THE CULPEPER BASIN FOLIO

The Culpeper basin is a structural trough filled with sedimentary and igneous rocks of Mesozoic age that borders the eastern front of the Blue Ridge in northern Va. It extends from the Rapidan River near Madison Mills northeastward across the Potomac River and terminates just west of Frederick, Md.

This report is one of a series being prepared as part of a study of the geologic and hydrologic resources of the Culpeper basin. The scale of the maps, 1:125,000 (1 inch = approximately 2 miles), permits only a regional overview or guide to evaluating hydrologic and geologic conditions that may influence certain types of land use. The maps are not intended for enlargement, nor are they, or any graphical or tabulated data included, intended to replace site investigations. Local details at a given site may differ from the general conditions portrayed on these maps and detailed studies are invariably required for site planning.

By combining the basic resource maps in a variety of ways, depending on the revelant limiting factors for any given land use, the user can derive a secondary series of maps that focus on specific problems. Potential uses of these maps and possible derivative products are discussed in the texts accompanying each map.

INTRODUCTION

Ground water is the source of supply for most privately owned water systems in the Culpeper basin in northern Virginia and adjacent parts of Maryland. In addition, several municipal and industrial water users at Poolesville, Md. and Leesburg, the Manassas area, and Culpeper, Va., pump ground water. Ground water generally is the only practical source for homes in sparsely settled rural areas, and also can be a practical alternative to surface water for new communities, including small towns, individual subdivisions, and trailer courts, not served by existing public-supply systems.

The series of larger-scale geologic maps of the basin by Lee (1979, 1980) would be particularly helpful in determining the rock type in which an existing or proposed well site is located.

PURPOSE AND SCOPE

The purpose of this report is to (1) describe the hydrogeologic conditions that affect ground-water occurrence and movement in the bedrock aquifers of the Culpeper basin, (2) use examples of past efforts at ground-water recovery to evaluate potential for additional development, and (3) suggest some factors that may affect plans to use ground water on either a local or regional basis.

A computer model of the ground-water system was developed to gain a better understanding of how various components of the hydrologic system interact. The model was used to simulate pumping from various rock types at different rates under both normal and drought conditions. The simulations are designed to show how a model can be used as a tool for managing ground-water supplies.

ACKNOWLEDGMENTS

Homeowners, well drillers, and personnel in the planning departments and health departments of counties in the study area, the Northern Regional Office of the Virginia State Water Control Board, the Fairfax County Water Authority, and the Greater Manassas Sanitary District cooperated fully in making available the information needed to prepare this report. Special thanks are extended to ground-water consultants Tucker Moorshead and Kenneth Vanlier for access to data and helpful discussions regarding exploration methods and potential development of ground water in fractured rocks.

GEOLOGIC SETTING

The Culpeper basin contains a variety of Mesozoic sedimentary rocks consisting of layers or beds of sandstone, shale, siltstone, and conglomerate (map units S1 through S5) many thousands of feet thick. The dip of the layers, generally 5° to 60° W., steepens progressively toward a major fault zone at the western margin of the basin (fig. 1). Upland areas within the basin are mantled by a clay-rich residuum, or by saprolite. Most stream valleys are covered by a thin layer of alluvium. In the western part of the basin, the sedimentary rocks are interbedded with basalt flows (unit B). All the sedimentary rock units are cut by intrusions of diabase (unit J), and the rocks adjacent to these intrusions have been thermally altered to a finely crystalline metamorphic rock (unit T). The basin is bordered and underlain by Precambrian and (or) lower Paleozoic metamorphic "basement" rocks (unit P). All rocks are cut by intersecting systems of joints, fractures, and partings, collectively called fractures (Leavy, Froelich, and Abram, 1983). These fractures can form as a result of several geologic processes: (1) Diabase and basalt may be cut by columnar cooling joints. (2) Bedding-plane fractures may form in sedimentary rocks because of reduction of pressure as overlying rocks are eroded. (3) Stresses that accompany tectonic activity (uplift, folding, and faulting) can cause fracturing to substantial depths. (Fetter, 1980, p. 214). However, fractures generally tend to decrease in size, number, and degree of interconnection with increasing depth because of compression by overlying material.

