitic limestone, and dolomite with abundant nodules, lenses, and beds of light- to dark-gray chert (Copeland and others, 1975; Szabo and others, 1988). Bedded chert is common throughout the unit but is more concentrated near the base. The percentage of chert in the formation is variable from 20 to 80 percent (Holler, 1975). The formation has an average thickness of about 160 feet.

The Tuscumbia Limestone overlies the Fort Payne Chert although in some areas it is lithologically indistinct. It is generally composed of a sequence of light-gray to light-brownish-gray coarse- to medium-grained bioclastic or micritic limestone, light-brownish-gray granular cherty calcareous dolomite, and randomly distributed light-gray and white nodular chert (Holler, 1975; Raymond and others, 1988). The Tuscumbia Limestone has an average thickness of about 150 feet.

Surface and near-surface parts of these units are weathered into clayey soils and karst terrains characterized by solution enhanced fractures. Well drilling in Madison County shows the local occurrence of fractures on multiple levels that store and transmit large amounts of water. Many of these karst features are connected to surface-water bodies so that water is readily exchanged between the surface and subsurface. Drilling also shows that in many areas fractures do not occur or are so small that they are not detected during drilling. Therefore, transmission of large amounts of ground-water over long distances is uncommon.

GROUNDWATER MOVEMENT

Aquifers in the Redstone Arsenal area are semi-confined or unconfined due to shallow depths and absence of confining layers that isolate groundwater from the water table and the land surface. Therefore, groundwater movement is controlled by gravity as water moves from topographic highs to topographic lows where it discharges as springs or to surface-water bodies. Groundwater movement in the Tuscumbia Limestone and Fort Payne Chert is preferential with respect to direction and velocity, related to the geometry and connectivity of fracture systems. Investigations by the GSA found that groundwater flow velocities in the Tuscumbia Limestone/Fort Payne Chert aquifer in the Muscle Shoals area of Colbert County varied from 65 to 1,800 feet per hour (Chandler and Moore, 1991) and in the Huntsville area from 50 to 142 feet per hour (Baker, 2002).

Groundwater movement in karst terrains is primarily determined by two techniques; tracer surveys and water surface mapping using water levels from wells, springs, and streams. Campbell (1997) reported that at least 10 dye trace surveys were performed by the Geological Survey of Alabama in the Redstone Arsenal area. Seven tracer surveys using dyes and optical brightener were performed by Rheams and others (1992) in the southern Madison County area. Detections of dye indicate water movement from 2,000 feet to 4.7 miles to the south and southwest. Five of these surveys were performed in the Matthews and Bobcat Cave areas. However, no dye was detected in the caves. Campbell reported other surveys where dye was detected in Bobcat Cave after introduction into the subsurface less than 300 meters south from the cave, indicating local recharge and northward water movement.

Two previous water level maps (Rheams and others, 1992 and Mann and others, 1997) indicate water movement generally southward to the Tennessee River with local westward water movement in areas of relatively high elevation near the eastern boundary of the arsenal. Water level mapping for this investigation indicates that Redstone Arsenal is located in a ground-water sink with the Tennessee River as the downgradient boundary. Ground-water flow throughout the study area is influenced by topography. Ground water flows westward along the eastern margin of the study area from Monte Sano, Garth, Morris, Weatherly, and Mathis Mountains toward Huntsville Spring Branch (plate 1). Along the western margin of the study area, ground water flows eastward from Rainbow and Betts Mountains to Betts Spring Branch and Indian Creek (plate 1). In the central part of the study area, ground water flows eastward and westward from the crests of Weeden and Madkin Mountains, and Redstone Airfield to Indian creek and Huntsville Spring Branch (plate 1). The connection of Rainbow Mountain and the ridge at the Redstone Airfield form a probable ground-water divide that routes ground water southeastward from areas north of Interstate 565 (plate 1).

GROUNDWATER RECHARGE AND SURFACE-WATER/GROUNDWATER INTERACTION

Unlike the Coastal Plain where groundwater can move long distances from recharge areas in aquifers that exceed depths of 2,500 feet (Cook, 2004) or the Valley and Ridge and Piedmont where large, complex faults create pathways for movement of recharge over long distances (Cook, 1997), groundwater recharge in much of the Tennessee River watershed is local. Recharge rates are controlled by a number of factors including porosity and permeability, which in Paleozoic aquifers are mainly secondary and are characterized by leached fossils, fractures, and solution development. Most carbonate rocks in the Tennessee River watershed are indurated and thoroughly cemented, resulting in limited intergranular porosity. Therefore, fractures provide much of the porosity and permeability for groundwater movement and storage. Fractures are characterized as stress-relief (vertical) and bedding-plane (horizontal) and are typically non-uniform and can vary significantly over short distances (Bossong and Harris, 1987).

