THE HYDROGEOLOGY OF LAMAR COUNTY, GEORGIA

Lee L. Gorday

DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION
GEORGIA GEOLOGIC SURVEY

Information Circular 80

Cover photo: North of Barnesville, two drillers install a 6-inch drilled well, using a down-the-hole hammer.

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ABSTRACT

Wells are the main source of water for domestic supplies in Lamar County. The county is underlain by igneous and metamorphic rocks that have very low primary porosity and permeability. In these crystalline rocks, ground water is stored and transported through discontinuities such as fault zones, stress-relief fractures, lithologic contacts, and smaller scale features such as joints and foliation planes. In order for a drilled well to yield appreciable water, discontinuities such as these must be encountered. Because the volume of the discontinuities in unweathered rock is relatively small, they furnish very little water-storage capacity. In order for a well to sustain a yield over a long period of time, the discontinuities supplying water to the well must be tied to a source of recharge. Saturated saprolite overlying the crystalline rock is the primary source of recharge to the discontinuities.

Ground water for domestic supplies is available in most of the county. Dry holes constitute only a small percentage of the total number of wells drilled. Only one incidence of multiple dry holes has been noted. The average yield of the 69 wells in the well inventory is 24 gallons per minute. The well inventory includes data for all drilled wells for which data could be obtained, mostly domestic wells. Wells drilled in an unnamed schist and gneiss unit south of the Towaliga fault zone have significantly lower yields than the average for Lamar County. Water quality is generally good; although iron, manganese, and fluoride concentrations exceeded recommended limits in several of the wells sampled.

Careful selection of a well site will reduce the chances of both inadequate well yield and later contamination of the well. Proper grouting of the well is important for water-quality protection. Topographic analysis, aerial-photograph analysis, magnetometry, and electrical resistivity studies have all proven useful in selecting well sites. In selecting a well site, it is important to consider both sources of potential recharge and sources of potential contamination.

ACKNOWLEDGEMENTS

I would like to thank the many residents of Lamar County who assisted me in compiling the well inventory for this study. With their help, I was able to field locate many wells for which I had no location information. Two people who were particularly patient with my questions were Mr. Frank Patrick, former superintendent of the Barnesville Water Plant, and Mr. Rodney Hilley, County Sanitarian. The cooperation of the water well contractors who serve the Lamar County area was greatly appreciated. Particular thanks are due to Mr. Jerry Colwell and Mr. James Breakey of Middle Georgia Water Systems, to Mr. Hoyt Waller of Waller Well Company, and to Mr. William Martin, Mrs. Mary Dutton, and Mr. Lamar Chastain of Virginia Supply and Well Company. Mr. Thomas Crawford of West Georgia College, Mr. Charles Cressler of the U.S. Geological Survey, and Mr. Thomas Watson of the Land Protection Branch of the Environmental Protection Division thoughtfully reviewed the manuscript and offered suggestions that were very helpful and greatly appreciated.

INTRODUCTION

PURPOSE

Water is an essential resource that is often taken for granted. In general, Georgia is blessed with plentiful supplies of water, particularly in the Coastal Plain where highly productive regional aquifers are combined with the downstream reaches of the state's major rivers. Lamar County is located in the Piedmont physiographic province (Clark and Zisa, 1976), where the availability of ground water, as well as surface water, is more limited. The Piedmont is the headwaters for many streams. Few streams in the Piedmont have large drainage areas and; thus, very few have large, reliable flows. Ground water in the Piedmont is limited by the geology of the region. Unlike the Coastal Plain, where the depth to a water-bearing unit can be reliably predicted, the depth to a water-bearing zone, or even its existence, generally cannot be predicted in the Piedmont. Consequently, dry holes are sometimes drilled in the Piedmont. The term "dry hole" typically includes not only the holes that yield no water, but also those wells that do not yield an adequate supply for a single residence. Although dry holes are legendary in the Piedmont, they constitute only a small percentage of the total number of wells drilled.

The purpose of this study was to make an assessment of ground-water availability in Lamar County. An additional purpose was to investigate techniques that might be useful in siting high-yield wells for use by industries and municipalities and for siting domestic wells to avoid dry, or nearly-dry holes. Several techniques were utilized to point out areas that may be favorable for the siting of high-yield wells.

DESCRIPTION OF STUDY AREA

Lamar County is located approximately 50 air-line miles south of Atlanta and is within commuting distance of both Atlanta and Macon (Figure 1). Lamar County occupies the divide separating the Ocmulgee River Basin, which drains into the Atlantic, from the Flint River Basin, which drains into the Gulf of Mexico. Because the county lies on the divide, the drainage areas of the streams within the county are small. The population of Lamar County grew 14 percent from 1970 to 1980 (U.S. Department of Commerce, 1982); a marked increase in growth rate (Figure 2). Population projections suggest a growth rate of approximately 20 percent from 1980 to 2000 (Office of Planning and Budget, 1983). The 14 percent growth in Lamar County's population was in areas outside of Barnesville (U.S. Dept. of Commerce, 1982), the county seat and the only town for which population figures are available. The total area of Lamar County is 186 square miles.

Lamar County contains parts of three districts of the Piedmont Physiographic Province (Figure 3). The Washington Slope District of Clark and Zisa (1976) includes the portion of Lamar County that is within the Ocmulgee River Basin. The Washington Slope District is characterized by broad shallow valleys with rounded divides. The portion of the county west of the Ocmulgee River Basin-Flint River Basin divide and north of the base of Pine Mountain is within the Greenville Slope District. Clark and Zisa (1976) characterize the Greenville Slope District as having shallow, open valleys with rounded divides. The remaining part of Lamar County, including Pine Mountain and the area to the south in the Flint River Basin, is in the Pine Mountain District. This district is characterized by the steep, north facing ridge of Pine Mountain and a gently dipping slope to the south with moderate relief.

WELL INVENTORY

Well data compiled for this study are presented in the Appendix. Each well is identified by sequential numbers that were assigned as the well information became available. The Appendix lists the following information for each well: latitude, longitude, total depth, estimated yield, owner (either at the time of this study, or when drilled), and source of the information. Gaps in the well identification numbers indicate wells for which some of the basic information listed above was not available.

U.S. Geological Survey well numbers are included in the Appendix to enable cross referencing between the two sets of well numbers. The U.S. Geological Survey assigns well numbers based on their Index to Topographic Maps of Georgia. Each quadrangle is designated by a number and letter. Letters increase alphabetically northward with I and O omitted. Numbers increase eastward. Wells are numbered consecutively within each quadrangle. For example, well 12Y003 is the third well inventoried in the Barnesville quadrangle, and corresponds to inventory number 1 of this report.

Plate 1 is a 1:100,000 scale map showing the location of the wells included in the inventory. Some areas of Lamar County contain relatively high concentrations of wells in the inventory. Similarly, there are several large areas for which the inventory contains no wells.

The well inventory is not a comprehensive listing of wells in Lamar County. It was often not possible to obtain drill records detailing the depth, yield and other information for known wells. In a number of instances the well records were complete, but the well could not be located. Bored and dug wells are more common than drilled wells in Lamar County; however, this study focused solely on drilled wells.

WATER SUPPLY AND USE

The city of Barnesville operates a water-supply system that utilizes water from a reservoir on Edie Creek, approximately 5 miles north-northeast of Barnesville. Water-use figures indicate that the Barnesville system withdrew an average of 1.68 million gallons per day (Mgal/d) in 1980. The 1984 data indicates no change in the withdrawal rate. The City of Barnesville supplies water to the William Carter Company and the city of Milner, as well as to residential customers.

The Barnesville system utilized ground water for a number of years prior to switching to surface water. Similarly, the City of Milner previously used ground water. Several community water supplies that serve subdivisions and mobile home parks use ground water.

Homes that are not within the service areas of public systems or community systems (such as trailer parks or subdivisions) must obtain their own supplies. Domestic supplies are almost exclusively

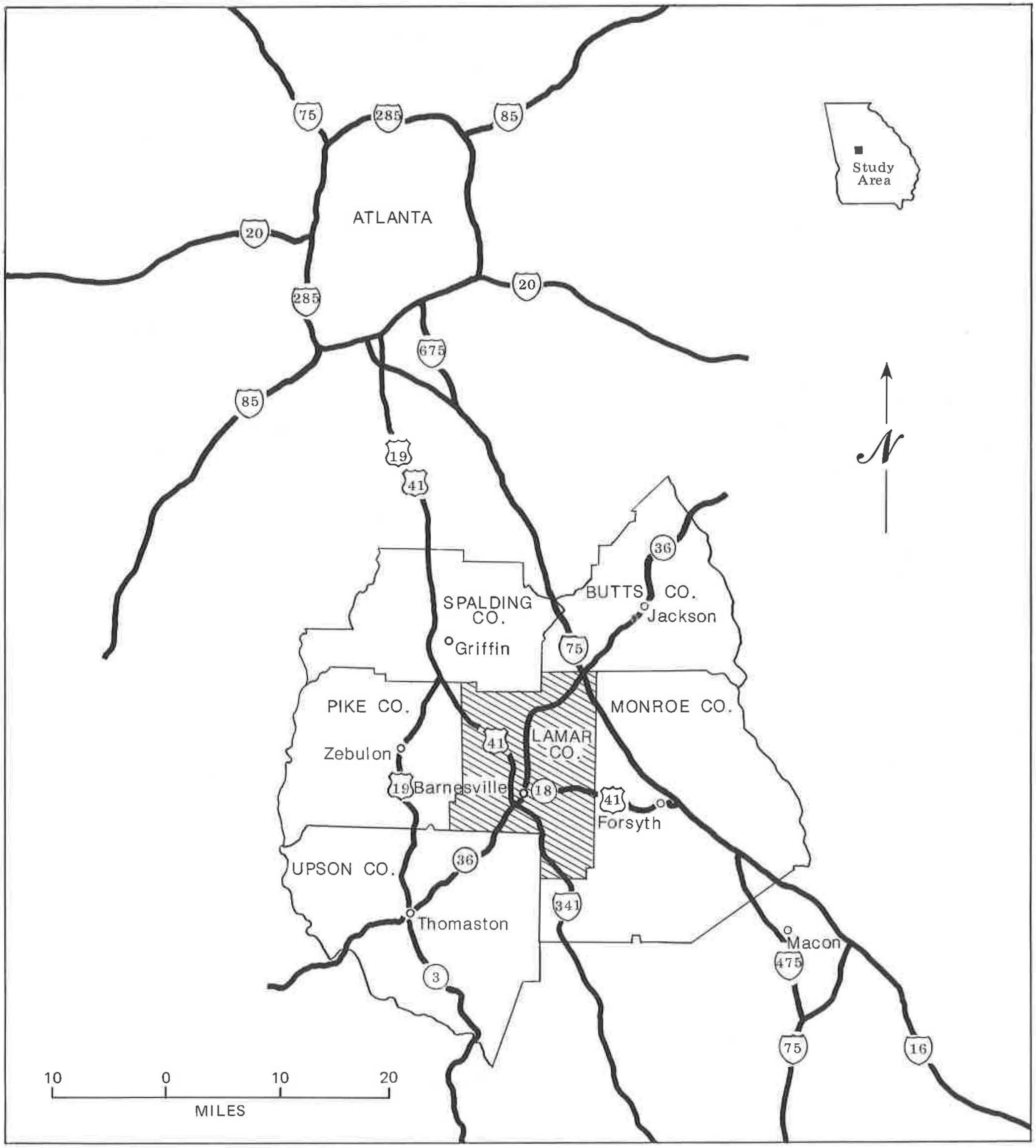


Figure 1. Location of study area. The location of adjoining county seats and major metropolitan areas are shown.

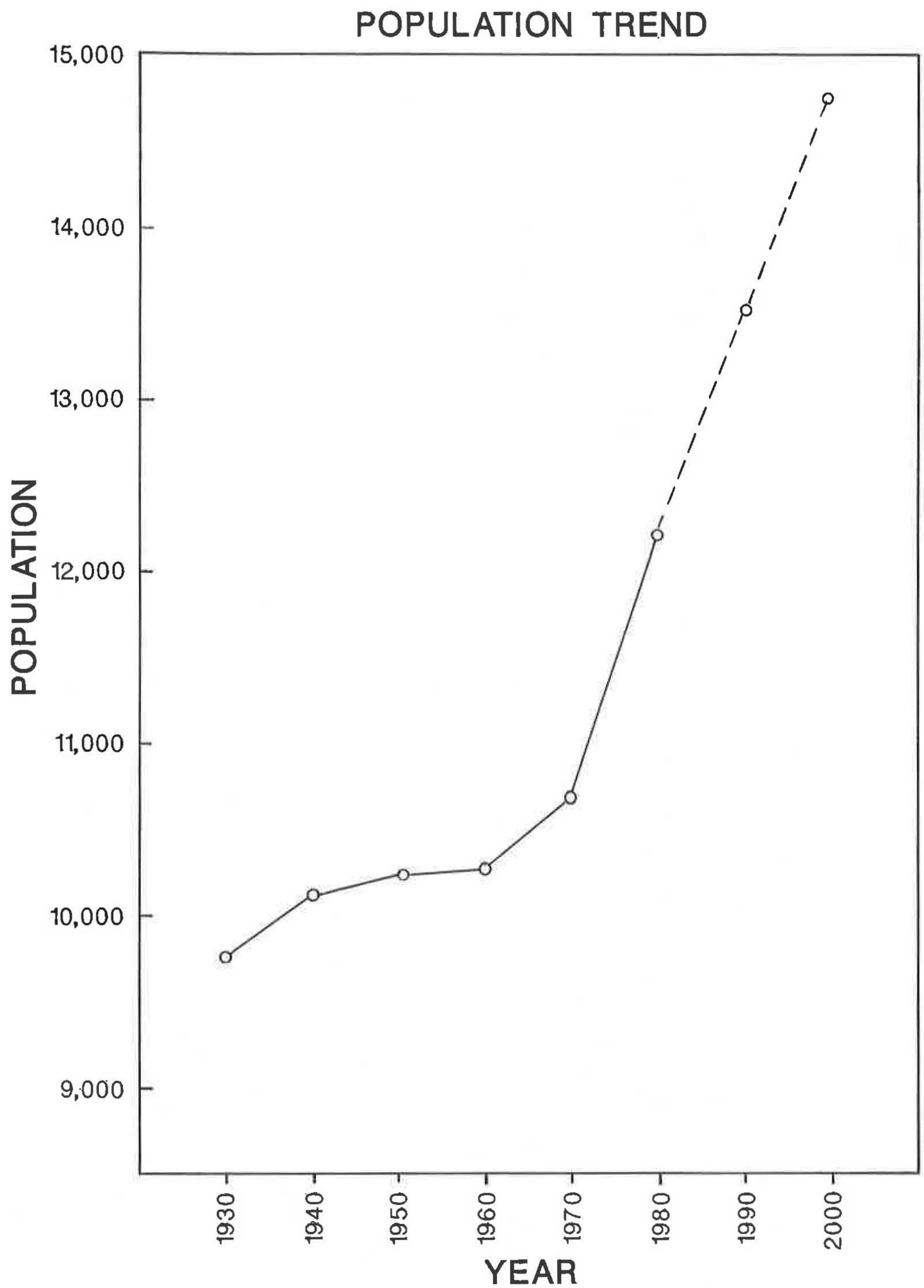


Figure 2. Population of Lamar County, 1930 to 1980, with projections to 2000. Data from U.S. Department of Commerce (1982) and Office of Planning and Budget (1983).

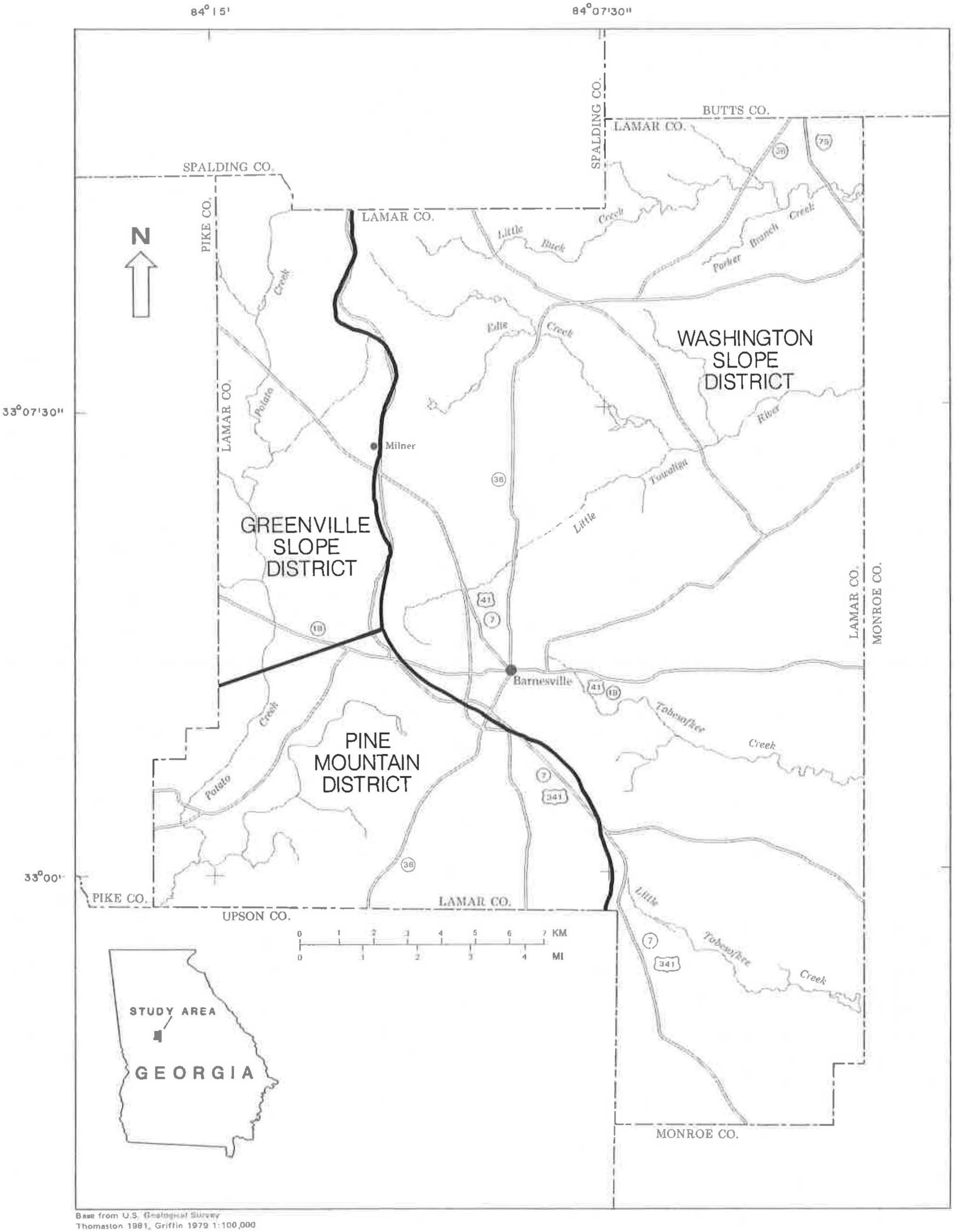


Figure 3. Physiographic districts in Lamar County; based on Clark and Zisa (1976).

obtained from wells. Estimates of 1980 water use indicate the rural domestic ground-water withdrawals averaged 0.34 Mgal/d. Rural water use is estimated by multiplying the population by an average-use figure. Agricultural water use for irrigation and livestock is estimated to be 0.33 Mgal/d, largely from surface-water sources.

GEOLOGY

GENERAL

The geology of Lamar County is complex, a result of long periods of deformation, igneous intrusion, and metamorphism. Lamar County is underlain by igneous and metamorphic rocks. In most areas, these relatively unweathered rocks are overlain by a layer of non-indurated, weathered material known as the regolith. In most instances, the regolith is composed of saprolite overlain by soil horizons. Saprolite is a material formed by in-place chemical weathering of the rock. Saprolite usually retains much of the texture and fabric of the rock from which it formed.

The Towaliga fault is a cataclastic zone that extends from eastern Alabama into central Georgia. The fault zone has a generally east-west strike and passes through the center of Lamar County. The description of the geology of Lamar County in this report will be divided into three areas: the area north of the Towaliga fault zone, the area south of the Towaliga fault zone, and the area of the Towaliga fault zone.

A geologic map of Lamar County is included as Plate II. The geologic map is based on reconnaissance work by Higgins and Atkins (unpublished) and locally on more detailed mapping by Atkins (in review).

The names of some lithologic units used in this report are currently informal with respect to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Capitalized rank designation or rock type indicate formal units; for example, Clarkston Formation and Hollis Quartzite. Uncapitalized rank designation or rock type indicate informal units; for example, Zebulon formation and Hollonville granite.

PREVIOUS INVESTIGATIONS

A number of reports refer to the geology of the region. Many of these studies, however, deal with the broad-scale geologic history and characterization of the region and, thus, contain little information that relates specifically to Lamar County.

LaForge and others (1925, p. 63) suggested that in the central plateau district both major and minor streams flow without regard to structure. Staheli (1976, p. 451) postulated that dendritic drainage patterns in the southern Piedmont area are a result of superimposing Coastal Plain streams onto the crystalline bedrock. Cressler and others (1983, p. 10) suggested that smaller drainage elements, such as intermittent streams in the uppermost reaches, are structure controlled.