OCCURRENCE AND MOVEMENT OF GROUND WATER

Basaltic rocks, diabase (and its thermally metamorphosed aureole), and the firmly cemented sedimentary rocks in the Culpeper basin are relatively impermeable. The water-transmitting ability and storage capacity of these rocks, and, consequently, their ground-water development potential, is primarily related to the presence of fractures. The volume of open space in the fractures is small, and in most places probably constitute no more than 5 to 10 percent of the total rock volume. However, where enlarged by weathering and solution, the fractures can store and transmit significant amounts of water. Drillers' reports for wells in limestone conglomerate in the Leesburg area indicate the presence of large voids, probably due to dissolution of calcareous material. Although fractures enhance the occurrence and availability of ground water, they also provide conduits for possible entrance and movement of pollutants into the aquifers.

Because no single shallow water-bearing structure extends horizontally for more than a few miles in the fractured-rock aquifers, local precipitation is the primary source of ground water in the study area. Ground water infiltrates the thin cover of residuum, passes through fractures in the bedrock, and moves from the uplands (recharge areas) toward the valleys (discharge areas). Some water is lost through evapotranspiration; the remainder is discharged into springs or streams. This ground-water discharge, or baseflow, sustains the flow of large streams during periods of reduced precipitation (fig. 2).

The water table is generally at or near the land surface in valleys and 50 to 100 feet below the surface beneath hills. A smooth, continuous water-table surface commonly found in loose, porous materials is not always present in consolidated rocks. Where fractures are not interconnected, the water table may be discontinuous or steplike.

The rock units in the Culpeper basin are listed in order of "relative ground-water productivity" in table 1. A summary of depths and yields of existing wells, aquifer lithology, and the properties that affect storage and movement of ground water in the various rocks is included. The distribution of these units (Leavy, Froelich, and Abram, 1983) is shown on the map.

AVAILABILITY OF GROUND WATER: WELL DRILLING RESULTS

The limestone conglomerate (unit S4) in the Leesburg area is the most productive aquifer in the basin due to the occurrence of solution openings. Drillers' logs for several wells in this unit contain references to cavities or caverns as great as 20 feet in vertical extent. [illegible]

(Kenneth Vanlier, written commun., 1981).

As part of an evaluation of the ground-water potential of the Triassic rocks in western Fairfax County, a 767-foot-deep test well was drilled in siltstone near the junction of U.S. Routes 50 and 28 (Leggette, Brashears, and Graham, 1980). Because of the very highly mineralized water in its lower section, the well was plugged with cement from the bottom up to 500 ft; the upper 500 feet of the hole was pumped at 450 gal/min for 96 hours. A transmissivity value (a measure of the capacity of an aquifer to transmit water) of 1,880 ft^2/d (feet squared per day) was calculated from data collected during recovery of the water level after pumping stopped. Transmissivity values based on aquifer test results and specific capacity data from other wells in the siltstone range from 1,000 to 2,000 ft^2/d.

The water-supply potential of the siltstone aquifer is limited by high concentrations of dissolved solids (from 2,000 to almost 5,000 milligrams per liter) in water from wells deeper than about 500 feet. The water is calcium-sulfate rich, which is probably related to the presence of gypsum ($CaSO_4 \cdot 2H_2O$) at depths of 475 feet and greater (Posner and Zenone, 1983). This water-quality problem has not been reported for shallower wells in the siltstone or for any wells in sandstone.