Recharge, originating from precipitation, may also be influenced by drought (fig. 10), seasonal precipitation (fig. 11), land surface slope, surface drainage, and the character of surface material. If the topography is relatively flat and surface materials are permeable, more surface water will infiltrate into local aquifers. Recharge may also be greater where faults and fractures are common, subjected to solution enhancement, and extend to the surface where they connect surface water and aquifers (Bossong, 1988; Baker and others, 2005). Estimates of recharge can be useful in determining available groundwater, impacts of disturbances in recharge areas, and water budgets for water-resource development and protection. Numerous methods have been used for estimating recharge, including development of water budgets, measurement of seasonal changes in groundwater levels and flow velocities. However, equating average annual baseflow of streams to groundwater recharge is the most widely accepted method (Risser and others, 2005).

An estimate of recharge was determined for the Redstone Arsenal area using two hydrograph separation techniques on discharge data from Indian Creek. Results indicate that groundwater recharge is about 6.9 inches per year (Cook and others, 2009). This equates to about 94 million gallons of groundwater per year being recharged to the aquifer system on Redstone Arsenal.

Cavities form from the solution of fractures, joints, and bedding planes in limestone and can allow for the rapid transport of water in a karst aquifer. Matthews and Bobcat Caves on Redstone Arsenal are cavity systems which have openings to the surface. Determining connectivity between cavities is difficult and usually requires the use of dye trace studies. In order to better visualize the cavity systems in the area, three dimensional cross-sections or fence diagrams were created using wells in the area that have geologic data recorded at the time of drilling (plate 2). As stated earlier, small cavities and fractures are not always detected during drilling. Imaginary wells Matthews-1 and Bobcat-1 were used to depict Matthews and Bobcat caves in the diagrams (plate 2).

Plate 3 is a fence diagram of all the wells in the study area with good recorded geologic information. As can be seen, establishing connectivity of the cavities is difficult. Because in most cases the lateral size and distance of the cavities in the wells is unknown. Elevations of the cavities vary greatly from well to well and several wells such as well MT-126 have multiple cavities while several wells, P-35, N-04, Q-07, O-01 have no recorded cavities. The regional perspective shown from plate 3 indicates that cavities recorded in wells are restricted to areas in and near the Indian Creek flood plain. This has profound implications for water and contaminant movement. However, Rheams and others (1992) documented ground-water movement in two dye tests outside of the Indian Creek flood plain.

Plate 4 focuses on the Matthews and Bobcat Cave area. The fence of Matthew-1 to P-27 crosses over the ground water divide depicted on the ground-water level map (plate 1). Wells MS-4 and MS-5 demonstrate the proximity of wells with dissimilar solution development MS-5 with a recorded cavity and MS-4 without a cavity. Wells CT-61, MS-7, and TW-4 in the same area lacked recorded cavities.

LAND USE AND WATER QUALITY

Land use/land cover data (USGS, NLCD, 2003) indicates that the area surrounding Redstone Arsenal is dominated by urban development and agriculture (plate 5). Plate 5 has varying shades of pink and red that indicate differing magnitudes of urban development and various shades of brown that indicate brush, grassland, pasture or hay, and cultivated crops. Plate 2 clearly shows intense development in Madison, west of the arsenal, the I-565 corridor and University of Alabama at Huntsville area north of the arsenal, and the city of Huntsville to the northeast and east. As discussed previously, much of the surface runoff and ground water from these areas flows onto the arsenal and directly impacts water quality.

Water quality monitoring in Bobcat and Matthews Caves was initiated by the Geological Survey of Alabama in 1990. Since that time, a large amount of hydrologic and geochemical data has been collected that indicates that water in Bobcat Cave has relatively low concentrations of nutrients (phosphorus, nitrate, and ammonia) and periodic elevated concentrations of cadmium, chromium, and lead (McGregor and O’Neil, 2006). Water in Matthews Cave is characterized by relatively high concentrations of nitrate, low concentrations of phosphorus and ammonia, and periodic elevated concentrations of cadmium, chromium, and lead (McGregor and O’Neil, 2006).

Continued urbanization and associated runoff containing nonpoint source contaminants in areas adjacent to the arsenal will have increasing deleterious impacts on water quality on the arsenal, especially the eastern part including Matthews Cave. Hydrologic and geochemical data indicate that Bobcat Cave may be isolated from much of the urban runoff that flows through the arsenal to the Tennessee River. Probable ground-water divides formed by Betts and Rainbow Mountains, interception of overland runoff and ground water by Indian Creek, and a local northward hydraulic gradient protect the cave from regional urban influences, particularly elevated concentrations of nutrients and bacteria. Identification of sources of toxic metals is more problematic and requires further investigation.

SUMMARY AND CONCLUSIONS

The geology of the Redstone Arsenal area is characterized by Tuscumbia Limestone at the surface, underlain by Fort Payne Chert. Well drilling in Madison County shows the local occurrence of fractures on multiple levels that store and transmit large amounts of water. Many of these karst features are connected to surface-water bodies so that water is readily exchanged between the surface and subsurface. Groundwater recharge is about 6.9 inches per year. This equates to about 94 million gallons of groundwater per year being recharged to the aquifer system on Redstone Arsenal. Ground-water movement in the Redstone Arsenal area of Madison County, Alabama is controlled by topography, surface-water features and by cavities and fractures that are difficult to map. Water quality on the arsenal will continue to be impacted by runoff originating from urban areas in close proximity to the arsenal. Interaction and exchange of groundwater and surface-water create pathways of movement for contaminants to move on the Arsenal and to eventually move to the Tennessee River. However, more comprehensive investigations of both ground-and surface-water systems will be required to determine specific sources and pathways of potential contaminants.

