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REMOTE SENSING AND FIELD TECHNIQUES TO LOCATE FRACTURE ZONES FOR HIGH-YIELD WATER WELLS IN THE APPALACHIAN PLATEAU, KENTUCKY

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Abstract

Water yields from wells in the Eastern Kentucky Coal Field, part of the Appalachian Plateau, are typically low compared to wells in other areas of the country. Wells that produce significant amounts of water (i.e., >30 gpm, which is above the 90th percentile of recorded well yields in eastern Kentucky) usually occur in proximity to secondary permeability features such as fracture or fault zones. The Kentucky Geological Survey is in the fifth year of a study to develop remote-sensing, field reconnaissance, and drilling techniques to locate secondary-permeability features and exploit them for high-yield water production for public and industrial water supplies.

Lineaments were selected for a 6,500-square-mile area from side-looking airborne radar imagery (SLAR, at 12 meter pixel resolution), Landsat TM imagery (30 meter pixel resolution), and two enhanced Landsat images (RGB transformation and principal component analysis). Using a GIS database, lineament coverage layers were overlain on topographic maps for site selection and field checking.

Field reconnaissance highlighted the importance of locating potential drilling sites through the use of outcrop or topographic expressions of a fracture zone, and biological indications of near-surface groundwater. Other important factors are ease of access for drilling equipment, proximity to potential water users, and anticipated depth of the freshwater-saltwater interface, which is shallow in third-order, and greater, watersheds in the Eastern Kentucky Coal Field. Outcrop evidence consisted of well-developed fractures, an increase in density of fractures in the fracture zone, and fractures propagated through more ductile rock units (shales). Biological indicators included the presence of cattails and willow trees.

Inclined drilling (40 to 45 degrees) was found to be the most successful and most economical method of identifying individual, water-bearing fractures in the fracture zones, which are estimated to be several hundred yards wide. A down-hole video camera was used to identify lithology and characterize fractures in the inclined, exploratory boreholes before drilling vertical productions wells.

Six sites have been drilled to date using the inclined technique. One did not encounter a significant water-producing fracture, and two encountered saline groundwater. At four sites where vertical production wells were drilled, groundwater yield ranged from approximately 67,000 gpd to 104,000 gpd. All of these wells are above the 95th percentile for well production recorded in their respective counties, and would serve 135 to 200 homes (at 500 gpd per home estimated consumption). At three of the sites, raw water is potable with respect to U.S. EPA drinking-water standards; the fourth was slightly saline.

Hydrogeology

A major obstacle in economic diversification and development in the Eastern Kentucky Coal Field (EKCF) is the lack of water supply, particularly away from major streams. This paper briefly summarizes efforts by Kentucky Geological Survey (KGS) since 1996 to site high-yield groundwater supply wells to help address this need (Andrews and others, in review). The EKCF is part of the Appalachian Coal Field which extends from Pennsylvania to Alabama (Fig. 1). The coal field is a large, intricately dissected upland characterized by narrow, crooked valleys and narrow, irregular steep-sided ridges. Most of the smaller creeks have narrow valley floors, whereas larger streams have flood plains of moderate width. Local relief increases from 300 feet in the north near the Ohio River to about 2,500 feet in the south along Pine Mountain, near the Tennessee-Kentucky border (Price and others, 1962). Bedrock underlying the coal field belongs to the Late to Middle Pennsylvanian age Breathitt Group consisting of interbedded shales, siltstones, sandstones, and coals (Chesnut, 1992). Many of these units are discontinuous and are truncated by intervening valleys.

Studies prior to 1985 have documented the permeability of the rocks within the Breathitt Group. Due to the low permeability of the sandstones in the Breathitt Group, groundwater flow primarily occurs in secondary permeability features such as fractures and joints (Price and others, 1962; Kirkpatrick and others, 1963). Ferguson (1967), Wyrick and Borchers (1981), and Kipp and Dinger (1991) document fracture control of groundwater movement in the Appalachian Coal Field.

Well Data

Analysis of water well yield data in the Kentucky Ground-Water Data Repository as of 1999 indicates that only 7 percent of the 6,075 wells drilled in the EKCF from 1985 to 1999, have yields equal to or greater than 30 gpm. Wells yielding greater than 30 gpm are considered high-yielding wells (Andrews and others, in review). Hydrogeologic studies conducted within the EKCF over the past forty years have indicated that these higher yields are the result of the wells intersecting secondary-permeability features, namely lengthy fracture zones.

Linear Feature analyses

One technique available to geologists for locating fractures is to examine remote-sensing imagery such as satellite imagery, low altitude radar, and aerial photographs for linear features. These linear features can represent roads, powerlines, pipelines, and railroad tracks as well as fracture zones that are on the order of few feet to several hundred feet wide, or surface features such as straight-line stream valleys which form along fracture zones. The use of linear features to locate fractures and groundwater supplies was pioneered by Lattman and Parizek (1964) in the folded and faulted sandstone interbedded carbonates of Central Pennsylvania.