The sandstone aquifer, is more thickly bedded and has more widely spaced joints than the siltstone. The sandstone therefore is characterized by somewhat lower yields (usually 300 gal/min or less). A 1,000-foot-deep test well in western Fairfax County was pumped at 300 gal/min for 11 hours. A step-drawdown test conducted prior to the standard continuous pump test indicated a decrease in specific capacity with increasing pumping rates (Leggette, Brashears, and Graham, 1980, p. 6–9). Strongly directional, fracture-controlled permeability in the sandstone is indicated by water-level measurements made at nearby private wells during the 11-hour test. Water levels declined from 25 to 32 feet at four wells that are from 1,100 to 1,300 feet from the pumped well along the trace of the productive fracture zone. Yet only 0.35 feet of drawdown occurred at a well 660 feet away but perpendicular to the fracture trace. A transmissivity of 520 ft^2/d was calculated for the pumped well; data from other wells in the sandstone indicate transmissivities that range from 250 to about 500 ft^2/d.

Wells less than 500 feet deep in the sandstone yield water that is slightly hard but is otherwise acceptable for private and public-supply uses. The test well described above contained very hard, sulfate-rich water in silty zones between 500 and 700 feet, but water from 700 to 1,000 feet deep was less mineralized.

The remaining mapped bedrock types in the Culpeper basin—basalt (unit B), diabase (unit J), thermally metamorphosed rocks (unit T), quartz-schist conglomerate (unit S3), and greenstone conglomerate (unit S5)—are of minor importance as public-supply aquifers. Closely spaced columnar cooling joints and fractures characteristic of basalt flows indicate conditions favorable for ground-water development. However, no large yields or attempts to obtain such yields are reported for the basalt. The intensity of jointing varies greatly in the diabase. A yield of 92 gal/min is reported for one well, but the rock generally is a poor aquifer. The thermally metamorphosed rocks that border the diabase intrusives are the poorest aquifers in the basin; drillers and homeowners have reported several "dry holes" in this unit. Many privately owned wells produce water from these rocks, but a deeper well is usually necessary.

POTENTIAL FOR ADDITIONAL DEVELOPMENT

Most methods used to estimate potential ground-water yield on a regional scale are based on the assumption that the aquifer hydraulic properties are uniform so that site-specific data can be applied to the entire aquifer. The occurrence and movement of ground water in the Culpeper basin is controlled principally by rock fractures and other secondary openings that are unevenly spaced. Thus, the assumption of a homogeneous and isotropic aquifer is not met and determining aquifer parameters from site-specific data must be approached with caution. Although estimating yields on an areal or regional basis is difficult, existing data can be used to (a) estimate the range of expected well yields, (b) suggest factors to consider in developing maximum possible yields, and (c) identify conditions that limit individual well yields and overall ground-water development in the basin.

A review of data on existing development is a logical starting point for making yield estimates of proposed new wells. It should be remembered, however, that the absence of high-yield wells in a specific area does not mean that such yields are not possible. There may have been little effort to develop ground water supplies in these areas. Furthermore, because many factors influence the potential yield of fractured-rock aquifers, one may expect large departures from average yields. Average yield figures may not accurately portray the full potential of a fractured-rock aquifer if most well records are for domestic wells only (Cederstrom, 1972, p. 2–3). The maximum reported yields and computed median yields for the various rock types in the Culpeper basin, based on historical development and exploration efforts, are shown in table 1. Dry holes have been locally reported from all rock types.

In order to develop the maximum possible supply, wells should be drilled in areas that have the most promising geologic and hydrologic conditions. In the Culpeper basin, these conditions are found in the most intensely fractured rocks. Thus, the mapping of fractures can be used to locate sites for high-yield wells (Sharpe and Parizek, 1979). Topographic maps, aerial photographs, or earth-satellite images are examined, and field surveys are then made to locate linear features. These linear features may be straight segments of stream valleys or elongated depressions on the land surface that may indicate the presence of fractures. Drilling sites are then located on a fracture lineament. The chances of obtaining a good supply of water are greatly increased by drilling at the intersection of two or more fractures, but no guarantee of success can be made before drilling begins.

In addition to trying to locate wells in fracture zones, other factors may be considered in order to obtain the maximum possible well yields from fractured rocks. The distance and direction to sources of recharge affect the long-term yield of a well. Ground water generally moves away from uplands toward valley bottoms and streams. Thus, lower parts of hillslopes and stream valleys have a greater ground-water potential than do uplands (fig. 2).