Hewett and Crickmay (1939) described the geologic controls on the occurrence of warm springs in Georgia. A geologic map of the Warm Springs, Georgia quadrangle (15′) is included as a part of their report. Hewett and Crickmay named and described the Woodland Gneiss, which has subsequently been mapped in Lamar County. Furcron and Teague (1943) inventoried mica-bearing pegmatites, including several in Lamar County. Crickmay (1952) presented an overview of the geology of the crystalline rocks of Georgia. Clarke (1952) described the geology of the Thomaston, Georgia quadrangle (15′), which includes a very small portion of Lamar County.

Grant (1967) described the geology of the Barnesville area with emphasis on the nature of the Towaliga fault. Grant considered the Towaliga to be a high-angle fault that has exhibited both vertical and strike-slip movement.

Higgins and Atkins prepared a reconnaissance geologic map of the Griffin 1:100,000 sheet (unpublished). Atkins (in review), studied and mapped the granites north of the Towaliga fault zone in more detail. Atkins' goal was to establish the mode of emplacement of the granites.

Penley and Sandrock prepared a reconnaissance geologic map (unpublished) of Lamar County for compilation into the 1976 geologic map of Georgia. They extended Clark's Jeff Davis Granite and schist-gneiss migmatite into Lamar County.

Stieve (1984) investigated the granulites and gneisses in the southern portion of the Johnstonville quadrangle and the northern portion of the Strouds quadrangle. Stieve's work focused on the petrologic variation and genesis of the gneisses and granulites.

Favilla (1985) conducted a gravity survey of Lamar County as a part of this study. Favilla's Bouguer gravity map is included as Figure 4. The observed Bouguer gravity correlates well with the geologic map presented in Plate II. The deviation of the regional gradient in the northwestern portion of Lamar County appears to be related to the outcrop of the Barrow Hill formation, which is more dense than the surrounding rock.

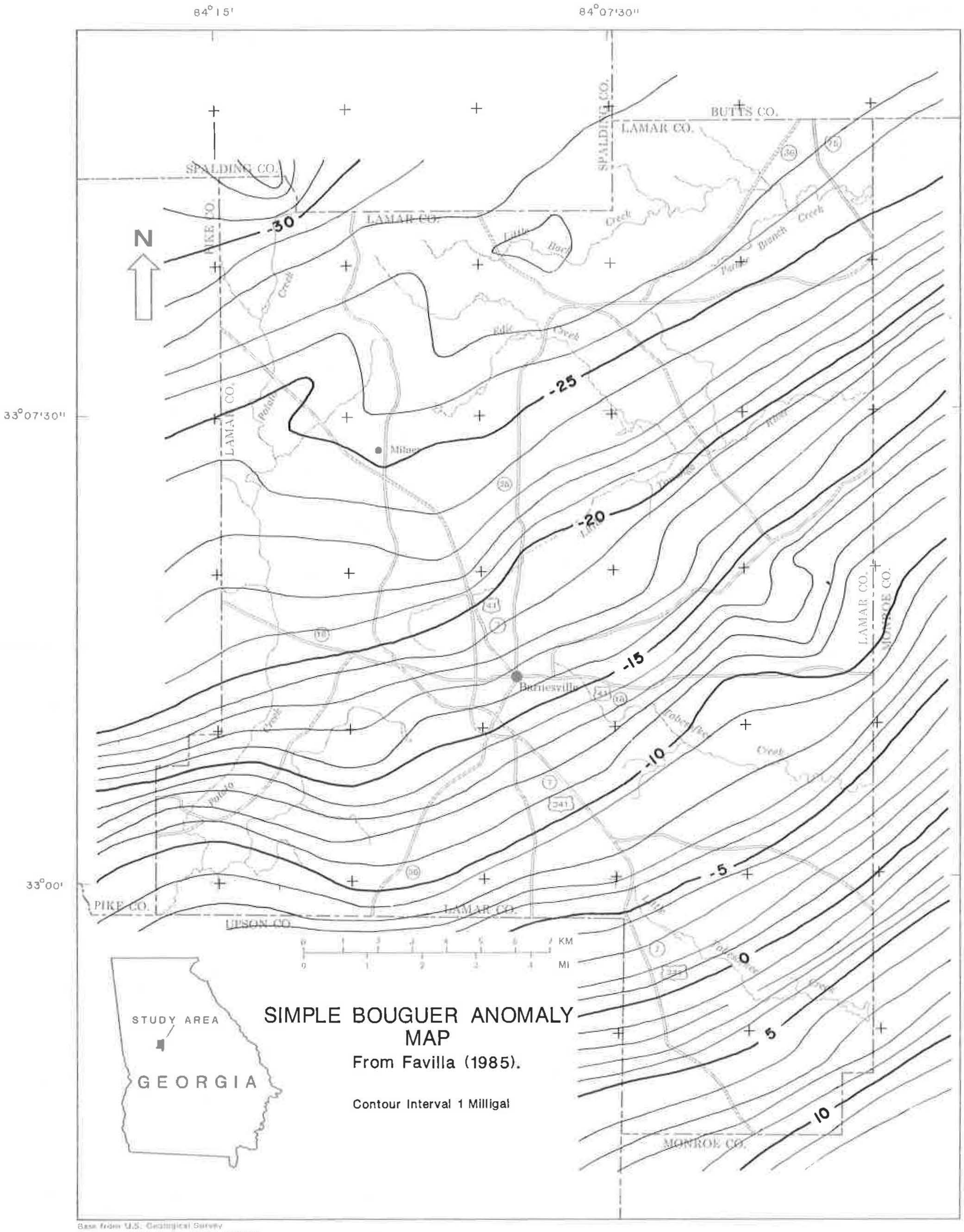


Figure 4. Simple Bouguer anomaly map; from Favilla (1985).

GEOLOGY OF THE AREA NORTH OF THE TOWALIGA FAULT ZONE

General

The area north of the Towaliga fault zone is underlain by metamorphic rocks that were intruded by granites subsequent to metamorphism. The description of the geology of the area north of the Towaliga fault zone is based on Higgins and others (1984), Higgins and Atkins (1981), Higgins and Atkins (unpublished), and Atkins (in review).

Lithologic Units

Zebulon formation — The Zebulon formation (Higgins and others, 1984, p. 10) consists of interlayered schists, amphibolites and gneisses that underlie a large part of northern Lamar County. The schists of the Zebulon formation generally contain garnet and sillimanite and weather to a pink or purple color. The amphibolites typically contain hornblende and plagioclase, but lack chlorite. The amphibolites weather to an ocher color. The Zebulon formation also contains biotite-plagioclase gneiss and granitic gneiss. Although the gneisses are less prevalent than the schists and amphibolites, their presence is important in distinguishing the Zebulon formation from the Clarkston Formation (R.L. Atkins, Georgia Geologic Survey, personal communication). Thin beds of spessartine quartzite are locally present. Both sedimentary and volcanic parent materials are indicated for the Zebulon formation.

Ison Branch formation — The Ison Branch formation (Higgins and others, 1984, p. 18) is a metamorphosed calcareous tuff. The Ison Branch is thinly laminated and contains significant pyrite, and traces of other sulfide minerals. The occurrence of the Ison Branch in Lamar County is limited to a very small, narrow band in the north-central portion of the county. A thrust fault bounds the unit below, and the Barrow Hill formation bounds the unit above.

Barrow Hill formation — The Barrow Hill formation (Higgins and others 1984, p. 18-22) is composed of spessartine quartzite, interlayered with schists and amphibolites. The spessartine quartzite occurs in thin layers that locally contain magnetite. Higgins and others (1984, p. 22) note that the Barrow Hill formation differs from the overlying Clarkston Formation only by the presence of the spessartine quartzite. The Barrow Hill is restricted to a narrow band in the northwestern portion of Lamar County. It is bounded below by the Ison Branch formation, where present, and by a thrust fault where the Ison Branch is absent.

Clarkston Formation — The Clarkston Formation (Higgins and Atkins, 1981, p. 17-18) is composed of interlayered schists and amphibolites. The schists weather to a pink or purple color. The amphibolites are typically a fine-grained assemblage of hornblende and plagioclase that weather to an ocher-colored residuum. The Clarkston Formation is present in much of the northwestern corner of the county and overlies the Barrow Hill formation. Higgins and Atkins (1981, p. 18) suggest that the parent materials for the Clarkston Formation were shales and mafic volcaniclastic rocks.

Hollonville granite — The Hollonville granite (Atkins, in review) intrudes the metamorphic rocks described above in the area north of the Towaliga fault zone. The Hollonville is one of several granites that constitute the Cedar Rock Complex, and is a medium-grained to porphyritic biotite granite. Microcline phenocrysts are typically less than 5 cm in length. The Hollonville granite locally exhibits flow banding. Evidence of the flow banding includes biotite segregation and, in some localities, rotation of grains. Xenoliths of country rock are common in the Hollonville.

High Falls granite — The High Falls granite (Atkins, in review) is an older granite that has been intruded by the Hollonville granite of the Cedar Rock Complex. The High Falls granite crops out in eastern Lamar County and is bounded by the Hollonville granite to the north and west, and by the Towaliga fault zone to the south. Like the Hollonville granite, the High Falls is a porphyritric biotite granite. The phenocrysts of the High Falls granite are larger, however, ranging from 3 to 10 cm. Strong flow banding is characteristic of the High Falls granite.

TOWALIGA FAULT ZONE

The Towaliga fault zone is the dominant structural feature in Lamar County. The Towaliga fault zone has been traced from eastern Alabama to at least Jasper County in central Georgia. In Lamar County, the Towaliga fault zone cannot be mapped as a discreet fault due to poor exposures and possible multiple stages of movement (Grant, 1967, p. 5-6). The fault zone is mapped based upon the occurrence of mylonites, blastomylonites, augen gneisses, and flinty crushed rocks. The location of the Towaliga fault zone on Plate II is based on mapping by Higgins and Atkins (unpublished).

Grant (1967, p. 3) states that the dip of the Towaliga fault zone is to the north at 50 to 70 degrees. The fact that the fault zone follows a straight path through both topographic highs and lows indicates that the fault has a high angle. Grant (1967, p. 5-6) notes both strike-slip and vertical components of movement along the fault.

Occurrences of microbreccias are indicated on the geologic map. The largest mapped occurrence is within the Towaliga fault zone. Smaller areas of microbreccia have been identified both north and south of the Towaliga fault zone. They have undergone extensive shearing and subsequent recrystallization. They are very brittle and, thus, have a tendency to be highly fractured.

GEOLOGY OF THE AREA SOUTH OF THE TOWALIGA FAULT ZONE

General

The discussion of the geology of Lamar County, south of the Towaliga fault zone, is based primarily on mapping by Higgins and Atkins (unpublished). The lithologic descriptions are based on the work of Stieve (1984), Higgins and Atkins (unpublished), Furcron and Teague (1943), and Hewett and Crickmay (1937). Detailed mapping by Stieve (1984) illustrates the high degree of lithologic variability that exists in the area.

Lithologic Units

Unnamed schist and gneiss — Much of Lamar County south of the Towaliga fault zone is underlain by an unnamed interlayered schist and gneiss unit. In the Johnstonville area, Stieve (1984) divided the gneisses of this unit into lithologies ranging from biotite-quartz-feldspar gneiss with compositional layering and local garnets, to wollastonite-biotite gneiss with a flaser texture, and augen gneiss. Biotite schist is also common in this unit. Pegmatites within the schist and gneiss are indicated on the geologic map. The locations of the pegmatites are based on Furcron and Teague (1943) and are approximate. The pegmatites typically contain very coarse quartz, feldspar, muscovite and biotite.

Unnamed garnet granite — A medium-grained garnet-bearing granite crops out along the Lamar-Forsyth County line immediately south of U.S. Highway 41. The garnet-bearing granite has a greenish-gray color and is the largest of several granites within the schist and gneiss that have been noted by Higgins and Atkins (unpublished) and Stieve (1984).

Manchester Schist — The Manchester Schist (Hewitt and Crickmay, 1937, p. 29) is a thick sequence of interlayered mica schist and biotite gneiss. The Manchester Schist in Lamar County crops out as a thin band along the crest of Hog Mountain. Muscovite is the dominant mineral along with lesser quantities of quartz, biotite and feldspar. Traces of garnet are present.

Hollis Quartzite — The Hollis Quartzite (Hewett and Crickmay, 1937, p. 27-29) forms the central portion of Hog Mountain. Its outcrop coincides with Hog Mountain. Small quantities of muscovite are present in the Hollis Quartzite, but the dominant mineral is quartz. In exposures along the former route of Georgia Highway 36 (just north of the Barnesville water-treatment plant) and along Hog Mountain Road, the quartzite exhibits multiple folding and extensive fracturing.

STRUCTURAL GEOLOGY

Higgins and others (1984) consider the Piedmont to be a stack of thrust sheets. In Lamar County they suggest that the Ison Branch, Barrow Hill, and Clarkston formations, as a group, were thrust over the Zebulon formation. The northern part of Lamar County lies on the southern flank of the Griffin synform (Higgins and others, 1984, p. 3), a northeast-southwest trending structural feature. The original structural trend is southwest-northeast. The Hollonville granite was intruded after the thrusting ceased, but before movement along the Towaliga fault zone. The granite truncates the metamorphic rocks and contains xenoliths of the metamorphic rocks. The Towaliga fault zone truncates the Hollonville granite. The intrusion of the Hollonville granite resulted in an aureole of contact metamorphism, indicated by the presence of randomly oriented biotite and sillimanite. These minerals are not restricted to the zone of contact metamorphism. However, in the metamorphic rocks outside of the zone of contact metamorphism, biotite and sillimanite minerals are oriented with the foliation of the rock, whereas they are unoriented in the contact metamorphosed rock (R.L. Atkins, Georgia Geologic Survey, personal communication). Another feature that is locally associated with the intrusion of the Hollonville granite is a lit-par-lit texture, in which the granite is thinly interlayered with the country rock. Both the zone of contact metamorphism and the area of lit-par-lit texture are indicated with screens on the geologic map. The age of the High Falls granite is unknown, but it is truncated by the Hollonville granite and the Towaliga fault zone.

GROUND-WATER OCCURRENCE

The crystalline rocks that underlie Lamar County are covered by the regolith throughout most of Lamar County. Pavement outcrops of relatively unweathered rock are present in some areas; however, they are small and widely scattered. The regolith includes alluvium and colluvium at some locations in Lamar County; however, in most areas, the regolith is composed of saprolite overlain by the soil horizon. The occurrence of ground water in the regolith is quite different than the occurrence in the relatively unweathered crystalline rock.

Ground water is stored in, and transmitted through, the spaces between the grains that comprise the regolith. The amount of ground water in storage is dependent on the porosity. Hydraulic conductivity is a measure of the relative ease or difficulty with which water flows through the material. In granular material such as the regolith, hydraulic conductivity decreases with smaller grain sizes and poorer sorting as the openings through which the water flows become smaller and clogged by the fine-grained material. The saprolite overlying the crystalline rock is in general poorly sorted; as a result, hydraulic conductivities are generally low. The hydraulic conductivity of saprolite varies widely with direction due to the influence of the texture of the parent rock. Studies by Stewart (1964) near Dawsonville in Dawson County demonstrate that the relict texture of the rock, preserved in the saprolite, controls the directional hydraulic conductivity and the ground-water flow rate.

The crystalline rocks of Lamar County, and the Piedmont province in general, do not have the intergranular pore spaces that are present in the regolith. A slice through most crystalline rocks, when magnified, will reveal that the individual mineral grains are interlocking as in a jigsaw puzzle. As a result, the volume of intergranular voids is very small. The porosity of crystalline rocks is typically in the range of 3 percent or less, compared to 15 to 40 percent for the overlying regolith. A large percentage of the few pores that are present in crystalline rocks are isolated or filled with secondary minerals and, thus, do not form pathways for the flow of ground water. The permeability of non-fractured, unweathered crystalline rock, known as the primary permeability, is generally so low as to be of little consequence in supplying water to a well.

The occurrence of ground water in the crystalline rocks is limited to discontinuities in the rock including: weathering zones associated with contacts between differing lithologies; fault zones; stress relief fractures, and smaller-scale structures, such as joints and foliation planes. These avenues of ground-water movement that develop after the rock is formed are known as secondary permeability. The primary permeability of the crystalline rock in Lamar County is so low, that it is necessary to encounter some form of secondary permeability in order to obtain an adequate yield, even for a domestic supply.

Discontinuities in the crystalline rock can transmit very large quantities of water if they are open and interconnected with other discontinuities. The total volume of these discontinuities is usually a very small part of the total volume of rock. As a result, the fractured rock often is able to transmit large quantities of water, but is able to store very little. Although it is unusual, the yield of a well may decline, drastically or totally, in a short time after beginning production of the well because of the limited storage in the crystalline rock. Cressler and others (1983, p. 12-14) describe the decline in well yield of several wells during the construction of the people-mover system at Atlanta's Hartsfield Airport. They concluded that the long-term yield of a well in crystalline rock is limited to the rate of recharge. The most important source of recharge to the discontinuities in the crystalline rock is from water stored in the pores of the regolith overlying the rock.

Ground water can be concentrated in contact zones between rocks of different lithologies. The degree to which a contact zone can store and transmit water can vary greatly. Weathering may progress at a faster rate or to a greater extent along a contact between rocks of different lithologies than within a homogeneous rock unit or along a contact between similar rock units. The rate of weathering may be accelerated by chemical interaction between the two rock types. An additional factor that may influence the weathering rate is the movement of water, the primary weathering agent, along existing discontinuities at and near the contact. The result of the weathering is to create voids that can store and transmit water. Ground water can also be concentrated at a contact by contrasts in the water bearing properties of the two units. An example of this is a thoroughly weathered rock that has developed an extensive secondary permeability overlying an unweathered, unfractured rock unit. In this instance, water could flow downward only to the top of the unfractured impermeable unit, where it would be ponded. The degree to which a contact may concentrate ground water is related to the nature of the contact, the topographic position of the contact, and the degree of difference in the lithologies of the rocks.

Fault and shear zones are the planes along which blocks of rock move relative to other blocks. The size of a fault zone or a shear zone can range from microscopic sizes to features which extend for many miles. The Towaliga fault is a prime example of large-scale faulting. Faults and shear zones rarely occur as a single plane of movement or fracture, but often contain numerous planes of movement. The stresses that produce the fault or shear zone can also produce concentrations of other smaller scale structures that may provide a pathway for ground-water flow in the area adjacent to the fault or shear zone. If the rock is broken into large fragments with open pores, the fault zone could provide an avenue for the flow of relatively large quantities of ground water. Fault zones and shear zones, therefore, may be excellent sites for high-yield wells, particularly where the fault or shear brings together rock of contrasting character (C.W. Cressler, personal communication). Not all fault zones and shear zones, however, provide a pathway for the flow of ground water. The movement of the rocks can grind particles of the rock into numerous fragments particularly under high confining pressure. If the particles that result from the shearing are fine grained or poorly sorted, or if the particles have been cemented, the fault or shear zone may restrict ground-water flow.

Smaller scale structures can provide important avenues for ground-water flow in crystalline rocks. Joints are fractures in the rock that formed with little or no movement and can have cross sectional areas that are large enough to allow considerable quantites of ground water flow through them. Because joints can be localized, it is imperative that a number of joints be interconnected in order to provide storage and recharge to reliably supply water for a well.

Stress relief fractures are moderate- to large-scale, sub-horizontal fractures that are believed to form due to the removal of overlying layers of rock through weathering and erosion. Cressler and others (1983, p. 15-29) discuss stress relief fractures in detail. They report that the opening of one sub-horizontal fracture encountered in drilling, and interpreted to be a stress relief fracture, was as large as six inches. When a large stress relief fracture is encountered in drilling, the yield of the well can be high. Identification of stress relief fractures is difficult even with highly sophisticated geophysical logs or core, neither of which is generally available.

WELL CONSTRUCTION

Three types of wells are used in Lamar County. The typical design of these wells is illustrated in Figure 5. Dug wells are excavated with a pick and shovel. These wells are usually 3 to 4 feet in diameter and extend to either a few feet below the water table or to the top of unweathered rock. Dug wells are typically uncased. Brick or stones may be used to shore the walls of the wells if caving or collapse is a problem. Because dug wells are relatively shallow and cannot extend more than a few feet below the water table, they are prone to go dry during a drought. If the dug well goes dry it must either be deepened or replaced.

Bored wells are the most common type of well in Lamar County. A bucket auger rig is used to construct a bored well. The bucket with an auger at the bottom is turned into the regolith until the bucket is full. The bucket is removed from the hole, dumped and returned to the hole to bore further. Competent rock or boulders cannot be removed by the bucket auger and limit the depth of the well, usually to 70 feet or less. Bored wells are cased with sections of concrete or terra cotta pipe (usually 24 to 36 inches in diameter). Water flows into the well through the joints between casing sections and through the bottom of the well.

The third type of well commonly found in Lamar County is the drilled well. Most drilled wells are cased with 6 inch steel or PVC casing. The casing extends a few feet into competent rock and is grouted in place to prevent water from the weathered zone from entering the well. After the casing is set, the hole is drilled through the rock by the use of a down-the-hole pneumatic hammer (air drilling) or, less commonly, by the repeated dropping of drilling tools to break up the rock (cable tool method).