In 1996, KGS began identifying lineaments (linear features greater than 1 mile (Parizek and Gold, 1997)) from remote-sensing imagery to identify fracture zones in the EKCF. The satellite imagery used in this study was collected from the thematic mapper (TM) on board Landsat 5. This study used two December 1991 scenes, each covering a 116 by 109 mile area. Scenes from this time of year were chosen because of the low sun angle which helps to illuminate the lineaments (Dunno, 1998). The low-altitude radar used in this study consisted of side-looking airborne radar (SLAR). The advantage of SLAR over Landsat TM data is that it is not dependent upon daylight or optimal weather conditions such as a cloudless day (Sabins, 1997).

All imagery was imported into Imagine, a remote-sensing software package developed by ERDAS, Inc., and geo-referenced to 7.5-minute topographic quadrangle maps. Using Imagine, two spectral enhancements were applied to the Landsat TM data in order to accentuate the lineaments or make them easier to select. Lineaments were selected from these images in the EKCF at view scales of 1:250,000 and 1:125,000 so that only lineaments, as opposed to smaller features, were identified. Lineaments derived from the different image types often appeared to be separate and offset when plotted on the same map. In reality, these lineaments more likely represent the same linear feature and are offset due to different image resolutions and errors due to plotting the lineaments at scales larger (1:24,000 for 7.5 minute quadrangle maps) than the original view scale.

Field checking and drilling

Lineament themes were overlain on 7.5-minute topographic maps (1:24,000 scale). Many locations were identified where the delineated lineaments correlated to straight-line topographic features including ridgelines, topographic saddles, and stream valleys of first through third orders, with first order being the smallest watershed. Field reconnaissance of approximately 70 sites considered available aerial photography, topography, general geology, vegetation, and fracture orientation seen in road cuts. A good example of a straight valleys correlating with selected lineaments is in Oakdale, Kentucky, along Clover Branch Road and Bowman Branch Road at the intersection of Kentucky Highway 52 (Fig. 2). Lineaments were also found to correlate with high fracture densities as seen from highway road cuts or other locations with extensive rock outcrops. Two large fractures are apparent in a road cut where Lineament A plots, whereas lineament B represents a ridge line that would not be a likely site for a high-yield well (Fig. 3).

KGS conducted exploratory drilling on lineaments and their intersections to identify water-producing fractures and determine the quality and quantity of the water available from these fractures. Major constraints on potential drilling sites were a contractual obligation to locate wells in a vicinity of water demand, and the need to find cooperative land owners. These constraints eliminated many sites of scientific interest, but provided adequate, diverse sites for testing. After drilling a total of six vertical wells with yields less than 30 gpm at two sites, an inclined bore hole was drilled at an angle of 40 degrees from the horizontal at the third site to locate a water-bearing fracture. This technique included pushing a down-hole video camera down the inclined bore hole to help define the producing fracture, drilling a vertical production well to the fracture for groundwater production, and proper abandonment of the inclined bore hole. This technique was adopted at all subsequent sites with success from both hydrologic and financial standpoints. Up to an 85 percent cost savings could be obtained from using this technique as opposed to drilling numerous vertical holes to search for a water-bearing fracture in a fracture zone (Andrews and others, in review).

Results and Conclusions

At four of the six sites where the inclined drilling technique has been applied, production wells have been installed that intersect fractures. The yields from these wells are greater than 47 gpm, surpassing the project goal of yields greater than 30 gpm. When compared to yields reported in the Kentucky Ground-Water Data Repository up through 1999, the yields from the four wells drilled were greater than 95 percent of yields from all the wells drilled within their respective counties and for all the wells drilled in the EKCF.

An insight gained during the study was that production wells should be drilled to an elevation no deeper than approximately 150 ft below third-order watersheds in order to minimize the occurrence of saline groundwater (Wunsch, 1993). Preferably, the location should also be underlain by sandstone as opposed to less permeable shales and siltstones, and be selected so that the near-surface fracture zone and coal seams may transmit water to the major producing fracture. Experience gained to date leads the authors to speculate that in the highly dissected EKCF it may be possible to delineate fracture zones and site high-yield wells using topographic maps, field reconnaissance, and the inclined drilling technique without having to analyze remotely sensed data. However, the use of remotely sensed data would initially be required if this program were expanded to the other major geologic settings of Kentucky that include the lower relief Illinois Coal Basin (Western Kentucky Coal Field), Ordovician and Mississippian karst, Devonian shales, and Cretaceous-age sediments in the Mississippi Embayment.

Analyses of aquifer tests for selected production wells drilled using the methods presented in this paper are discussed in Andrews and others (2002).