LITERATURE CITED

Baker, R. M., 2002, Dye trace investigations in the vicinity of Chapman Mountain, city of Huntsville, Alabama: Alabama Geological Survey open file report, 35 p.

Baker, R. M., Cook, M. R., Moss, N. E., Henderson, W. P., 2005, Discharge and water withdrawal assessment, Mountain Fork watershed, Madison County, Alabama: Geological Survey of Alabama Open-File Report 0527, 27 p.

Bossong, C. R., and Harris, W. F., 1987, Geohydrology and susceptibility of major aquifers to surface contamination in Alabama; Area 1: U.S. Geological Survey Water Investigations Report 87-4068, 23 p.

Bossong, C. R., 1988, Geohydrology and susceptibility of major aquifers to surface contamination in Alabama: Area 2: U.S. Geological Survey Water Investigations Report 88-4177, 16 p.

Campbell, C. W., Sullivan, S. M., Roberts, L. R., Booher, E., Cochran, B., Frank, M., Samples, J., Wood, T., Protection of the Alabama cave shrimp field work and modeling, Department of Civil Engineering, The Universeity of Alabama in Huntsville, 37 p.

Campbell, C. W., 1997, Contaminant transport model for the Bobcat Cave watershed, The University of Alabama in Huntsville Research Institute, 24 p.

Chandler, R. V., and Moore, J. D., 1991, Fluorescent dye trace tests for storm water drainage wells in the Muscle Shoals area, Alabama, Final report: Alabama Geological Survey open file report, 305 p.

Cook, M. R., 1997, Origin and evolution of anomalous hydrogeochemical character of the Tuscaloosa aquifer system of west-central Alabama: University of Alabama unpublished Masters Thesis, 94 p.

Cook, M. R., 2004, Alternative water source assessment: An investigation of deep Cretaceous aquifers in southeast and south-central Alabama: Geological Survey of Alabama open file report, 43 p.

Cook, M. R., Moss, N. E., Jennings, S. P., 2009, Groundwater hydrogeology, recharge, and water availability in the Tennessee River watershed of Alabama: Geological Survey of Alabama open file report 0910, 44 p.

Copeland, C. W., Bolin, D. E., Doyle, F. L., Holler, D. P., Kidd, J. T., and Moser, P. H., 1975, Geology, in Geological Survey of Alabama, Environmental geology and hydrology, Huntsville and Madison County: Alabama, Alabama Geological Survey Atlas Series 8, 118 p.

Holler, D. P., 1975, Recognition and projection of the contact between the Mississippian Fort Payne Chert and Tuscumbia Limestone in Madison County, Alabama: University of Alabama, M.S. thesis, 76 p.

Mann, S. D., Baker, R. M., Raymond, D. E., 1997, Documentation for a wellhead protection program: Madison County water Department, Madison County, Alabama, Geological Survey of Alabama Open File Report, 56 p.

McGregor, S. W., O'Neil, P. E., 1996-2008, Water quality and biological monitoring in Bobcat and Matthews Caves, Redstone Arsenal, Alabama, Alabama, Annual Geological Survey of Alabama Open File Reports.

McGregor, S. W., O'Neil, P. E., Shepard, T. E., Henderson, P. W., 2004, Monitoring of Tuscumbia Darter (Etheostoma tuscumbia) populations on Redstome Arsenal, Alabama, 2000-2004, Geological Survey of Alabama Annual Open File Report, 6 p.

McGregor, S. W., O'Neil, P. E., 2006, Water quality and biological monitoring in Bobcat and Matthews Caves, Redstone Arsenal, Alabama 1990-2006 open file report 0620, Alabama, Annual Geological Survey of Alabama Open File Report, 33 p.

Raymond, D. E., Osborne, W. E., Copeland, C. W., and Neathery, T. L., 1988, Alabama stratigraphy: Geological Survey of Alabama Circular 140, 97 p.

Rheams, K. F., Moser, P. H., McGregor, S. W., 1992, Geologic, Hydrologic, and biologic investigations in Arrowood, Bobcat, Matthews, and Shelta caves and selected caves, Madison County, Alabama, Geological Survey of Alabama Open File Report, 262 p.

Risser, D. W., Gburek, W. J., and Folmar, G. J., 2005, Comparison of methods for estimating ground-water recharge and baseflow at a small watershed underlain by fractured bedrock in the eastern United States: U.S. Geological Survey Water Scientific Investigations Report 2005-5038, 31 p.

Szabo, M. W., Osborne, W. E., Neathery, T. L., and Copeland, C. W., Jr., 1988, Geologic map of Alabama, (1:250,000): Alabama Geological Survey Special Map 220.

US Geological Survey, 2003, National Land Cover Database, USGS, Sioux Falls, SD.

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