GROUND-WATER AVAILABILITY

Ground water generally is available in adequate quantities for domestic purposes in Lamar County. The average person uses approximately 100 gallons of water each day for drinking, washing, cleaning, and sanitation. Thus, total water needs for most residences are 700 gallons per day or less, excluding uses outside of the house such as lawn and garden irrigation. A well with a yield of as little as one gallon per minute (gpm) would provide over 1400 gallons per day and would adequately supply a residence, if adequate storage were designed into the water system to meet peak demands.

The Appendix contains a partial inventory of drilled wells in Lamar County. The well inventory includes only those drilled wells for which construction data and an accurate location are known. Locations of all wells in the Appendix have been field checked. In those instances in which the well had been abandoned, the property owner provided the well location. The wells included in the inventory are only a few of the total number of drilled wells in Lamar County.

The yield values are, for the most part, drillers' estimates of the amount of water blown from the hole by the compressed air that flushes cuttings from the hole and powers the down-the-hole hammer. Where specific capacity values are listed, the yield is based on actual pumping or bailing information. The yield estimated by the driller is an instantaneous yield which may or may not be related to the long-term sustainable yield.

Most of the wells included in the inventory were drilled for domestic use. As such, they were not drilled for maximum yield, but rather for the amount of water needed for household use with a margin of

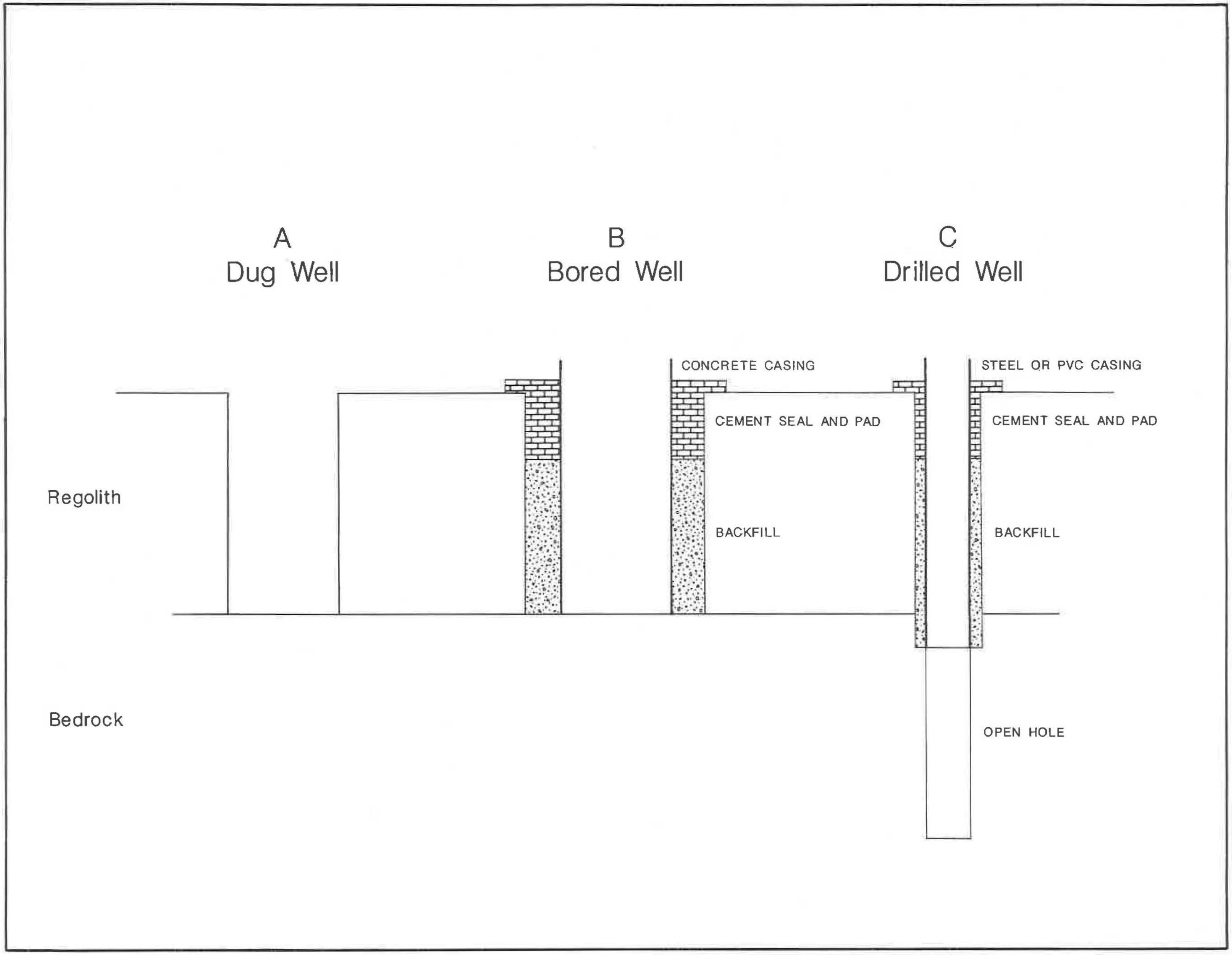


Figure 5. Typical construction of wells in Lamar County.

safety. Drilling commonly ceases once an adequate supply of water has been obtained.

Very few drilled wells fail to yield an adequate supply of water for a single residence. Approximately 5 percent of the wells drilled for domestic purposes in the Piedmont region of Georgia are dry or inadequate (William Martin, Virginia Supply and Well Company; Hoyt Waller, Waller Well Company; personal communications). The Appendix contains information on five dry wells. Three of those dry holes (19, 21, 44) are on a single piece of property east of Barnesville. Pavement outcrops of gneiss are exposed within several hundred feet of the dry holes. A discussion of the development of a water supply at this site is included in a subsequent section of this report. No other reports of multiple dry holes were received during the compilation of the well inventory.

Utilization of the data in the Appendix or any other data set that contains a large percentage of wells not drilled for maximum yield requires that possible skews in the data be recognized. The data in the Appendix are skewed toward the relatively shallow, low yield well, because most of the wells are drilled for owners who need only low yields, and who desire the shallowest well possible in order to minimize drilling costs.

The average yield of the wells in the Appendix is 24 gpm. Figure 6 is a graph showing the percentage of wells falling into various yield ranges. The cumulative percent curve indicates that 57 percent of all of the wells in the survey have yields of 15 gpm or less. This illustrates the prevalence of the low-yield domestic wells in the well inventory.

Plate I illustrates the location of wells in the inventory and the distribution of well yields. Too few wells are included in the inventory to compile meaningful statistics on well yields for each rock unit. Thirty-two of the wells in the inventory are located in the unnamed schist and gneiss unit south of the Towaliga fault. Four of the five dry holes included in the inventory are located in this unit. The average yield of wells in the schist and gneiss is 11 gpm. Wells of five gpm or less comprise 47 percent of the inventoried wells in this unit. In the area outside of the schist and gneiss unit only 15 percent of the inventoried wells yield five gpm or less. The data collected for this study suggest that the schist and gneiss is less productive than other rock units. However, there is documentation of only one instance of a severe problem in obtaining a domestic water supply.

Larger well yields are needed for many uses including public or community supply, irrigation, industrial use, and dairy operation. Little information is available on the development of these larger water supplies. The City of Barnesville utilizes surface water for public supply. The City of Milner and industries in the area obtain their water from the City of Barnesville. Several mobile home parks and subdivisions are supplied from wells. There is no record of major problems in obtaining an adequate yield for the public and community supplies.

One instance of difficulty in obtaining an adequate water supply for a drip irrigation system in southwestern Lamar County was documented. Four wells were drilled before obtaining a yield that was adequate for the irrigation system. The water-supply development at this site is discussed in a subsequent section of this report.

GROUND-WATER QUALITY

Table 1 lists the results of inorganic chemical analyses on ground water from 21 wells in the well inventory. The results of the analyses indicate that water quality from drilled wells in Lamar County is good. Total dissolved solids are generally low, falling in the range of 32 to 168 milligrams per liter (mg/1). The only drinking water standards exceeded in any of the samples were iron, manganese, and fluoride.

The concentration of a particular ion or the value of a parameter is related to a number of factors. In general, the longer that water has been in the subsurface (both in the saturated and the unsaturated zones), the higher the total dissolved solids. The composition and solubility of the rocks through which the water flows also influences the chemical character of the water. A systematic variation of chemical quality could not be identified in Lamar County. Elevated concentrations of fluorides were measured in samples from several wells. The presence of the fluoride could not be attributed to any particular rock type or unit. The higher concentrations of fluoride appear to be associated with waters having higher pH values. The fluoride levels exceed the safe drinking water limit in two wells.

Figure 7 is a Piper diagram that indicates the relative percentage of the major anions and cations. Bicarbonate (HCO_3-) is the dominate anion in most of the samples. The concentration of bicarbonate in the samples is obtained from the alkalinity value reported by the lab and is based on the assumption that bicarbonate is the sole contribution to alkalinity (Hem, 1985, p. 57).

The cations are not dominated by a single ion, but are more equally split. In Figure 7, the percentage of Sodium (Na) and Potassium (K) are plotted together. The contribution of potassium is small compared to sodium. The Piper diagram illustrates that in most of the samples the number of calcium ions is roughly equal to the number of sodium and potas-

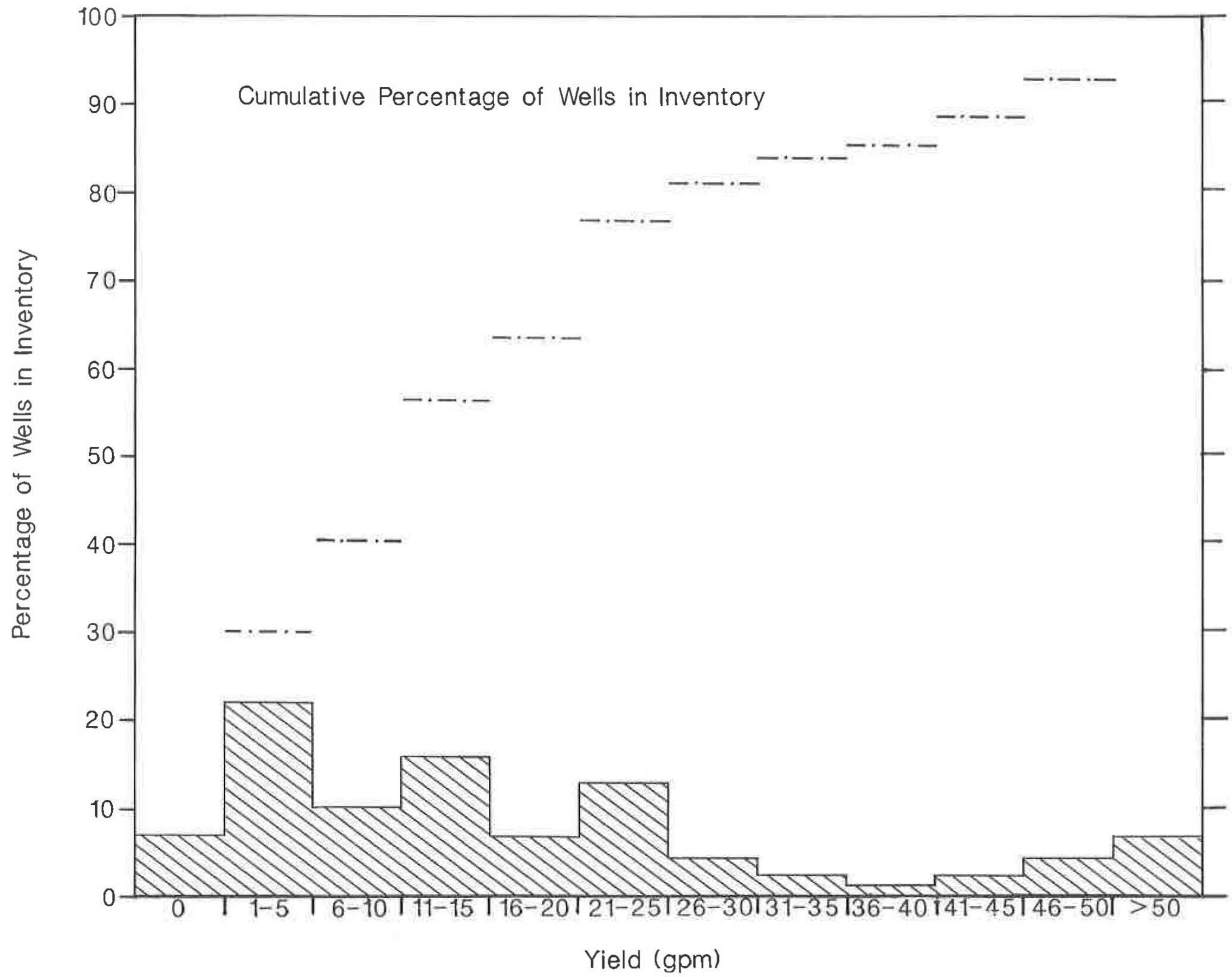


Figure 6. Histogram of the yields of wells in the inventory. Both the percentage of the wells in a yield range and the cumulative percentage of all wells of the corresponding yield range and lower are plotted.

sium ions. The percentage of magnesium is low with the exception of the C.B. Cole Well (inventory number 54). In general, the water from these sampled wells would be characterized as a sodium and calcium bicarbonate water.

The most common water-quality faced by drilled-well users in Lamar County is the presence of excessive iron or manganese. The recommended maximum concentration limits for iron and manganese are 300 to 50 micrograms per liter (ug/1) respectively. These limits were established for aesthetic purposes only. No health problems have been associated with excessive iron or manganese. The limits were established to prevent staining of fixtures and clothing. Three common forms in which iron can occur are ferrous iron (Fe^{++}), ferric iron (Fe^{+++}), and iron associated with bacteria. Ferrous iron is in a reduced state and is found dissolved in clear water. When exposed to oxygen, ferrous iron will oxidize to form ferric iron, which is insoluble. Ferric iron forms a red precipitate that discolors the water and stains porcelain and laundered items. Iron metabolizing bacteria produce a reddish-brown slime that can foul and clog pipes and fixtures.

Treatment of ground water for iron problems can be accomplished through several techniques. Iron can be removed through the use of a softening, or a catalytic oxidizing filter, and by pre-oxidation followed by filteration (Lehr and others, 1980, p. 172-178). The staining effects of iron can be reduced or eliminated in many instances by the addition of polyphosphates to the water. The selection of a treatment method will depend upon the form and concentration of the iron, the pH, other water-quality parameters, and the water-quality and quantity needs of the user.

Table 1 — Water-quality data

2	Paul Milner	2-19-86	6.15	17.8	90	68	1.7	2.9	1.8	4.9	3.0	10	14.6	<.5	0.2	78	<10	14,600	35
17	Jim Graham	2-19-86	7.85	18.7	194	120	20.7	2.5	1.2	13.3	2.0	<2	90.3	<.5	0.7	26	18	19,000	80
18	Joe McGaha	1-16-86	-	-	-	100	15.6	1.1	0.8	10.9	4.5	4	61.0	<.5	2.9	<10	29	16,500	39
23	Roland Andrews	1-30-86	6.65	18.4	88	168	4.1	2.0	0.5	4.7	4.0	<2	29.3	<.5	0.3	43,200	71	21,800	22
25	J.R. Cole	1-30-86	7.48	17.7	195	116	17.1	1.2	1.1	14.4	10.0	4	73.2	<.5	0.9	<10	22	14,600	42
29	W.Z. Martin	2-19-86	5.04	18.0	88	56	2.0	3.8	1.9	3.8	7.0	<2	68.3	4.8	<.1	<10	57	5,750	28
32	Triple H. Farms	2-19-86	5.80	17.7	42	32	1.1	1.1	0.6	2.3	3.0	7	7.3	0.6	<.1	25	11	6,510	10
33	Mrs. Fred Hand	3-06-86	8.31	16.8	190	128	22.9	1.4	2.2	11.0	2.0	6	105.	<.5	2.9	<10	10	16,700	95
42	Rex Coplen	2-19-86	6.85	18.5	75	72	5.0	1.8	1.0	5.4	3.0	5	26.8	0.7	0.2	22	<10	13,500	31
49	George Click	2-10-86	6.76	17.1	88	52	5.9	1.4	0.7	3.0	1.9	3	43.9	<.5	0.1	43	14	8,990	16
50	Pauline Wallace	1-30-86	7.12	16.6	145	104	13.9	2.3	2.0	8.5	2.5	7	68.3	<.5	0.6	1,120	78	20,300	70
51	Beamer Donahue	1-16-86	7.25	17.4	118	80	8.8	3.0	2.0	6.8	4.0	4	48.8	<.5	1.4	195	<10	19,100	37
54	C.B. Cole	1-30-86	6.47	17.4	105	56	7.6	1.4	4.3	1.2	2.0	<2	48.8	<.5	<.1	165	<10	5,620	13
55	Charley Jones	1-30-86	7.79	18.9	178	108	18.2	1.6	2.8	8.8	2.5	9	73.2	<.5	0.7	105	35	18,000	75
56	Donald Royal	1-30-86	7.70	17.1	85	64	4.0	1.8	1.2	4.7	3.0	2	19.5	<.5	0.3	720	14	16,700	16
58	William Key	1-16-86	6.66	17.2	125	108	7.9	2.0	1.2	8.3	3.0	13	51.2	<.5	0.5	2,850	76	26,300	35
60	Jeff Baker	1-16-86	6.45	17.9	77	76	4.1	1.6	1.0	6.1	3.0	4	24.4	<.5	0.4	95	<10	21,000	<10
61	Milton Pritchet	1-16-86	7.63	17.7	153	96	3.0	2.6	1.7	7.8	3.0	4	78.1	<.5	0.2	1,930	17	17,900	48
66	Marion Underwood	2-10-86	8.26	17.5	150	96	16.8	1.7	0.5	12.7	2.4	5	80.5	<.5	0.7	48	<10	14,100	93
67	Carl Sawyer	2-10-86	5.71	17.6	47	32	2.2	2.2	0.5	2.8	3.4	3	9.8	1.0	<.1	95	<10	7,360	18
68	Joseph Bush	2-10-86	6.24	17.6	69	44	1.2	2.7	0.3	3.2	1.9	3	14.6	.6	0.1	600	<10	14,100	<10
High			8.31	18.9	195	168	22.9	3.8	4.3	14.4	10.0	13	105	4.8	2.9	43,200	78	26,300	95
Mean			6.91	17.7	115	85	8.8	2.0	1.4	6.9	3.4	-	49.4	-	-	-	-	15,200	-
Low			5.04	16.8	42	32	1.1	1.1	0.3	1.2	1.9	<2	7.3	<.5	<.1	<10	<10	5,620	< 10

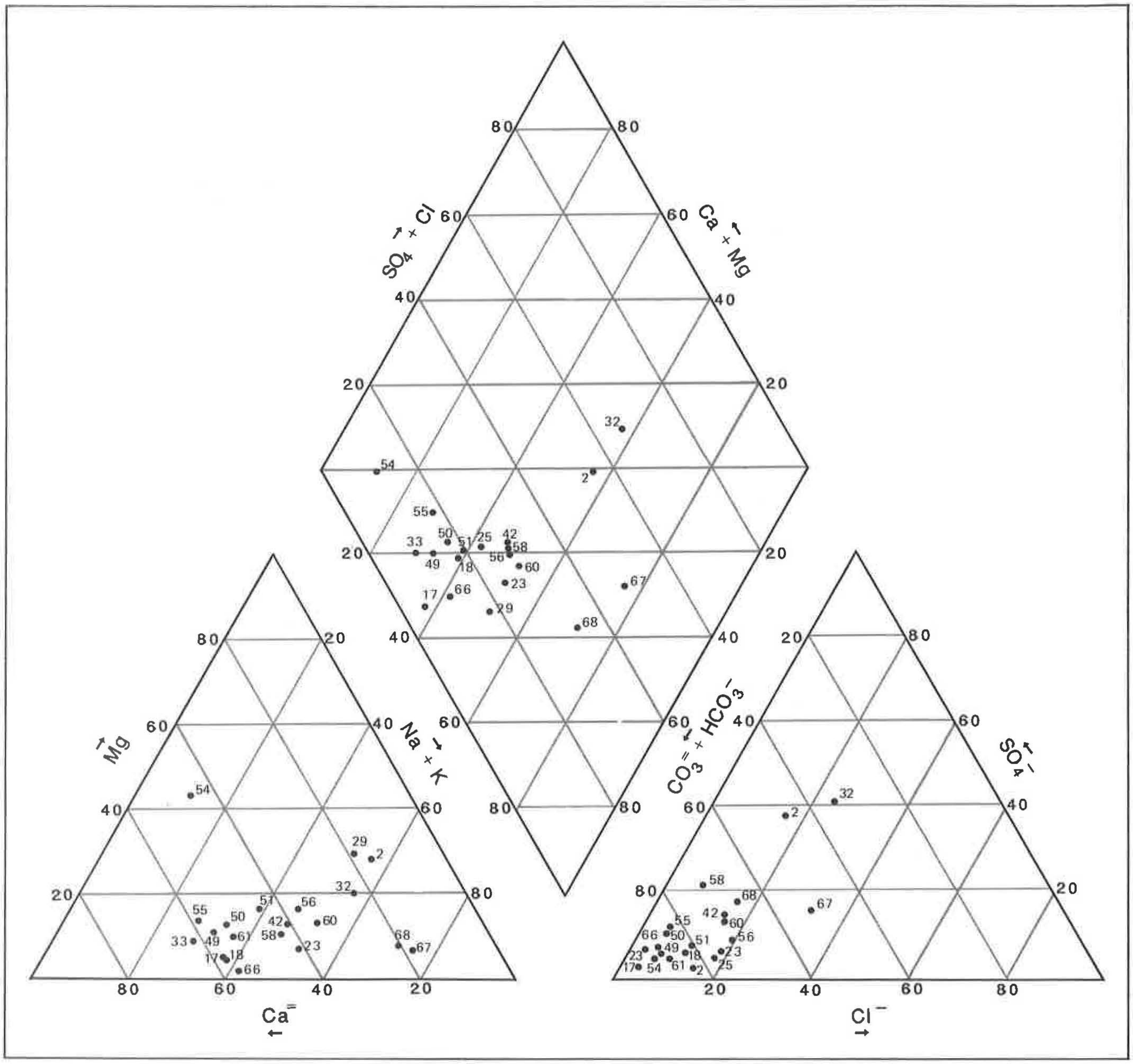


Figure 7. Piper diagram illustrating the relative percentage of anions and cations.