When searching for large water supplies, exploratory wells generally are not drilled to depths exceeding 1,000 feet. A large part of the total yield of test wells in siltstone in western Fairfax County and in Montgomery County, Md., was obtained from depths between 500 and 1,000 feet (Leggette, Brashears, and Graham, 1980, and Otton, 1981). Finally, because maximum sustainable pumping rates of wells in fractured rocks generally cause large water-level declines, the amount of drawdown must be determined during testing of a well and the depth of the production pump set to take advantage of that drawdown.

Several factors limit well yields in the Culpeper basin:

1. The specific capacity of wells completed in fractured rocks may decrease with declines in water levels. This has occurred in the Manassas area (John Sloper, Greater Manassas Sanitary District, oral commun., 1981; Geraghty and Miller, 1979, p. 11). This is probably due to the decrease in the number and size of fractures with depth.
2. Pumping rates may have to be decreased during low-flow periods in order to limit the amount of pumping-induced recharge from streams.
3. Interference between high-yield pumping wells is likely if the wells are located in the same fracture zones.
4. The poor quality of water at depths greater than 500 feet in siltstone.

SIMULATION OF THE GROUND-WATER SYSTEM

Computer modeling is a tool that can aid the study of ground-water problems and improve the understanding of ground-water systems. A digital computer model was developed to simulate ground-water flow in the Culpeper basin. This model integrates physical properties of the ground-water system critical to the movement of water into, through, and out of the basin, and allows a limited quantification of the hydrogeologic relationships discussed in earlier sections of this report.

MODEL SELECTION AND DESCRIPTION

The scope of the project, conceptualization of the flow system, and the types of data available provided the basis for selection of an appropriate model. These data include water levels in wells, streamflow hydrographs, results of short-term aquifer tests at a few scattered locations in the northern part of the basin, and a generalized bedrock map (Leavy, Froelich, and Abram, 1983). Parameters derived from these data provided input for a modified version of the two-dimensional finite-difference model (Trescott, Pinder, and Larson, 1976) that is used in this study. In this model, the fractured-rock aquifer system of the Culpeper basin is simulated as an equivalent porous medium by:

1. Assigning a directional anisotropy factor (T_{xx}:T_{yy}), coincident with the regional fracture-trace directions, to values of transmissivity.
2. Averaging fracture and matrix properties of each bedrock type into a single value.
3. Simulating a time period long enough to eliminate the effects of individual fractures on the movement of ground water.

A simplified schematic conceptualization of the ground-water system is shown in figure 2. A node-centered rectangular grid was constructed that approximately coincides with the natural hydrologic boundaries of the basin (fig. 3). The model area extends north to include the Potomac River, south to include the Rappahannock River, and east and west across basin geologic boundaries into the Piedmont and Blue-Ridge geologic provinces, respectively. The northern and southern boundaries are treated as stream nodes that simulate constant-head (water-level) conditions. The eastern and western boundaries are treated as impermeable (no-flow) boundaries. As many no-flow nodes as possible are located at ground-water divides. Where this is impractical, the nodes are placed far enough outside the basin boundaries to minimize any effect on head and drawdown computations within the basin. Ground-water discharge and recharge to streams is simulated by assigning a "leakance value" (vertical conductivity of the stream bed divided by the streambed thickness multiplied by the area of the stream divided by the area of the stream node) to stream nodes. This value controls the flow of water into or out of the stream.