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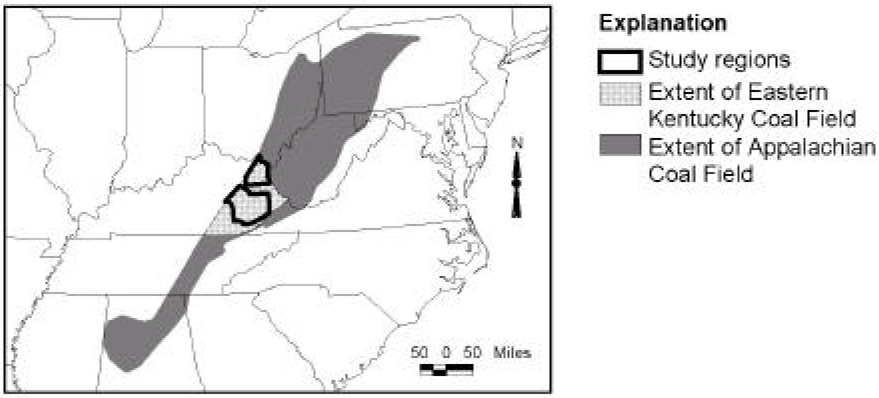

Figure 1 - Location of study regions.

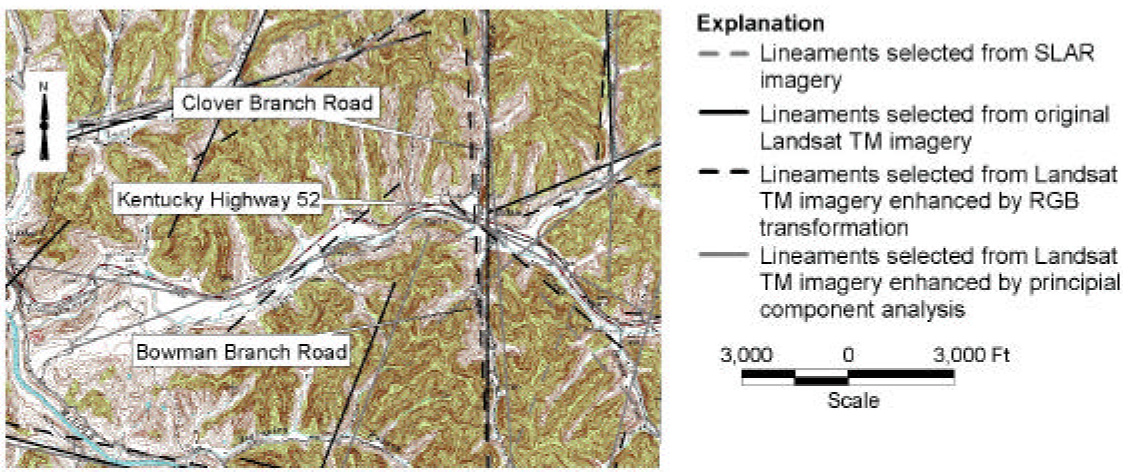

Figure 2 - Topographic map showing lineaments selected from Landsat TM and SLAR imagery correlating with a straight-line stream valley at Oakdale, Kentucky. The straight-line stream valley extends from Clover Branch Road to Bowman Branch Road.

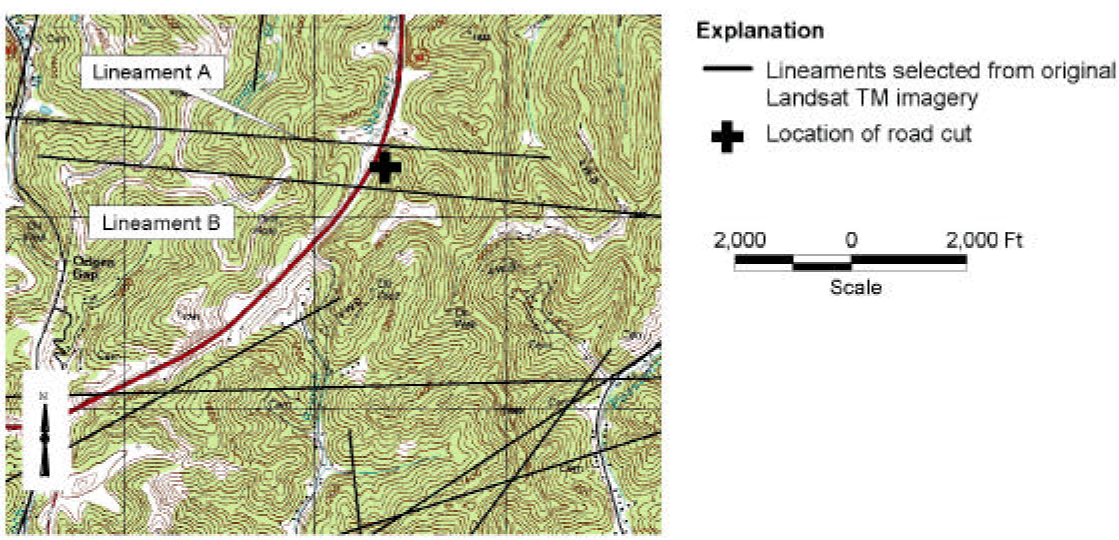

Figure 3 - Topographic map showing original Landsat TM lineaments and location of road cut along Kentucky Highway 80, north of Hindman, Kentucky.

Biographical Sketches

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