Records from the Lamar County Health Department and the Environmental Protection Division water-quality lab indicate that contamination of wells by bacteria, particularly coliform organisms, is relatively common. Coliform bacteria are present in human and animal wastes. Septic tanks are one of the most common sources of bacterial contamination. Septic tank effluent can enter wells regardless of depth; however, dug and bored wells are more susceptible to contamination from septic tanks than drilled wells because they obtain water from the regolith into which the septic tank effluent is discharged.

Potential sources of contamination, in addition to septic tanks, include feed lots, waste impoundments, leaking storage tanks, and storage areas for agricultural or other toxic chemicals. These potential sources of contamination should always be avoided in selecting a site for a well. Maintaining the specified separation between waste disposal system components and a well as prescribed by state law or county code is an important way to reduce the potential for contamination of the well. These specified distances can also be used as a guide for the minimum safe distance to other sources of contamination. Well sites immediately downhill from potential sources of contamination should be avoided. It is important to consider septic tanks or other potential contamination sources on adjacent lots if the well is near a property line.

Proper well construction is another way in which the water-quality of a well can be protected. Grouting of the well prevents contaminants from flowing downward along the side of the casing and into the well. The construction of a sloping cement pad around the well casing directs surface water away from the well. A cap and well seal protects against items falling into the well and prevents surface-water inflow.

GROUND-WATER EXPLORATION TECHNIQUES

TOPOGRAPHIC ANALYSIS

LeGrand (1967) developed a ranking system for well sites based upon soil thickness and topography. The LeGrand method requires no specialized training or skills to compare the apparent favorability of various sites. Rating points are assigned for each site based on the topographic position and on the thickness of soil. The sum of the points for the two criteria can be utilized to estimate the probability of obtaining various yields at a particular site.

LeGrand's method is based on two assumptions. The first is that the probability for obtaining water increases with the thickness of the unconsolidated and weathered rock layer. The second assumption is that well yields, in general, are greater in topographically low areas than in topographically high areas. LeGrand's ranking of topographic position (1967, p. 2) from least favorable to most favorable is:

Steep ridge top
Upland steep slope
Pronounced rounded upland
Midpoint ridge slope
Gentle upland slope
Broad flat upland
Lower part of upland slope
Valley bottom or flood plain
Draw in narrow catchment area
Draw in large catchment area

This ranking relies not only upon site elevation compared to local highs and lows, but also upon the steepness of the slope. In areas of uniform soil thickness or where information on soil thickness is lacking, the above topographic favorability ranking can be used alone to compare potential well sites.

One of the primary goals in selecting a well site in a crystalline rock terrain is to identify a location where the bedrock is fractured. Unfractured rock is less susceptible to chemical weathering due to the fact that there are no open pathways to bring fresh supplies of the main weathering agent: water. Because fractured rock is more easily eroded than unfractured rock, topographic lows are more likely to occur on fractured rock. Topographic lows, however, are not necessarily associated with fractured rock.

Faults and fractures in the rock tend to be planar or sub-planar structures. In many instances, these structures will have a linear trace on the earth's surface. Staheli (1976) and Cressler and others (1983) note that the drainage pattern south of the Brevard fault zone is dendritic and claim that the location of streams, with the possible exception of the smallest tributaries, are controlled not by the structure of the rock, but by the position of the streams in a sedimentary cover that has subsequently been eroded. Figure 8a is a map of the drainage system of Lamar County. The drainage pattern is generally dendritic as noted by Staheli (1976) and Cressler and others (1983). There is, however, an alignment of many streams and drainages that suggests some regional geologic influence on the streams and drainage patterns. Three preferred stream orientations are noted. A northwest orientation is the most prevalent. The streams aligned in this direction are highlighted in Figure 8b. Figure 8c illustrates the streams aligned in a north to north-northwest direction. This orientation is not as prevalent as the northwest orientation, but is more prevalent than the third orientation noted, to the northeast. Streams oriented to the northeast are shown in Figure 8d. These prevalent orientations are mostly in the smallest intermittent and perennial tributaries, but also include some of the larger perennial streams. The occurrence of a linear stream segment is an indication that a discontinuity may be present, particularly if the orientation of the stream is aligned with other streams in the area. It is generally believed that drill sites located near linear streams are more likely to produce a desired quantity of water than a randomly selected drill site. Cressler and others (1983, p. 35), however, noted a lack of success in drilling test wells along linear streams south of the Chattahoochee River.

AERIAL-PHOTOGRAPH ANALYSIS

Aerial-photograph analysis is another technique that is widely used to select potential well sites or to screen areas for further consideration. A number of investigators (including Brook and others, 1984; Staf-

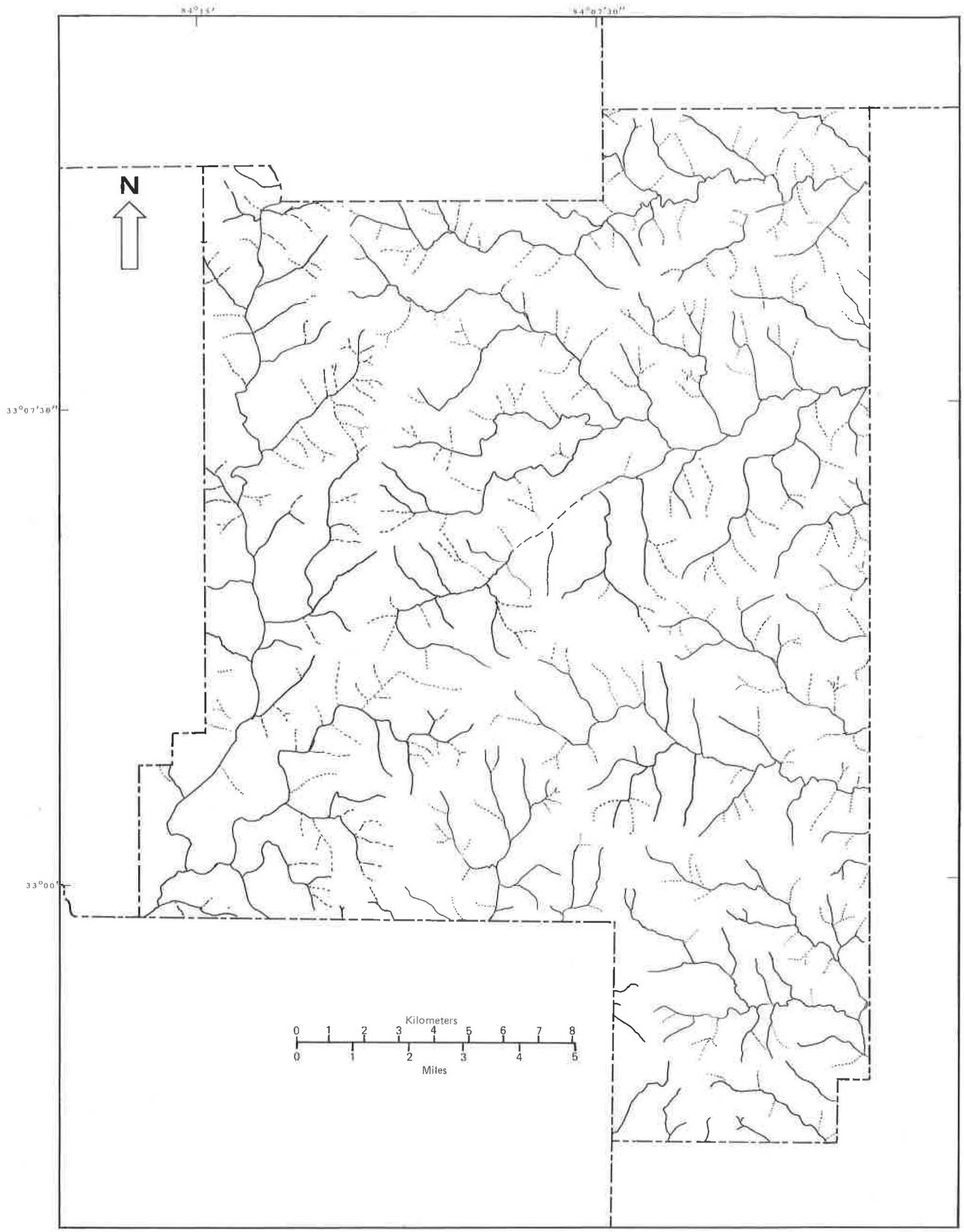


Figure 8a. The drainage network in Lamar County.

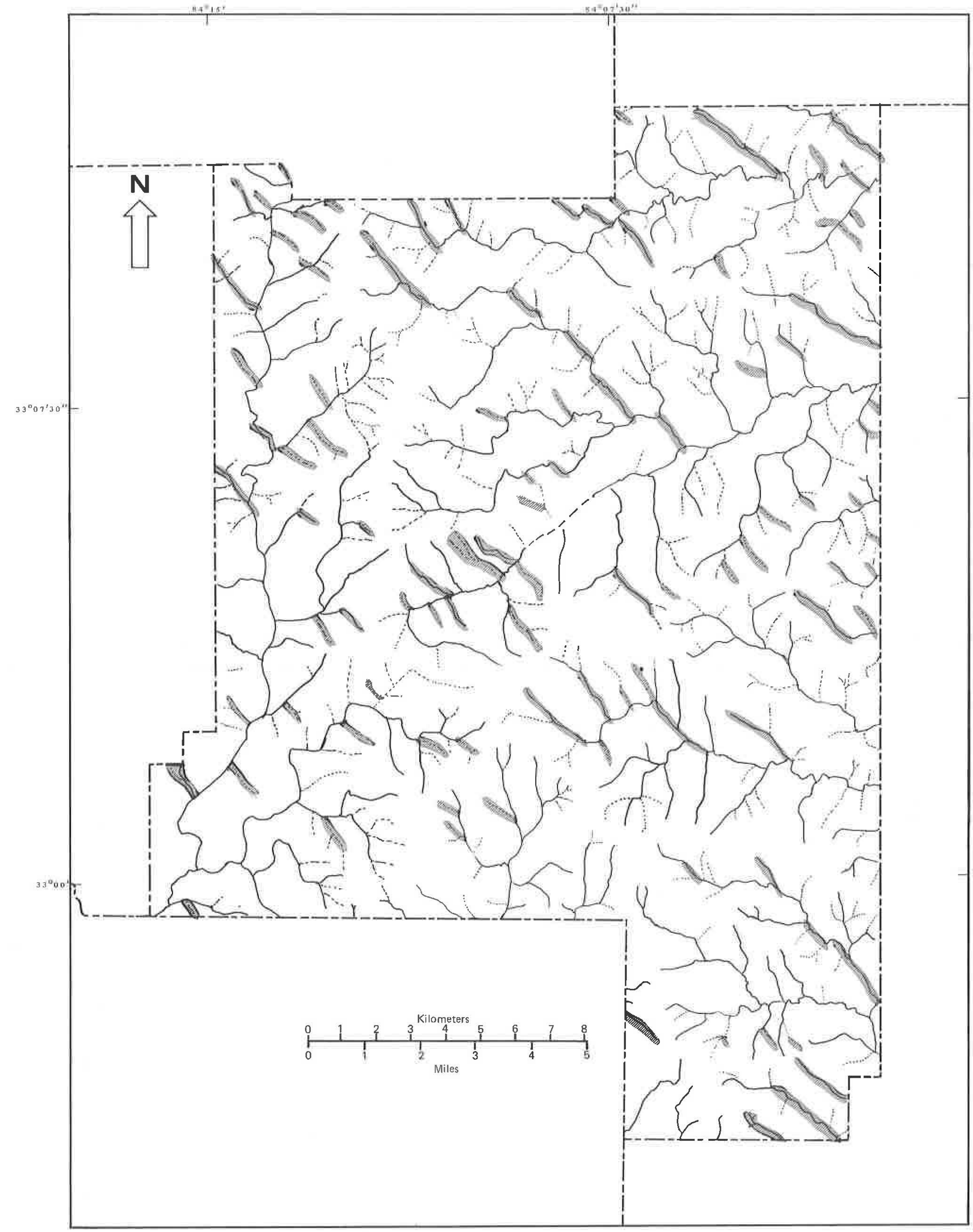


Figure 8b. Drainage network in Lamar County indicating alignment of streams in a northwest direction.

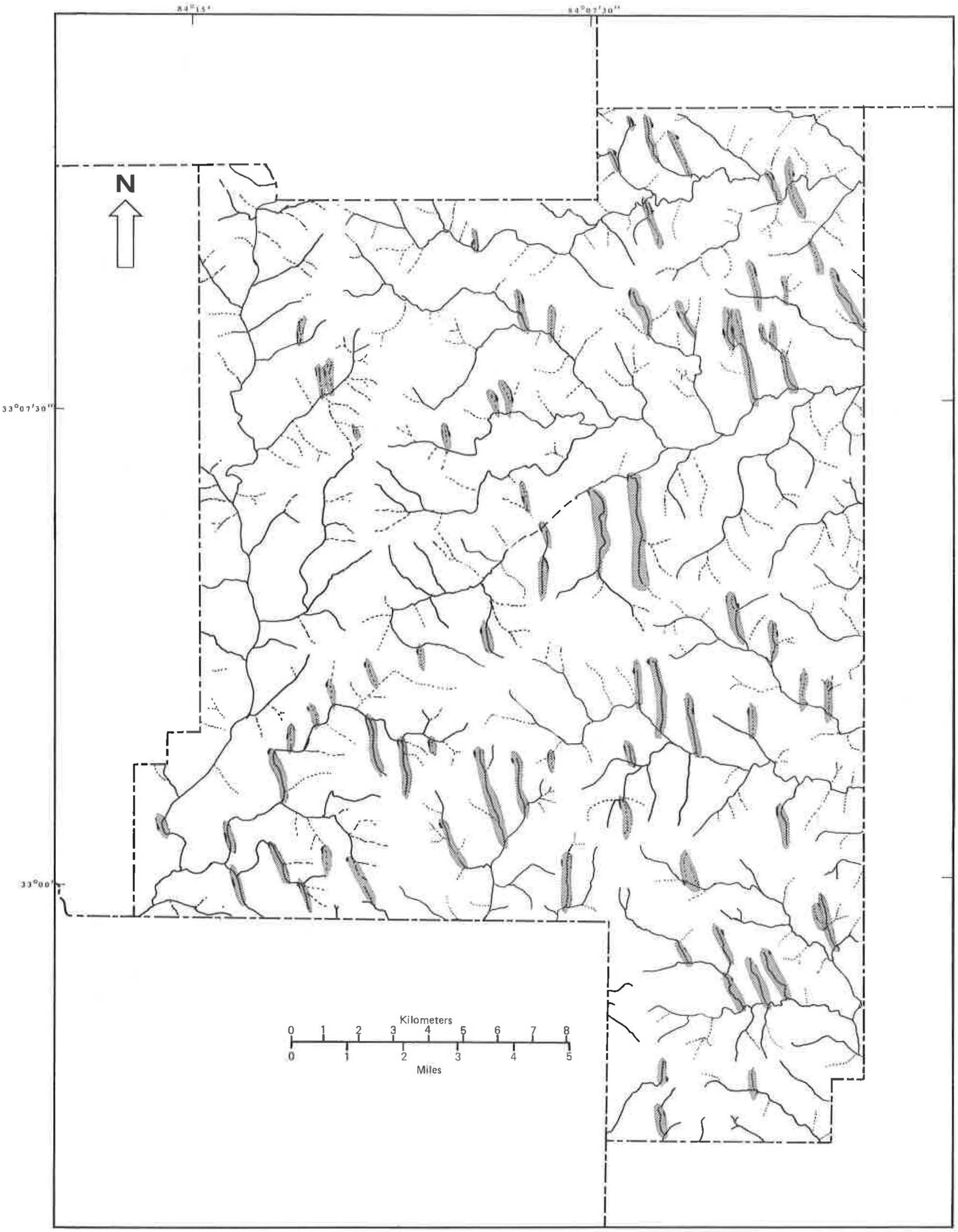


Figure 8c. Drainage network in Lamar County indicating alignment of streams in a north and north-northwest direction.

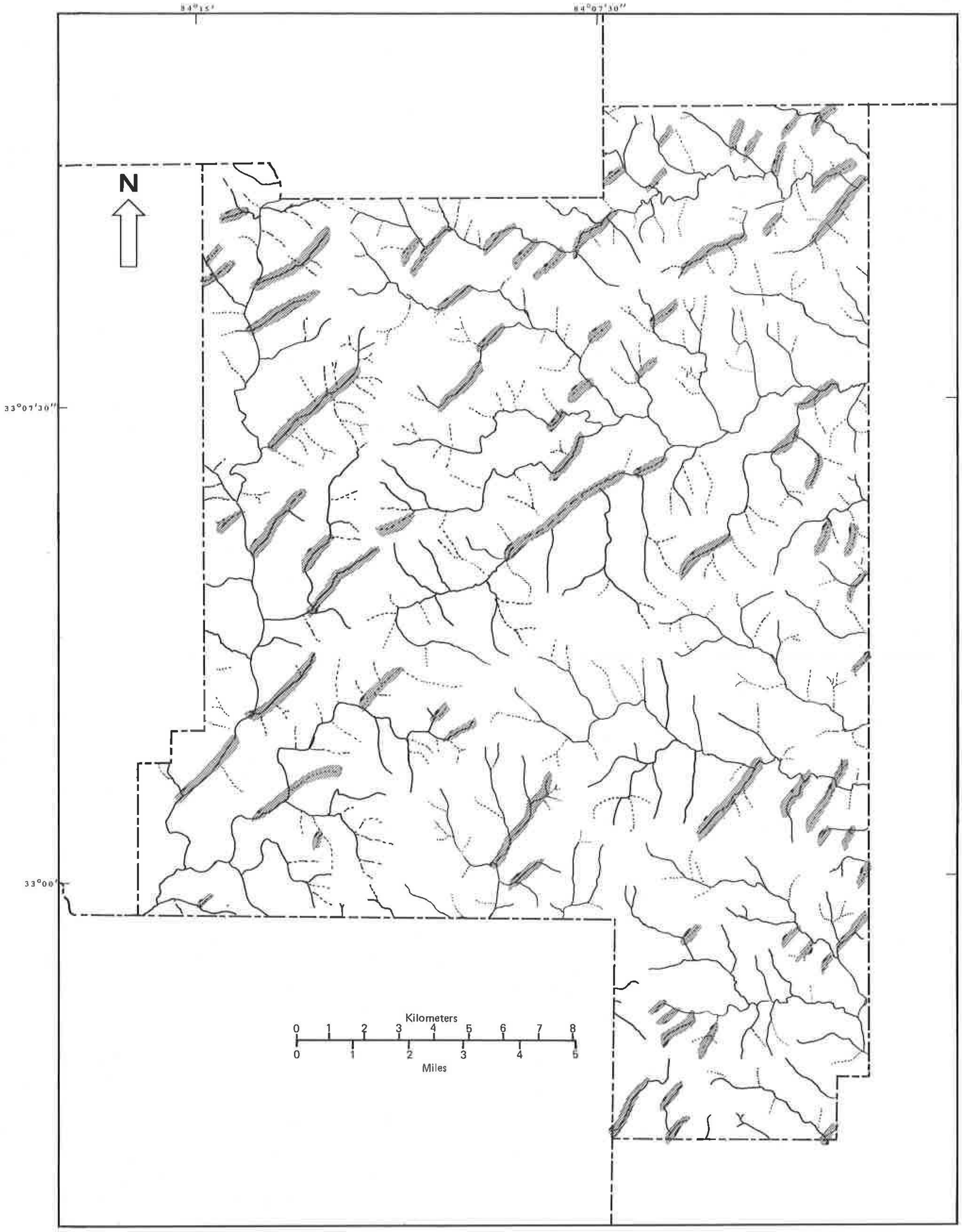


Figure 8d. Drainage network in Lamar County indicating alignment of streams in a northeast direction.

ford and others, 1983; and Jammallo, 1984) have used aerial photography to identify linear features that may be related to discontinuities in the bedrock. The aerial photographs are examined for linear features such as straight stream segments, linear slope changes, linear ridges, linear changes in soil tone and linear changes in type or condition of vegetation. It is important to avoid the inclusion of man-made or man-induced linear features such as fence rows, power lines, abandoned roads, pipeline right of ways, and trails. This technique is based upon the assumption that the linear features being identified are related to discontinuities in the rock.