TABLE 1.—Aquifer characteristics and summary of data on present ground-water development

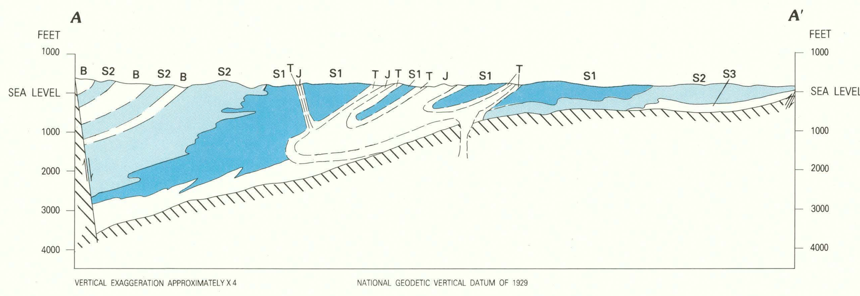


FIGURE 1.—Generalized geologic cross section across Culpeper basin from A–A'. Constructed from data in Leavy, Froelich, and Abram, (1983).

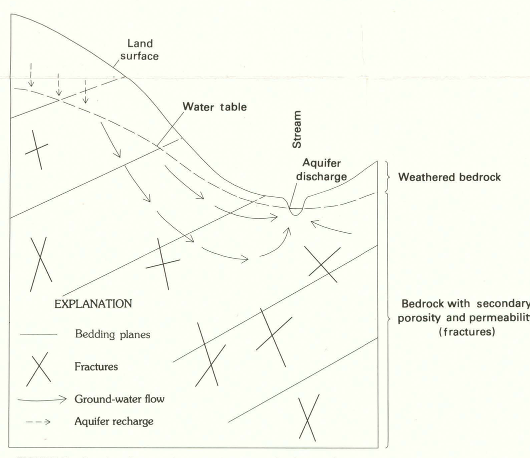


FIGURE 2.—Simple schematic diagram of conceptualized ground-water system in Culpeper basin.