Aerial photographs are available in a wide range of scales and types. High altitude black-and-white photographs at a scale of 1:80,000 were examined for this study using a stereoscope. Figure 9 is a map showing the locations of the linear features identified in the analysis of the high altitude black-and-white photographs. Land use is an important factor in the identification of photo linears. Linear features are much easier to identify in unmanaged forests and other areas with little disturbance of the vegetation and soil than in planted pine forests and cultivated fields.

Areas with concentrations of linear features would be expected to be more favorable for the development of ground-water supplies than areas with few or no linear features. Intersections of two or more linear features are generally considered to be prime targets for high-yield wells due to the fact that several discontinuities may be encountered by the same well. Figure 9 was divided into one mile square cells in order to evaluate the density of photo linears and photo-linear intersections throughout the county. The total length of photo linears in each cell was measured and the number of intersections counted. The total length of photo linears per cell range from 0 to 25,500 feet as indicated in the histogram in Figure 10. Figure 11 is a histogram of the number of intersections of photo linears in the cells. Cells ranking in the top 20% in photo-linear length are arbitrarily designated as favorable for the development of ground-water supplies. Four levels of favorability are delineated in Figure 12. The cells assigned to the most favorable level are the top 10% in total length of photo linears and contain a minimum of 5 photo-linear intersections. The data base of wells for this study is inadequate to evaluate well yields in the areas designated as favorable compared to well yields in other areas.

FIELD GEOLOGY

Geologic information is used widely in the selection of well sites. Faults and contact zones, as described in the discussion of ground-water occurrence, are discontinuities that may provide large quantities of water to wells that encounter them. The geologic map included in this report provides general information on the location of a number of these features. On a local scale, the location and orientation of contacts, faults, joints, and foliations are helpful in selecting a well site. Changes in soil type may indicate the presence of a contact. Locating a well near a contact may increase the likelihood of obtaining an adequate or high yield. Soil, however, may hinder identification of geologic features. In the event that the orientation of a discontinuity can be determined, the well should be drilled at a location that will permit the discontinuity to be intercepted at depth.

Figure 13 illustrates a hypothetical situation in which a fault zone has been identified on the basis of a mylonite outcrop. If the dip on the fault can be inferred, the well can be located to intersect the fault at depth, as in Well A. If the presence of the fault is identified on the basis of mylonite fragments in the soil, it will probably not be possible to infer the dip of the fault. If the dip of the fault is unknown, or if the dip is not considered, the well may not intersect the fault, as in Well B. If the well can not be drilled on the down-dip side of the fault, or if the dip of the fault is not known, it is nevertheless advantageous to locate the well near the fault (as in Well B) because a fault is rarely a single plane. The fault may instead consist of a main plane of movement along with a number of off-shooting zones of movement called splays. Another common occurrence is the presence of a series of parallel but offset, enchelon, faults. In many instances discontinuities are created in the area of the fault that might enhance well yields.

MAGNETOMETRY

Magnetometry has been utilized to identify potential well sites. Britton (in Voytek, 1986, p. 57) reports success in locating high-yielding wells in New England through the use of magnetometry. Britton reports wells in magnetic lows producing high yields whereas wells outside of the magnetic lows produce low yields. Jammallo (1984) utilized magnetometry for field location of fracture traces identified on aerial photographs. In most instances the fracture traces were indicated by a magnetic high. Many of the fracture traces were associated with diabase dikes (a contact zone). Regression analyses indicate limited correlation between well yield and the proximity of a linear magnetic anomaly (Jammalo, 1984, p. 125).

Figure 14 is a magnetic profile conducted along Johnstonville Road from Johnstonville northward into the Towaliga fault zone. The magnetic profile was conducted in order to evaluate whether the

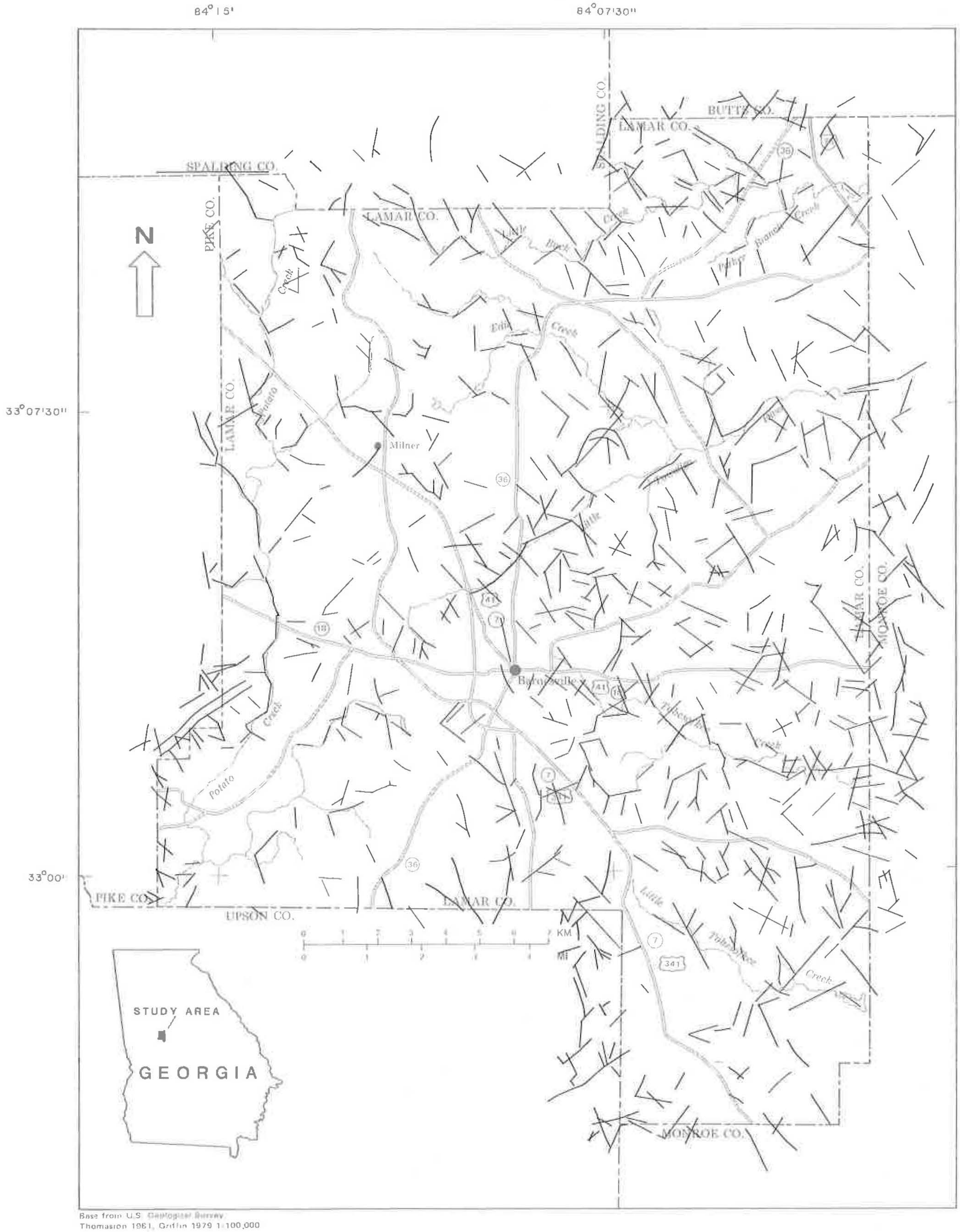


Figure 9. Composite of photo linears from the stereoscopic examination of high-altitude black-and-white aerial photographs.

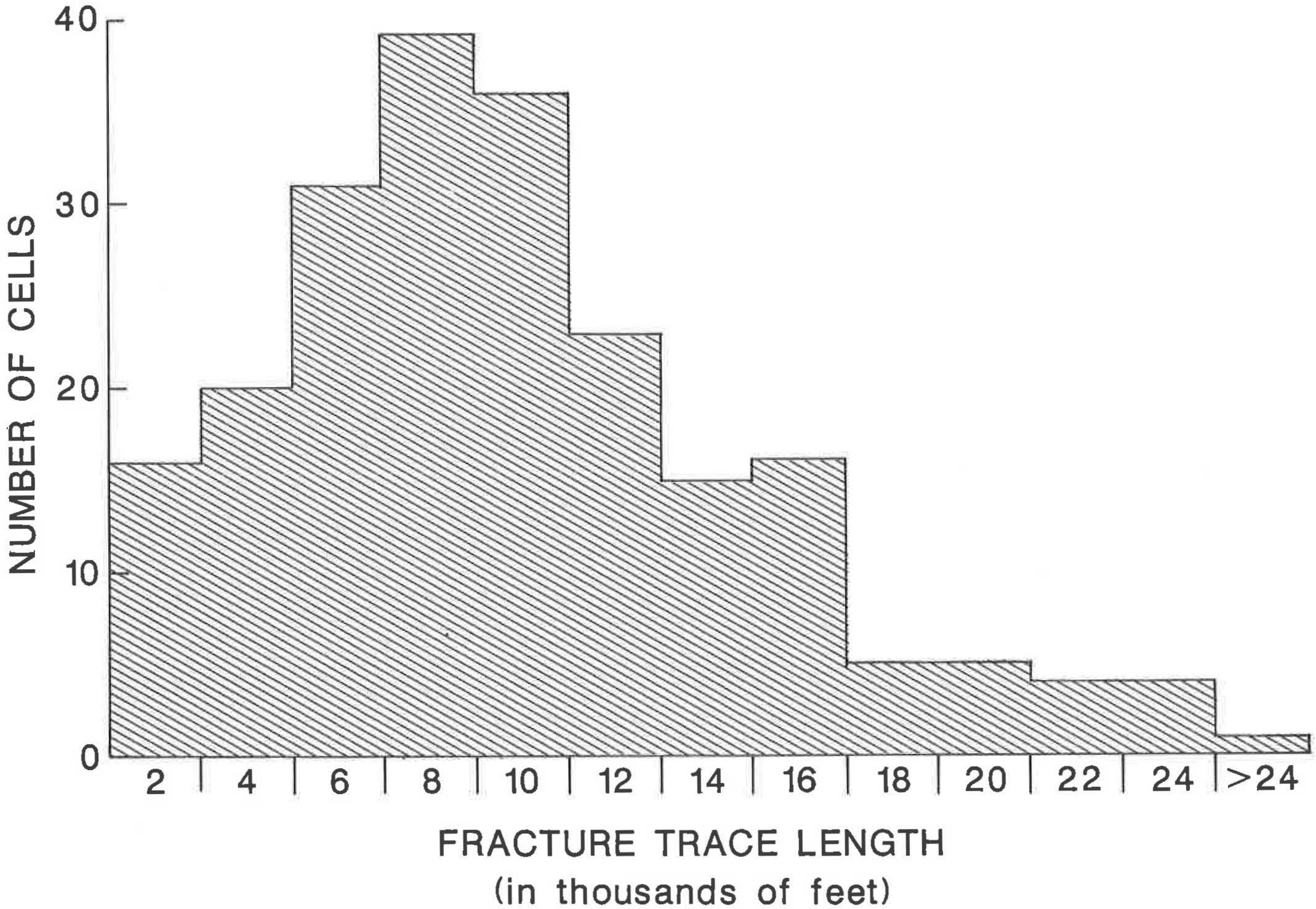


Figure 10. Histogram of photo-linear length per 1 square mile cell.

Towaliga fault could be located using magnetometry. Figure 14 indicates that the Towaliga fault zone does not exhibit a markedly different magnetic field strength compared to areas outside the fault. However, there is a large anomaly that occurs in the Towaliga fault zone. This anomaly extends over an area of approximately 700 feet in line B. It is not known whether the magnetic anomaly is related to the fault. Outside of this anomaly there is little variation of the magnetic field strength. Magnetometry may be most effective in identifying a single drill site from one or several small areas of favorability, rather than as a broad screening technique.

ELECTRICAL RESISTIVITY

Electrical resistivity is commonly used in assessing sites for water wells. Crystalline rocks generally have a high resistivity due to the fact that the porosity and fluid content are low. Fractured rock that contains water will tend to have a lower resistivity due to the conductivity of the fluid. A number of investigators have used electrical resistivity in prospecting for ground water in crystalline rocks. Scarbrough and others (1969) conducted electrical resistivity profiles in the Heflin, Alabama area. Areas of low resistivity, thought to be associated with the occurrence of ground water, were identified. Test drilling of sites selected on the basis of electrical resistivity, seismic refraction (for depth to bedrock) and topography resulted in well yields (Wilson and others; 1970, p. 13) that averaged approximately 8 to 9 gpm. Only one of the wells had a yield that would be considered above average; however, the wells were relatively shallow.

Seven vertical electric soundings were conducted in the Johnstonville area of Lamar County. The resistivity curves of these soundings are presented in Figure 15 along with a location map. Sounding 1 was conducted in the Towaliga fault zone. Sounding 2 was conducted on the northern margin of the fault zone. The remaining soundings were conducted south of the fault zone. The soundings utilized an offset

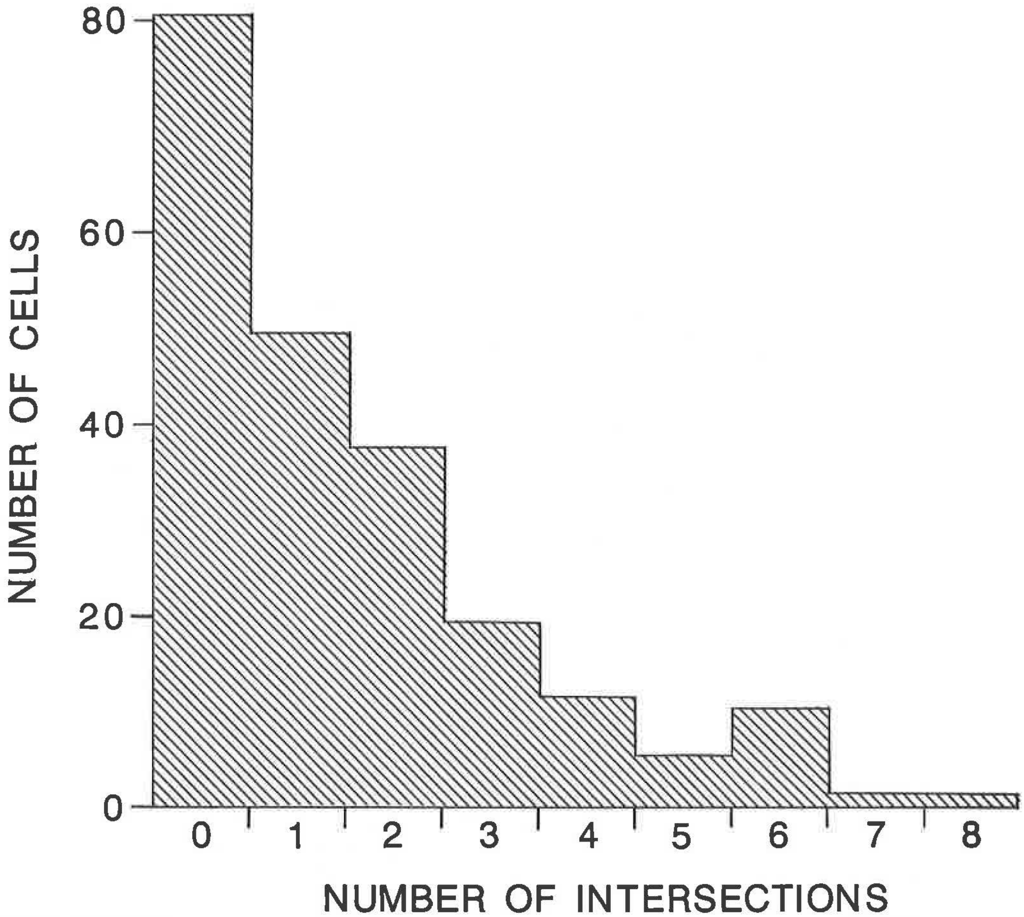


Figure 11. Histogram of photo-linear intersections per 1 square mile cell.

multiconductor cable based on the Wenner electrode array. Interpretations of the soundings would amount to speculation in that no well data exist for the immediate area of the soundings.

A productive well site in theory would consist, electrically, of a three-layer case. The uppermost layer of unsaturated soil and/or saprolite would have an unpredictable, but intermediate resistivity. Saturated saprolite underlying the upper layer would have a very low resistivity due to the water in the pores and the presence of clay in the saprolite. The third layer, composed of crystalline rocks, would have a high resistivity due to the very low porosity, even if the rock were thoroughly fractured. This theoretically-favorable setting would produce a resistivity sounding curve that would have a shape as indicated in Figure 16. If the difference in resistivity of fractured versus unfractured rock is small compared to the contrast between the rock and the saturated saprolite, it is unlikely that the difference between the fractured and unfractured rock can be detected (T.L. Schmitt, Georgia Geologic Survey, personal communication). In order to assess the degree of fracturing of the bedrock, knowledge of the range of electrical properties of the rock unit would be needed.

Some investigators, including Harmon and others (1984) and Carrington and Watson (1984), have utilized alternate electrode arrays in an attempt to better identify fractures in the crystalline rock. Detailed studies at a large number of sites are needed to evaluate the most effective use of electrical resistivity in exploring for ground water.

RECOMMENDATIONS FOR THE SELECTION OF A WELL SITE

INTRODUCTION

A well that produces a reliable supply of clean water must combine three factors. The well must encounter discontinuities in the rock in order to produce a significant flow of water. The discontinuities in the rock must be connected to a source of recharge in order to sustain the yield of the well. Thirdly, the well must be protected from potential sources of con-

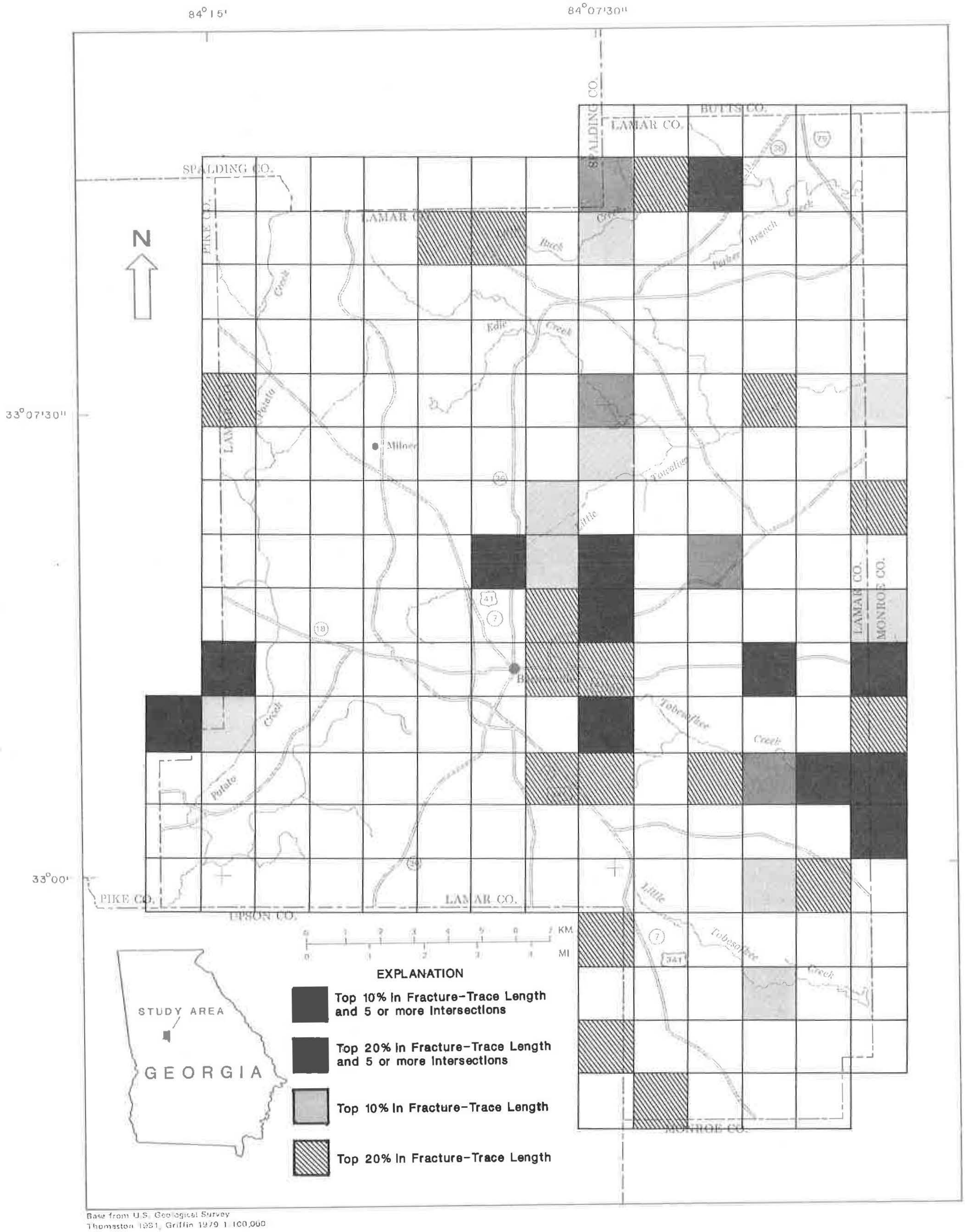


Figure 12. Areas favorable for the development of ground-water supplies based on aerial photograph analysis.

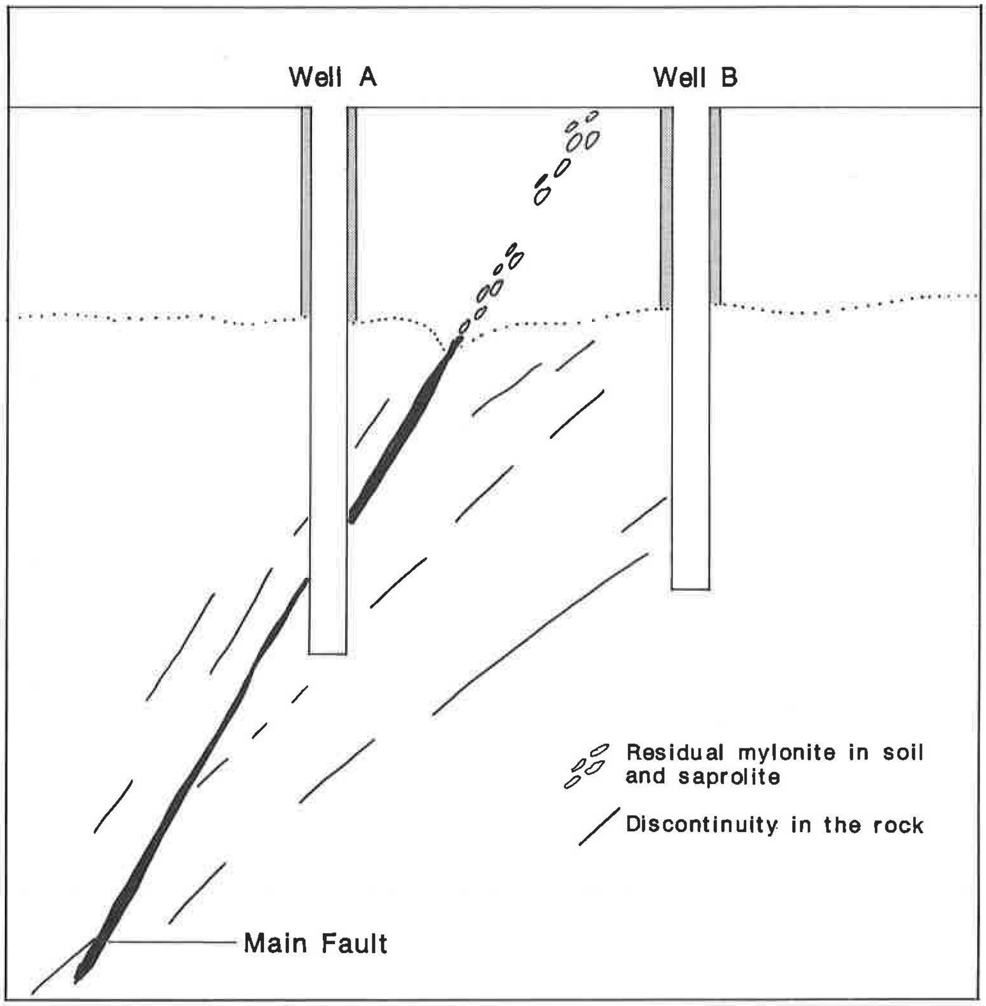


Figure 13. Hypothetical placement of wells near a dipping fault. Well A intersects the fault at depth. Well B misses the fault due to failure to take the dip into account.

tamination. If any one of these factors is not present, then the well will fail, either in the short or long term. Therefore, the selection of a site to drill should consider these factors. The protection of a well from contamination, through both site selection and construction, has been discussed in the water-quality section.

Five techniques for ground-water exploration have been discussed earlier. In selecting a well site, it is advisable to utilize as many techniques as possible in order to increase the odds of success. By utilizing an integrated approach to the selection of a well site, the shortcomings of individual techniques may be overcome.

SELECTING A SITE FOR A HIGH-YIELDING WELL

The effort devoted to selecting a well site should be proportional to the quantity of water needed and the inherent characteristics of the area. The area under consideration in siting a high-yield well is usually much larger than for most domestic wells. Generally, anywhere from as little as a hundred acres to as much as several square miles may be under consideration.

The first step in selecting a site for a high-yield well is to gather as much published or readily-available information on the area as possible. The goal of the first stage in the site-selection process is to utilize relatively inexpensive exploration techniques to identify areas that are favorable for further consideration. The information collected should include any available geologic maps, satellite imagery or high-altitude photography. The geologic maps should be examined for features that suggest the presence of water-bearing discontinuities such as fault zones, contacts, and rock units composed of alternating lithologies. The satellite images or high-altitude pho-

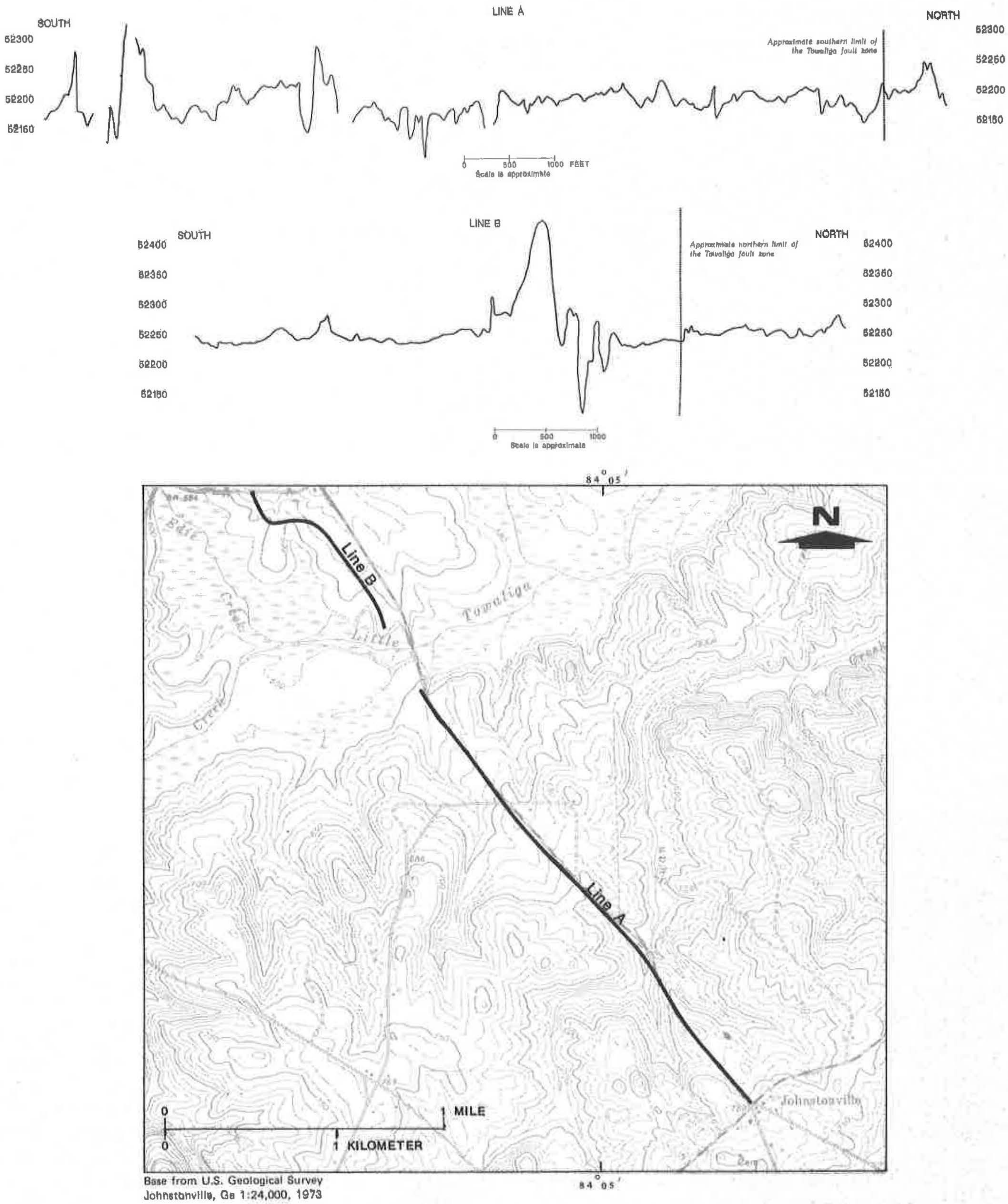


Figure 14. Magnetic profile from Johnstonville northward into the Towaliga fault.

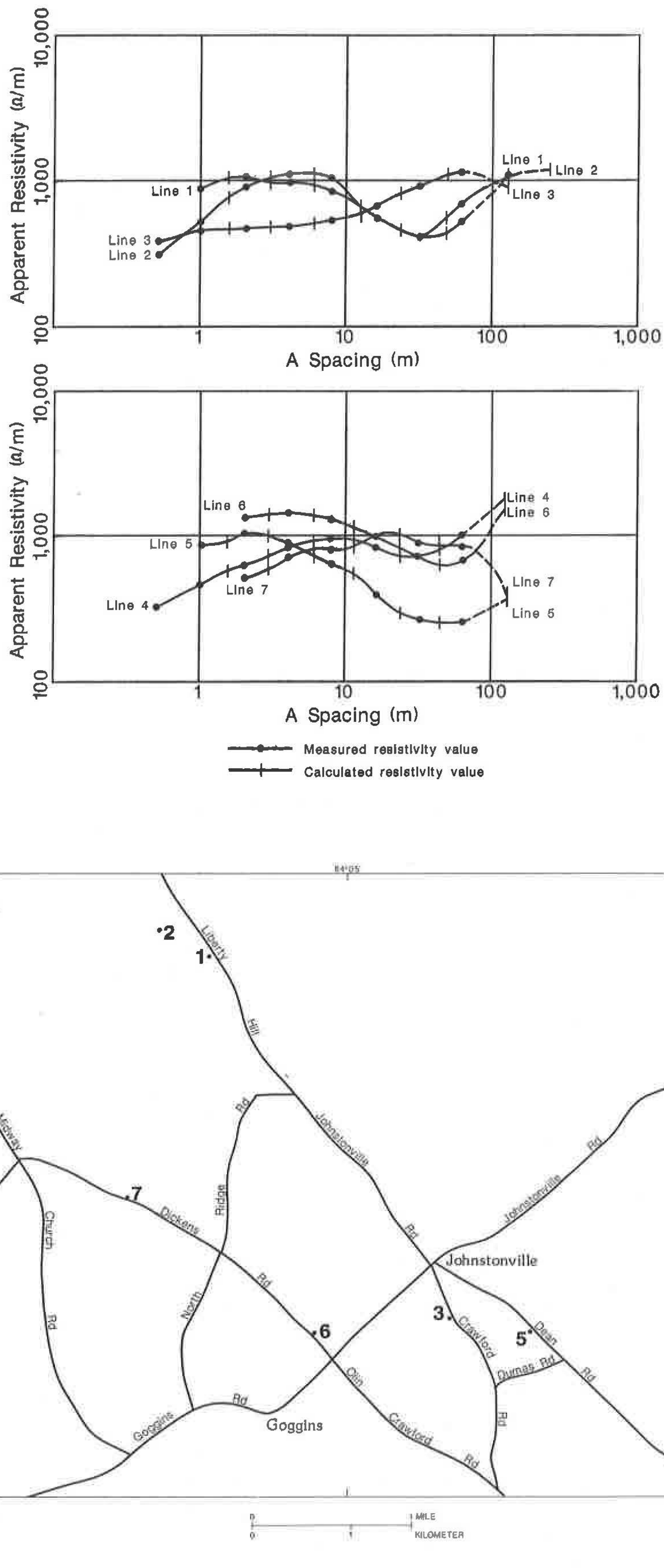


Figure 15. Resistivity soundings in the Johnstonville area.

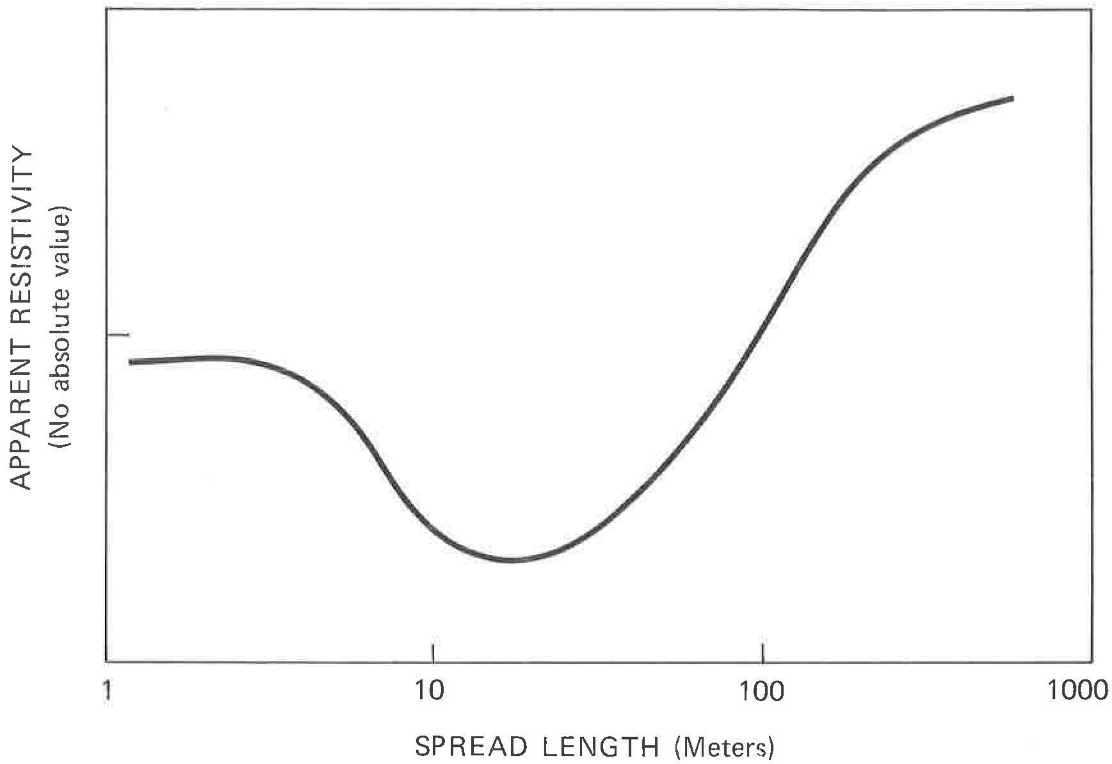


Figure 16. Theoretically favorable electrical resistivity sounding curve.

tographs, or both, should be examined for linear features that may indicate the presence of discontinuities. Analysis of the geologic maps, satellite imagery, and aerial photographs should indicate areas that may contain water-bearing discontinuities. Topographic analysis can then be utilized to evaluate the recharge potential of the sites. The final step of this first stage in the site-selection process should be to eliminate from consideration any favorable sites that may be adversely affected by sources of contamination.

The second phase of the site-selection process utilizes site-specific field studies to identify drilling sites within the favorable areas identified in the first phase. Analysis of low-altitude aerial photography may result in the identification of smaller-scale photo linears than was noted on the high-altitude photographs or satellite images. In addition, the low-altitude photographs should be used to more accurately locate the previously identified photo linears. Detailed examination of the geology of the favorable areas can identify discontinuities that may provide a pathway for the movement of ground water. Electrical resistivity soundings can be utilized to estimate the thickness and saturation of the regolith as well as to provide clues as to the nature of the rock. Magnetometry can also be used to evaluate the potential for discontinuities in the rock.

The final step of the second phase in the site-selection process should be to review the information on each of the potential well sites. At this point, the potential well sites should be compared to evaluate which sites are most favorable for the development of a clean, reliable supply of water.

The third phase of the site-selection process is to finally select the site for the well. Ideally this would be the site that is most favorable in a hydrogeologic sense. Other factors, however, may preclude the use of the most favorable site, including a lack of access, distance to point of use, and competing land use.

SELECTING A SITE FOR A DOMESTIC WELL

The area under consideration for a domestic well is generally only a few acres or less. Consequently, the initial screening that is suggested for selecting a high-yield well site may not be warranted for a domestic well. The first step in the site selection procedure should be to identify potential sources of contamination in the area under consideration and adjacent areas.

Random drilling is likely to produce an adequate domestic supply throughout most of Lamar County. However, in order to decrease the risk of inadequate yield, the topographic positions of potential well sites should be compared. A general procedure that can be used by persons with no geological training has been described in the section on ground-water exploration techniques. In addition to topographic position, the thickness of the regolith should be considered. Although it is not possible to easily measure the regolith thickness without drilling or boring equipment, pavement outcrops and areas with large boulders in the soil can be easily identified and should be avoided as drill sites.

Analysis of low-altitude aerial photographs is recommended in areas where well yields are known to be low. For the selection of a domestic well site, one must identify the photo linears that may be related to discontinuities that provide an avenue for the movement of ground water. Local Agricultural Stabilization and Conservation Service (ASCS) offices maintain several series of low-altitude aerial photographs. Copies of the photos can be ordered through the ASCS.

Selecting a site for a well on a piece of property of one acre or less can present major problems. If a septic system is used on the property, then the area left for the well, after allowing for prescribed minimum separations, is limited. This problem is compounded if septic systems on adjoining parcels are located near the property line. Even without having to maintain the separation from a septic system, the range of sites available for the well on a small piece of property is limited. It is recommended to **always** establish the water supply before initiating construction.

CASE HISTORIES

Attempts to develop a water supply on two pieces of property provide evidence that supports present theories on the selection of well sites. Both of these sites are located within the area of the unnamed schist and gneiss unit, which has lower average yield than other rock units in the county.

Problems have been encountered in developing a reliable domestic supply to replace a dug well at a residence on Galvin Bush Road, just south of US 41. The Appendix includes the records of three wells (numbers 19, 21, and 44, Plate 1) that have been drilled on this property. A fourth drilled well was started on the property, but was abandoned prior to the intended depth owing to the loss of the drilling tools in the hole (Paul Milner, former resident, personal communication). A pavement outcrop is present within 500 feet of each of the wells. None of these wells produced an adequate yield to supply the residence. Figure 17 shows the location of the wells and the pavement outcrop.

An analysis of the well sites based on topography and soil thickness, such as the LeGrand (1967) method, indicates that these sites are not favorable for the development of a reliable water supply. The thin regolith (19 feet based on casing lengths) and proximity to a pavement outcrop suggest that even if a water-bearing discontinuity had been encountered, that the potential for recharge to the well is limited. The existing dug well was eventually replaced by a bored well located at a lower elevation than the three drilled wells. The bored well location was chosen by the property owner so that it would lie along a photo linear detected on low-altitude aerial photographs (Vernon Heinline, property owner, personal communication).

Four wells were drilled to develop a water supply to irrigate a pecan orchard in southern Lamar County. The orchard is located on Finney Lake Road, west of Highway 36. Figure 18 shows the sites of the four wells at the orchard along with three other nearby wells for which records are available (see the Appendix). The approximate location of a photo-linear detected on the high-altitude black-and-white photographs is included on Figure 18. Wells 62, 63, and 64 are all located near the crest of a hill, which means that the potential for recharge to the well is limited. Well 63, and to a lesser extent, well 64 are near minor linear stream segments. Wells 62, 63 and 64 are not particularly favorable sites for a high-yielding well considering the large area that was available. The yields of these wells (from 1 to 4 gpm) would be adequate for a domestic supply, especially considering the volume of water in storage in the deep well bore. However, in terms of supplying water for irrigation, the yields are inadequate.

Well 65, in contrast to wells 62, 63 and 64, is in a location that is favorable both in regard to the occurrence of water-bearing discontinuities and to recharge potential. This well is located next to a photo-linear observed on the high-altitude black-and-white photographs and to the intersection of a linear stream segment with a linear intermittent stream. The linear stream segment is aligned with another linear stream segment across the hill and to the southeast (Figure 18). The combined length of these linear stream segments is 6000 feet. This site, based on the topography and the high-altitude aerial photography is the most favorable site in the pecan orchard. The driller estimates the yield of the well to be 20 gpm. Although this well has a yield that is average with respect to the county as a whole, the yield is nearly double the average for wells in this rock unit. The wells at the pecan orchard produce yields that are in keeping with the relative favorability of the sites.