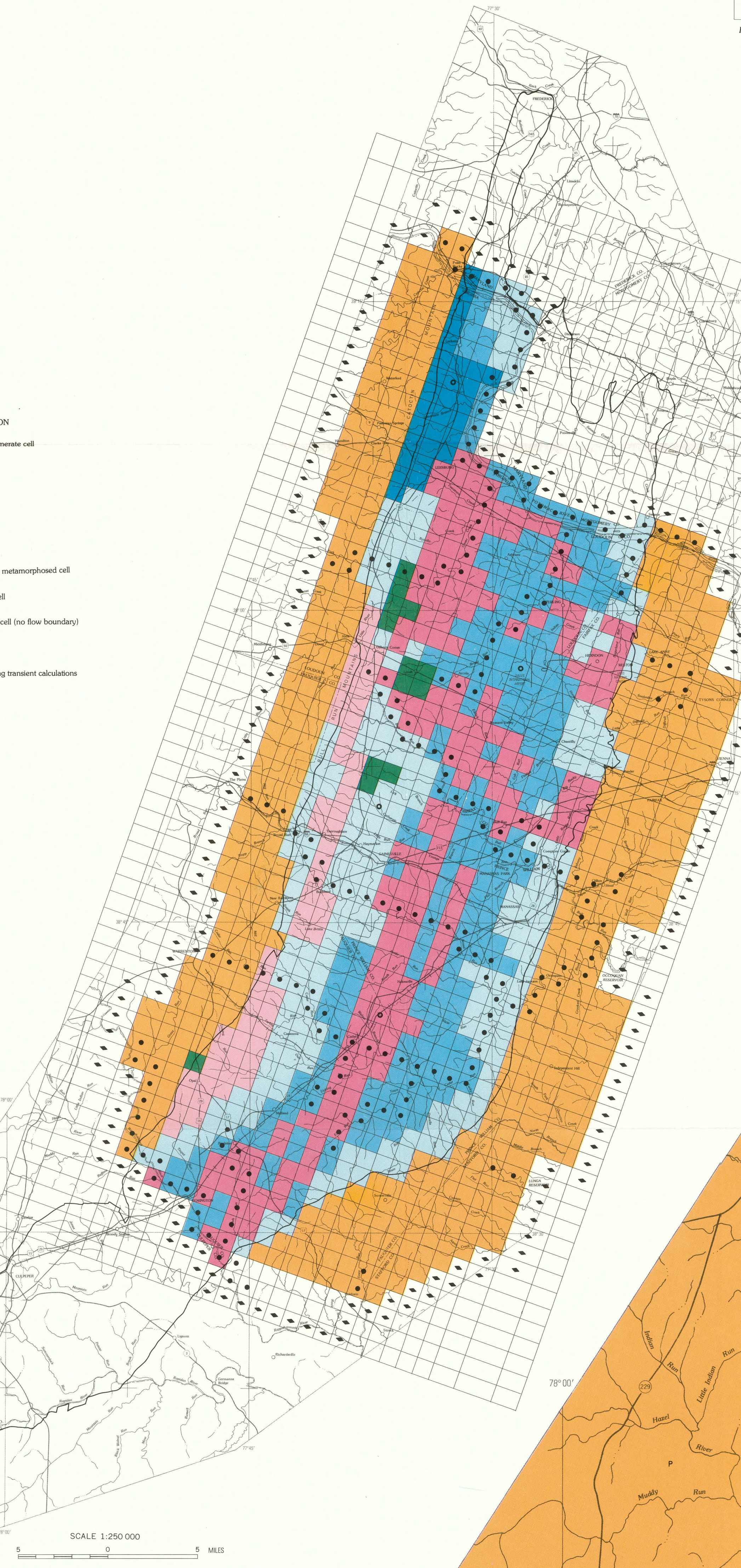
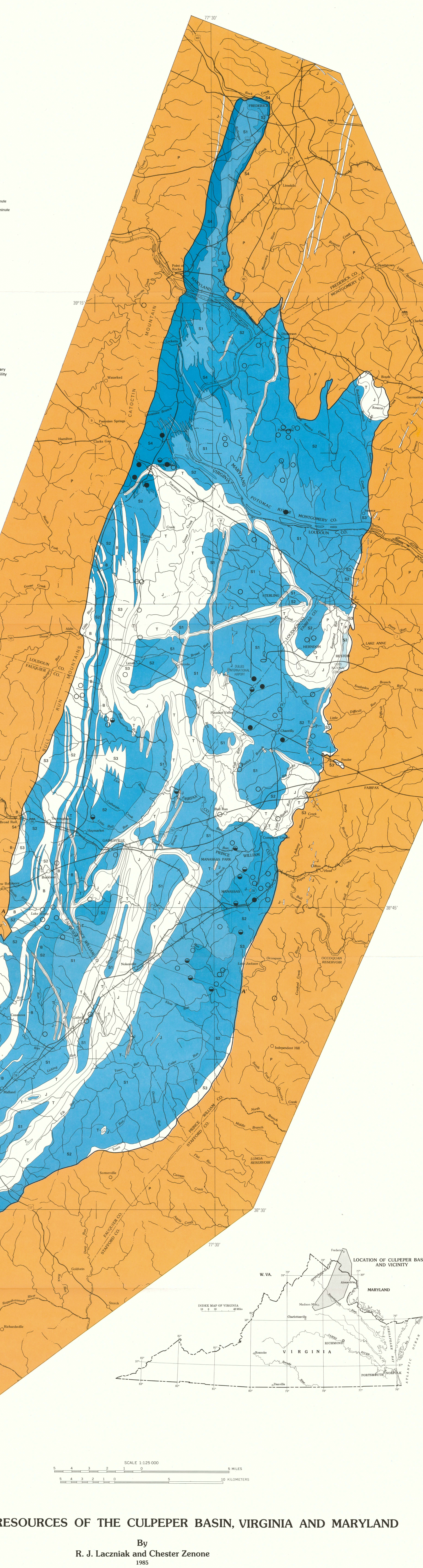


FIGURE 3.—Finite difference grid showing surface lithology and model boundary conditions. Areas of equal transmissivity correspond directly to lithology.



LOCATION OF CULPEPER BASIN AND VICINITY

GROUND–WATER RESOURCES OF THE CULPEPER BASIN, VIRGINIA AND MARYLAND

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