Three additional wells are plotted on Figure 18. Because well 49 is located next to a long linear stream segment, it occupies a topographic position that is

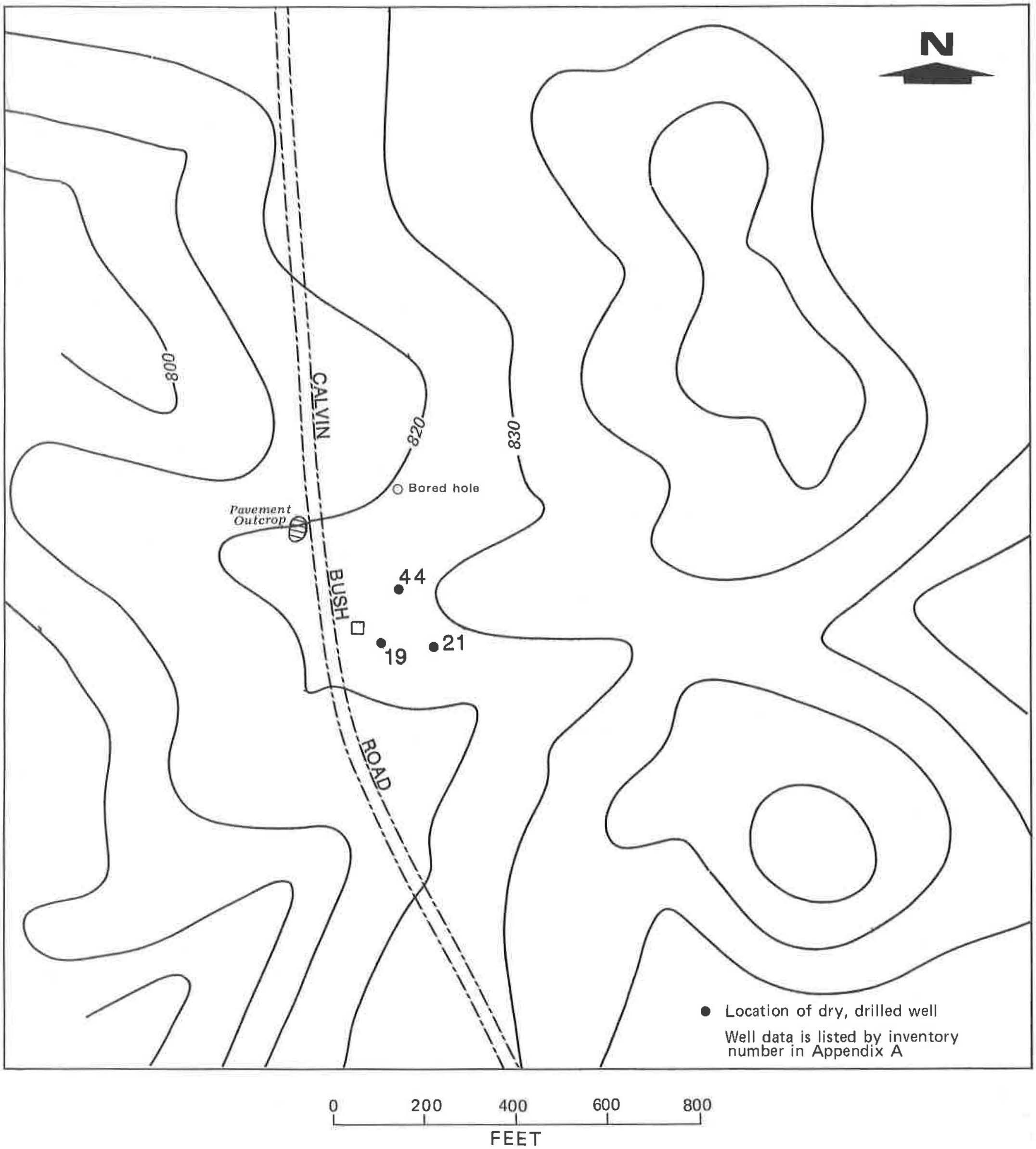
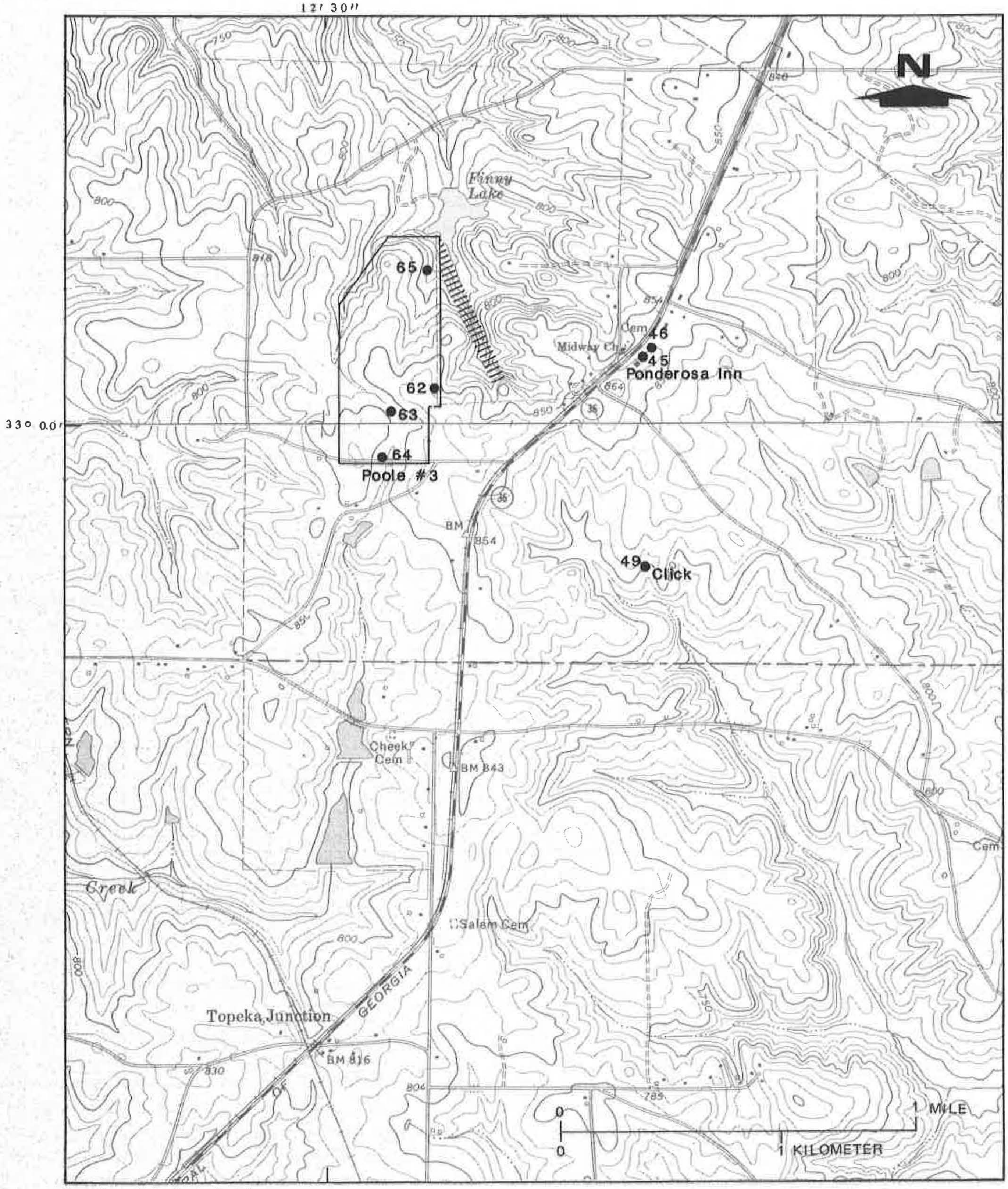


Figure 17. Location map of dry holes in relation to a pavement outcrop, eastern Lamar County.



Base from U.S. Geological Survey
Barnesville, Ga. 1:24,000, 1973
and Yatesville, Ga 1:24,000, 1973

Figure 18. Location of wells drilled to supply water for irrigation, southwestern Lamar County. Orchard to be irrigated is outlined. Shaded area indicates the location of a photo-linear from high-altitude, black-and-white photography. Map from portions of the Barnesville and Yatesville 7.5' U.S. Geological Survey Maps.

more favorable for producing a given supply than wells 45 and 46 or wells 62 and 64. The records of these wells, however, indicate that the yield of wells 45 and 46 are several times the yield of well 49. Therefore, although the apparent favorability of a site can be evaluated, the actual yield cannot be known until a well is drilled.

WELL DEPTH

The average depth of the drilled wells in the inventory is 296 feet. Drilled well depths range from a 53 ft. deep, 30 gpm well (29) to a 780 ft. deep dry hole (44). The percentage of wells falling into a number of depth ranges is indicated as Figure 19. This figure indicates that 59% of the wells in the inventory were 300 feet deep or less. Figure 20 is a plot of well yield versus depth. The random scatter of the data points indicate that well yields correlate poorly with depth. Yields of wells that are 500 feet deep or more, however, are generally low. Similar statistics in other areas led LeGrand (1967) and Snipes and others (1984) to suggest that there is a lower probability of obtaining water at deeper depths. A more likely explanation for the generally low yields of deep wells is that the wells are deep **only** because an adequate yield was not obtained at a shallower depth. The lower yields of the deep wells are probably due to the lack of secondary permeability in that specific area rather than a general decrease in the number of fractures with depth.

The question of how deep to drill a well is one of the most difficult questions in the field of crystalline-rock hydrogeology. LeGrand (1967, p. 5) recommends maximum depths of between 150 to 300 feet. Cressler and others (1983, p. 53) state that drilling beyond 650 feet, without other information, usually can not be justified. Snipes and others (1984, p. 16-20) report well yield statistics indicating a tendency toward higher yield and productivities (yield divided by the open length of the well) at shallower depths. This trend is attributed to decreasing fracture density and opening size with depth (Snipes and others, 1984, p. 20).

Fenix and Scisson, Inc. (1964) conducted a study on the feasibility of constructing a natural gas storage cavern north of Milner. Six core holes were drilled at the site. Fenix and Scission Inc. (1964, p. 7) report that open fractures occurred in all six holes. The test drilling indicated that open fractures are most common from the surface to a depth of approximately 275 feet and below 400 feet to the total depth of the holes. Selected 22 foot intervals were tested with straddle packers to measure the flow rate under a surface gauge pressure of 75 psi. Four of the six test holes had zones that accepted water at a rate that would not allow for a build up of pressure. The flow rates of these zones were not determined, but are known to exceed 0.75 gpm. The high-flow rate zones occurred at depths ranging from 287 to 530 feet. Test depths ranged from 266 to 572 feet. R.D. Bentley's description of core from the test holes (Fenix and Scisson Inc., 1964, Appendix A) notes occurrences of feldspars being altered to kaolinite in each of the holes. The presence of kaolinite indicates considerable groundwater flow through the rock. The data from the propane storage site indicates that avenues of groundwater flow exist at depths exceeding 500 feet in Lamar County. Little data are available concerning the occurrence of ground water at depths exceeding 600 to 700 feet. However, Seeburger and Zoback (1982) note little, if any, decrease in fracture density with depth in wells of 3000 feet or more.

The depth at which to abandon a hole and drill at another location depends on the nature of the site and the conditions encountered. This aspect of well drilling is a common subject of debate for well drillers and geologists. The following general guidelines for domestic wells seem reasonable, based on the data collected and reviewed as a part of this study; however, site-specific conditions may dictate other guidelines. Abandoning a well at a depth of less than 450 feet may be premature. If some water has been obtained, but more water is needed, drilling to depths of 600 feet or more may be appropriate if the rock is exhibiting changes in texture or lithology. Drilling beyond 600 to 700 feet may not be feasible due to high drilling costs; however, ground water may be available beyond those depths. If the yield has increased in the previous hundred feet of drilling, and the well is approaching the desired yield, then continued drilling is advised. In the event that initial efforts are unsuccessful, or if problems are encountered, it is recommended that an experienced ground-water professional be consulted.

CONCLUSIONS

Ground water in Lamar County occurs in discontinuities in the essentially impermeable crystalline rock and in pore spaces in the regolith overlying the rock. Discontinuities in the rock that may provide pathways for the movement of ground water include faults; contacts between rock units; stress relief fractures; and smaller scale structures, such as planes of foliations and joints. Because the primary permeability of the rock is very low, most wells must encounter a discontinuity to produce an adequate yield.

Well records from 69 drilled wells are available in Lamar County. Most of the wells included in the

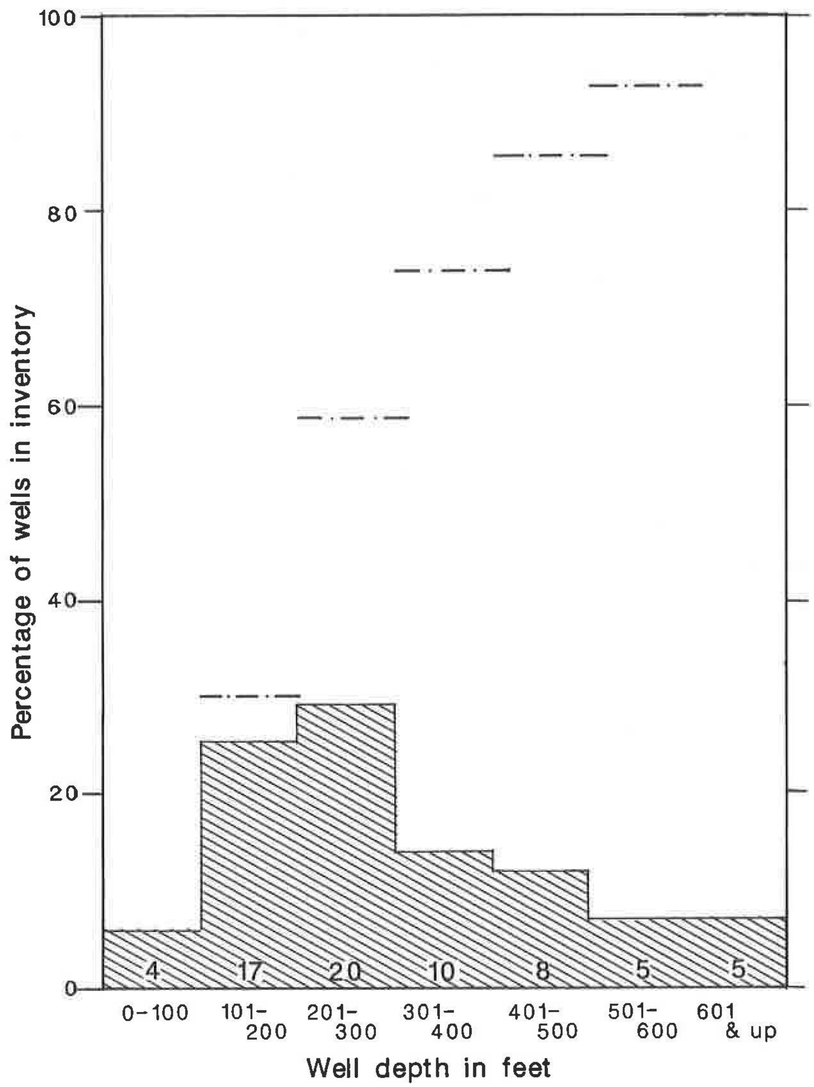


Figure 19. Histogram of the depths of wells included in the well inventory. Both the percentage of wells in the survey and the cumulative percentage of the corresponding depth range and shallower are plotted.

inventory are for domestic use; therefore, few of the wells were drilled for maximum yield. Thus, the data base is skewed toward shallow, low-yield wells drilled at sites that were selected based on convenience. The average yield of the wells in the inventory is 24 gpm. The wells range in depth from 53 feet to 780 feet with an average depth of 296 feet. Well yields in a schist and gneiss unit in the southern half of the county are significantly lower than in rock units elsewhere in the county. Four of the five dry holes noted in the inventory are located in this low-yielding schist and gneiss unit.

The water from drilled wells in Lamar County is of the calcium and sodium bicarbonate type. Total dissolved solids values are generally low. Iron and manganese concentrations exceed the recommended drinking water limits in seven of the twenty-one wells tested. Although the iron and manganese are a nuisance to the well owners, there are no known health risks associated with iron or manganese in ground water. Fluoride concentrations exceeded drinking water limits in two wells. The high fluoride concentrations may result in the mottling of tooth enamel in children.

The drilling of a well in Lamar County, and in the Piedmont province in general, always carries the risk of a dry or nearly dry hole. With adequate storage, however, as little as 1 gpm can supply the needs of a single residence. Careful selection of the location of a well can increase the chances of producing the desired yield. Property owners with no training in geology can compare potential well sites based on

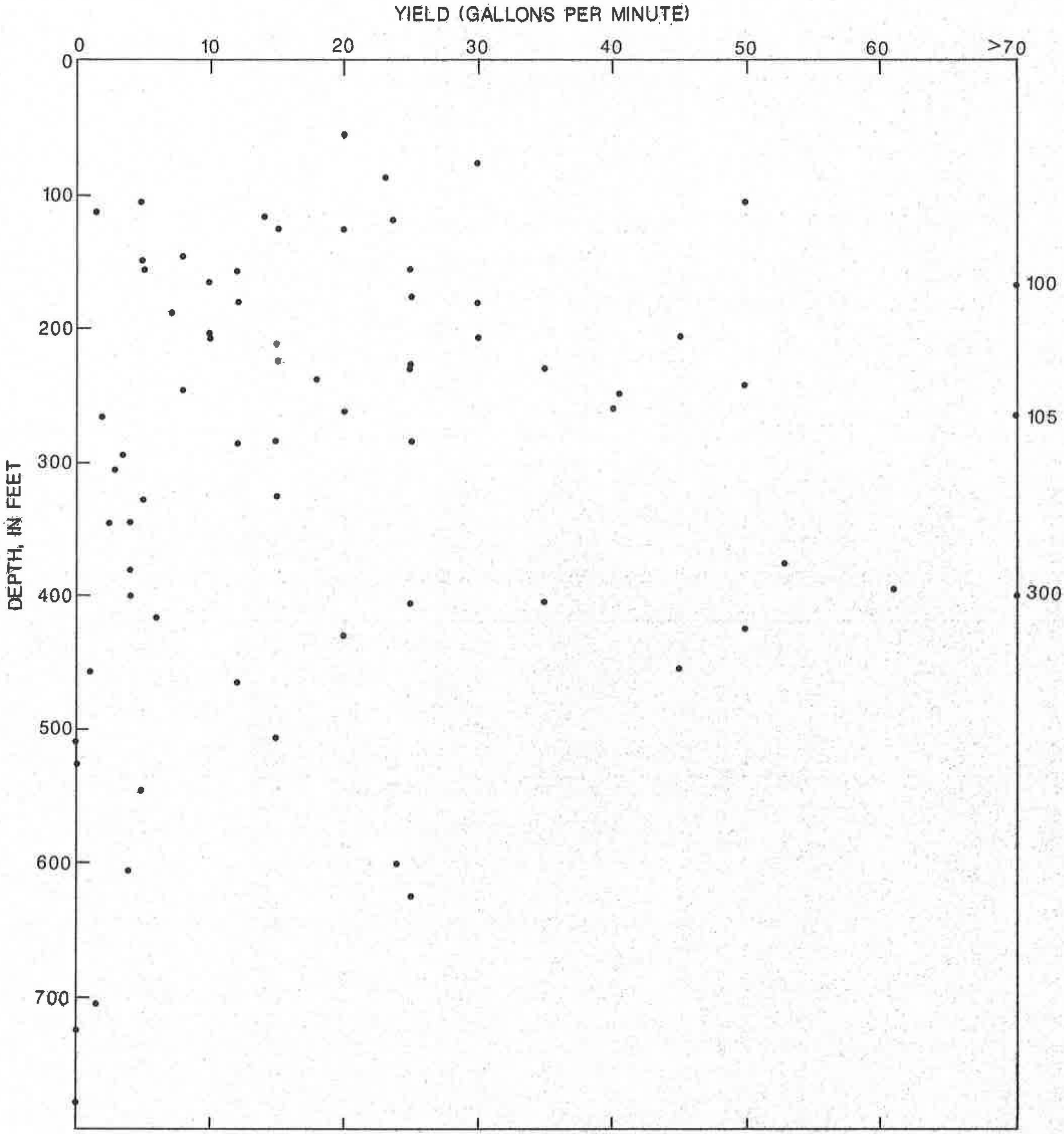


Figure 20. Plot of well yield as a function of total depth.

topography and soil cover. By examining the topography and soil cover of a property, it is possible to identify areas where the discontinuities that control the movement of ground water are more likely to occur. In general a topographically-low site is more likely to produce a desired yield than a topographically-high site.

Linear features can be utilized to identify places where discontinuities in the rock are likely. These linear features may include stream segments, changes in slope, heartiness of vegetation and soil tone. It is important that the linear features be natural and not man-induced. Although the drainage pattern in Lamar County is generally dendritic, the alignment of some smaller streams suggests that there is a degree of underlying geologic control on the location of drainages, and that the drainage systems are not entirely superimposed, if at all.

Electrical resistivity, magnetometry and analysis of aerial photographs can all be helpful in identifying sites for productive wells in a fractured-rock terrain. These methods have been utilized in Lamar County. However, the effectiveness of these methods can not be statistically evaluated because of the limited well data available. In selecting a site for a well, it is important to use as many selection techniques as practical. In this way, the drawbacks of the individual methods can be minimized.

The potential for recharge and the potential for contamination are of critical importance in selecting a well site. The discontinuities that provide pathways for ground-water flow store little water. Therefore, in order for a well to provide a continuous yield, the fractures must be connected to a source of recharge. Water stored in the unconsolidated material overlying the rock is the main source of recharge. Potential recharge increases as the thickness of the unconsolidated cover increases and as the watershed upslope from the well site increases in size. Potential sources of contamination to a drilled well include septic tanks, feed lots, waste impoundments, landfills, and chemical and pesticide storage areas. Maintaining a safe distance from these sources, particularly if the well is down-slope, reduces the risk of well contamination.

The most favorable area for the development of high-yielding wells in Lamar County, based on the information compiled for this report, is in the Towaliga fault zone. Northeast of Barnesville, the Towaliga fault zone is located in the valley of the Little Towaliga Creek, which has a sizeable drainage area. The resistivity studies indicate that the thickness of saprolite may be greater within the fault zone than outside of the fault. The rocks of the Towaliga fault zone include fractured mylonite. The Towaliga fault zone is an area of known shearing which may have produced pathways for ground-water flow. The existence of a number of factors suggesting the presence of discontinuities and the excellent potential for recharge make the fault zone a likely area for the development of high-yielding wells.

REFERENCES

Atkins, R.L., in review, Geology of the granites and gneisses of the Cedar Rock Complex: Georgia Geologic Survey.

Brook, G.A., Sun, C., and Lloyd, T.S., 1984, Geological factors influencing well productivity on the Georgia Piedmont: Technical Completion Report ERC 05-84, Environmental Resources Center, Georgia Institute of Technology, Atlanta, 91 p.

Carrington, T.J., and Watson, D.A., 1981, Preliminary evaluation of an alternate electrode array for use in shallow-subsurface electrical resistivity studies: Ground Water, v. 19, p. 48-57.

Clark, W.Z., and Zisa, A.C., 1976, Physiographic map of Georgia: scale 1:2,000,000, Department of Natural Resources, Geologic and Water Resources Division (Georgia Geologic Survey), Atlanta, Georgia.

Clarke, J.W., 1952, Geology and mineral resources of the Thomaston Quadrangle, Georgia: Georgia Geologic Survey Bulletin 59, 99 p.

Cressler, C.W., Thurmond, C.J., and Hester, W.G., 1983, Ground water in the greater Atlanta region, Georgia: Georgia Geologic Survey Information Circular 63, 144 p.

Crickmay, G.W., 1952, Geology of the crystalline rocks of Georgia: Georgia Geologic Survey Bulletin 58, 54 p.

Favilla, L.J., 1985, A gravity survey of Lamar County, Georgia: Georgia Geologic Survey Open-File Report 86-3, 33 p.

Fenix and Scisson, Inc., 1964, Feasibility report, mined LP gas storage cavern for Dixie Pipeline Company: unpublished consulting report, 120 p.

Furcron, A.S. and Teague, K.H., 1943, Mica-bearing pegmatites of Georgia: Georgia Geologic Survey Bulletin 48, 192 p.

Grant, W.H., 1967, Geology of the Barnesville area and Towaliga fault, Lamar County, Georgia: Georgia Geologic Survey Guidebook 6, 16 p.

Harmon, D.H., Watson, D.A., and Duffey, T., 1984, Georgia's Piedmont ground water: Water Well Journal, v. 38, p. 33-38.

Hem, John D., 1985, Study and interpretation of the chemical characteristics of natural water, 3rd ed.: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hewett, D.F., and Crickmay, G.W., 1939, The warm springs of Georgia, their geologic relations and origin, a summary report: U.S. Geological Survey Water-Supply Paper 819, 37 p.

Higgins, M.W., and Atkins, R.L., unpublished, Geological maps of the Griffin and Thomaston, Georgia, scale 1:100,000 quadrangles. On file at the U.S. Geological Survey, Doraville office.

Higgins, M.W., and Atkins, R.L., 1981, The stratigraphy of the Piedmont southeast of the Brevard zone in the Atlanta, Georgia area, *in* Wigley, P.B., ed., Latest thinking on the stratigraphy of selected areas in Georgia: Georgia Geologic Survey Information Circular 54-A, p. 3-40.

Higgins, M.W., Atkins, R.L., Crawford, T.J., Crawford, R.F., III, and Cook, R.B., 1984, A brief excursion through two thrust stacks that comprise most of the crystalline terrain of Georgia and Alabama: Georgia Geologic Society 19th Annual Field Trip Guidebook, Atlanta, 67 p.

Jammallo, J.M., 1984, Use of magnetics to enhance identification of bedrock fracture trace zones for well locations, *in* Nielson, D.M., and Curl, M., eds., NWWA/EPA conference on surface and borehole geophysical methods in ground water investigations: National Water Well Association, Worthington, Ohio, p. 105-133.

LaForge, L., Cooke, W., Keith, A., and Campbell, M.R., 1925, Physical geography of Georgia: Georgia Geological Survey Bulletin 42, 189 p.

LeGrand, H.E., 1967, Ground water of the Piedmont and Blue Ridge Provinces in the Southeastern States: U.S. Geological Survey Circular 538, 11 p.

Lehr, J.H., Gass, T.E., Pettyjohn, W.A. and DeMarre, J., 1980, Domestic water treatment: McGraw Hill, New York, 264 p.

North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: American Association of Petroleum Geologists Bulletin, v. 67, p. 841-875.

Office of Planning and Budget, 1983, Population projections for Georgia counties, 1990 and 2000, Atlanta, p. 9.

Penley, H.M., and Sandrock, G.S., unpublished, Reconnaissance geological map of Lamar County, scale 1:63,360. On file at the Georgia Geologic Survey, Atlanta.

Scarbrough, W.L., Joiner, T.J., and Warman, J.C., 1969, Electrical resistivity survey in the Piedmont area, Alabama: Geological Survey of Alabama Circular 57, 20 p.

Seeburger, D.A., and Zoback, M.D., 1982, The distribution of natural fractures and joints at depth in crystalline rock: Journal of Geophysical Research, v. 87, p. 5517-5534.

Snipes, D.S., Barnett, L.L., Wylie, J.A., Sacks, L.A., Heaton, S.B., Dalton, G.A., Israel, B.A. and Padgett, G.G., 1984, Indicators of ground water quality and yield for a public water supply in rock fracture zones of the Piedmont: Water Resources Research Institute Report 115, Clemson University, 80 p.

Stafford, D.B., Ligon, J.T., and Snipes, D.S., 1983, Fracture trace mapping and water well yield in the Piedmont region of South Carolina: Water Resources Research Institute, Report 112, Clemson University, 66 p.

Staheli, A.C., 1976, Topographic expression of superimposed drainage on the Georgia Piedmont: Geological Society of America Bulletin, v. 87, p. 450-452.

Stieve, A.L., 1984, Petrologic variation of the granulites and related gneisses of the Pine Mountain Terraine, Georgia: unpublished M.S. thesis, Emory University, Atlanta, 107 p.

Stewart, J.W., 1964, Infiltration and permeability of weathered crystalline rocks, Georgia Nuclear Laboratory, Dawson County, Georgia: U.S. Geological Survey Bulletin 1133-D, 59 p.

U.S. Bureau of the Census, 1982, 1980 census of population, volume 1, characteristics of the population, Chapter A, number of inhabitants, part 12, Georgia: U.S. Department of Commerce, p. 9.

Voytek, J., Jr., 1986, Hard drilling through hard rock: Water Well Journal, v. 40, p. 57-59.

Watson, T.W., 1984, Hydrogeology of Greene, Morgan and Putnam Counties: Georgia Geologic Survey Information Circular 60, 16 p.

Wilson, G.V., Joiner, T.J., and Warman, J.C., 1970, Evaluation, by test drilling, of geophysical methods used for ground water development in the Piedmont area, Alabama: Geological Survey of Alabama Circular 65, 15 p.

Subsequent to the preparation of this report the Zebulon, Ison Branch, and Barrow Hill formations were formally described in: Higgins, M.W., Atkins, R.L., Crawford, T.J., Crawford, III, R.F., Brooks, R., and Cook, R.B.: U.S. Geological Survey Professional Paper 1475, 173 p.

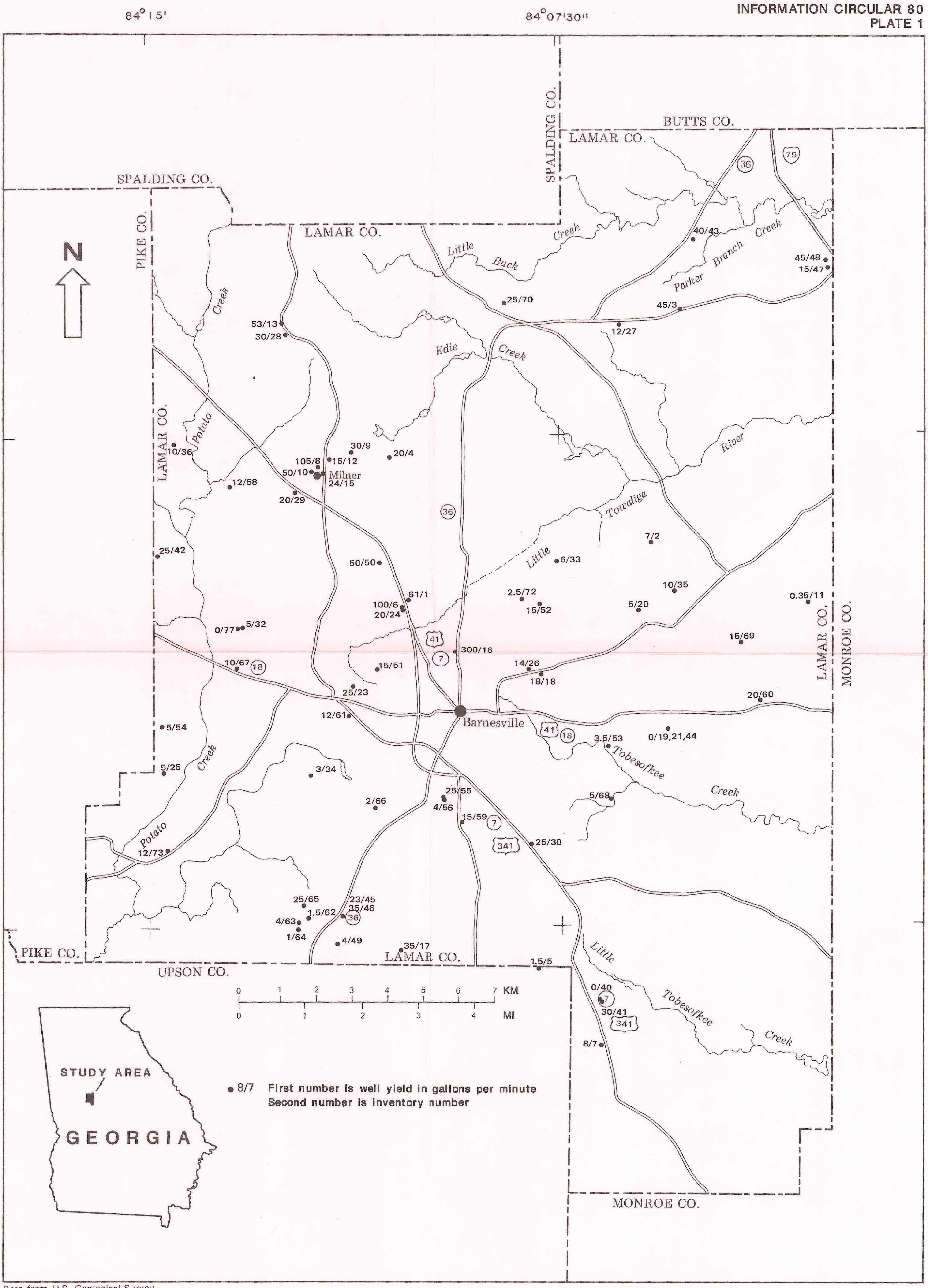
APPENDIX — WELL RECORDS

Inventory Number	Owner	Latitude	Longitude	Depth (feet)	Diameter (inches)	Casing Length (feet)	Yield (gpm)	Specific Capacity (gpm/ foot of drawdown)	Year Drilled	Driller	U.S.G.S. Well Number
1	Barnesville Community Park	33° 05′ 01″	84° 10′ 19″	395	6	97	61	0.31	1971	Unknown	12Y003
2	Paul Milner	33° 05′ 49″	84° 05′ 51″	187	6	90-100	7	-	1963	Waller	13Y001
3	Crystal Springs Park	33° 09′ 24″	84° 05′ 17″	205	6	70	45	-	-	Askew Morris	13Z001
4	Kendall's Mobile Home Park	33° 07′ 09″	84° 10′ 35″	124	6	65	20	-	-	Waller	12Y004
5	Copeland Milner	32° 59′ 22″	84° 07′ 55″	112	6	25	1.5	0.14	1961	Va. S & W.	12X002
6	Liz Acres Subdivision	33° 04′ 58″	84° 10′ 25″	165	8	-	100	-	1946	Va. S & W.	12Y005
7	W.C. Hudgins	32° 58′ 08″	84° 06′ 48″	144	6	85	8	-	1956	Va. S & W.	13X001
8	Milner School	33° 07′ 02″	84° 11′ 56″	263	6	87	102	1.27	1945	Va. S & W.	12Y001
9	Herman Davis	33° 07′ 14″	84° 11′ 20″	180	6	77	30	0.75	1951	Va. S & W.	12Y045
10	Maude Wilson	33° 06′ 56″	84° 12′ 02″	241	6	62	50	1.43	1951	Va. S & W.	12Y006
11	J.E. Trice	33° 04′ 54″	84° 12′ 59″	100	6	34	0.35	-	1944	Va. S & W.	13Y002
12	J.J. Darden	33° 07′ 08″	84° 11′ 44″	225	8	86	15	0.15	1945	Va. S & W.	12Y007
13	U.S. Engineers #1	33° 09′ 13″	84° 12′ 34″	375	8	120	53	0.41	1942	Va. S & W.	12Z003
15	City of Milner	33° 07′ 00″	84° 11′ 48″	600	6	90	23.7	0.14	1965	Va. S & W.	12Y008
16	City of Barnesville	33° 04′ 11″	84° 09′ 22″	400	6	30	300	-	1908	Unknown	13Y009
17	Jim Graham	32° 59′ 30″	84° 10′ 22″	230	6	34	35	-	1978	Waller	12X003
18	Joe McGaha	33° 03′ 52″	84° 07′ 54″	238	-	34	18	0.2	1951	Va. S & W.	12Y010
19	E.C. Milner	33° 02′ 57″	84° 05′ 34″	509	6	-	0	-	1951	Va. S & W.	13Y003
20	Paul Milner	33° 04′ 51″	84° 06′ 05″	148	6	104	5	0.05	1950	Va. S & W.	13Y004
21	E.C. Milner	33° 02′ 57″	84° 05′ 34″	355	6	19	0	-	1950	Va. S & W.	13Y005
23	Major Andrews	33° 03′ 40″	84° 11′ 16″	154	6	95	25	-	1950	Va. S & W.	12Y011
24	B. Lloyd Woodall	33° 04′ 57″	84° 10′ 23″	260	6	147	20	0.67	1948	Va. S & W.	12Y012
25	Dr. S. B. Taylor	33° 02′ 22″	84° 14′ 47″	328	6	56	5	-	1946	Va. S & W.	12Y013
26	F.J. Stocks	33° 03′ 54″	84° 08′ 04″	116	6	38	14	-	1943	Va. S & W.	12Y014
27	M.L. Ball	33° 09′ 13″	84° 06′ 24″	157	6	64	12	0.08	1951	Va. S & W.	13Z002
28	U.S. Engineers #2	33° 09′ 04″	84° 12′ 30″	76	8	28	30	-	1942	Va. S & W.	12Z004
29	Ruth Martin	33° 06′ 38″	84° 13′ 34″	43	6	32	20	0.5	1950	Va. S & W.	12Y018
30	341 Mobile Home Park	33° 01′ 11″	84° 08′ 01″	225	6	105	25	-	1967	Waller	12Y019
32	Triple H. Farms	33° 04′ 39″	84° 13′ 17″	545	6	40	5	-	1981	Waller	12Y020
33	Mrs. Fred Hand	33° 05′ 34″	84° 07′ 35″	415	6	51	6	-	1981	Waller	12Y021
34	William Lovejoy	33° 02′ 17″	84° 12′ 03″	305	6	46	3	-	1981	Waller	12Y022
35	Jerry Hayes	33° 05′ 06″	84° 05′ 25″	205	6	25	10	-	1981	Waller	13Y006
36	W.A. Rowell	33° 07′ 21″	84° 14′ 35″	205	6	35	10	-	1981	Middle GA	12Y023
40	Roger Legg	32° 58′ 50″	84° 06′ 46″	525	6	-	0	-	1979	Waller	13X002
41	Roger Legg	32° 58′ 49″	84° 06′ 46″	205	6	30	30	-	1979	Waller	13X003
42	Rex Coplen	33° 05′ 43″	84° 14′ 52″	285	6	86	25	-	1979	Waller	12Y024

APPENDIX — WELL RECORDS/Continued

Inventory Number	Owner	Latitude	Longitude	Depth (feet)	Diameter (inches)	Casing Length (feet)	Yield (gpm)	Specific Capacity (gpm/ foot of drawdown)	Year Drilled	Driller	U.S.G.S. Well Number
43	United Pentecostal Church	33° 10′ 24″	84° 05′ 02″	260	6	80	40	-	1979	Waller	13Z003
44	Vernon Hineline	33° 02′ 58″	84° 05′ 34″	780	6	18	0	-	1971	Askew Morris	13Y007
45	Ponderosa Inn	33° 00′ 09″	84° 11′ 33″	87	6	30	23	-	1961	Adams	12Y025
46	Ponderosa Inn	33° 00′ 09″	84° 11′ 34″	405	6	35	35	-	1977	Middle GA	12Y026
47	Jellystone Park	33° 10′ 02″	84° 02′ 34″	505	6	57	15	0.07	1970	Va. S & W.	13Z004
48	Jellystone Park	33° 10′ 10″	84° 02′ 39″	455	6	52	45	0.75	1970	Va. S & W.	13Z005
49	George Click	32° 59′ 39″	84° 11′ 34″	345	-	-	4	-	1984	Bedsole	12X004
50	Donnie Wallace	33° 05′ 34″	84° 10′ 46″	425	6	19	50	-	1984	Interstate	12Y027
51	Beamer Donahoe	33° 03′ 56″	84° 10′ 51″	125	6	-	15	-	1974	Aqua	12Y028
52	Tom Bodkins	33° 04′ 55″	84° 07′ 52″	325	6	85	15	-	1984	Va. S & W.	12Y029
53	Billy Weaver	33° 02′ 43″	84° 06′ 39″	294	6	20	3.5	-	1979	Bedsole	13Y008
54	C.B. Cole	33° 03′ 04″	84° 14′ 46″	165	6	-	5	-	1971	Bedsole	12Y030
55	Charley Jones	33° 01′ 58″	84° 09′ 39″	405	6	68	25	-	1977	Askew-Morris	12Y031
56	Donald Royal	33° 01′ 56″	84° 09′ 39″	400	6	-	4	-		Va. S & W.	12Y032
58	William Key	33° 06′ 35″	84° 13′ 30″	180	6	40	12	-	1985	Bedsole	12Y033
59	H.S. Turner	33° 01′ 33″	84° 09′ 19″	210	6	201	15	0.11	1968	Va. S & W.	12Y034
60	Jeff Baker	33° 03′ 23″	84° 03′ 46″	430	6	-	20	-		Morgan	13Y009
61	Milton Pritchett	33° 03′ 14″	84° 11′ 21″	465	6	11	12	-	1974	Askew-Morris	12Y035
62	Harry Poole #1	33° 00′ 05″	84° 12′ 11″	705	6	30	1.5	-	1985	Va. S & W.	12Y036
63	Harry Poole #2	33° 00′ 01″	84° 12′ 17″	605	6	58	4	-	1985	Va. S & W.	12Y037
64	Harry Poole #3	32° 59′ 55″	84° 12′ 20″	465	6	7	1	-	1985	Va. S & W.	12Y005
65	Harry Poole #4	33° 00′ 23″	84° 12′ 12″	625	6	20	25	-	1985	Va. S & W.	12Y038
66	Marion Underwood	33° 01′ 49″	84° 10′ 53″	265	6	42	2	-	1956	Va. S & W.	12Y039
67	Carl Sawyer	33° 03′ 56″	84° 13′ 27″	165	6	-	10	-	1966	Waller	12Y040
68	Joseph Bush	33° 01′ 54″	84° 06′ 38″	104	6	-	5	-	1967	Waller	13Y010
69	Robert Paris	33° 04′ 25″	84° 04′ 14″	285	6	-	15	-	1986	Waller	13Y011
70	Dan Faulkerson	33° 09′ 28″	84° 08′ 32″	175	6	-	25	-	1986	Morgan	12Z006
72	Dale Vaughn	33° 05′ 00″	84° 08′ 11″	345	6	50	2.5	-	1986	Waller	12Y041
73	Mt. Pleasant Baptist Church	33° 01′ 11″	84° 14′ 49″	285	6	100	12	-	1986	Middle GA	12Y042
74	Tony Mark Turner	33° 00′ 23″	84° 11′ 56″	245	6	-	8	-	1986	Askew-Morris	12Y043
75	Sarah Lemmons	33° 10′ 20″	84° 12′ 27″	230	6	104	25	-	1986	Askew-Morris	12Z005
76	Billie Sue Bean	33° 11′ 33″	84° 07′ 08″	105	6	-	50	-	1986	Askew-Morris	13Z006
77	Triple H. Farms	33° 04′ 39″	84° 13′ 15″	725	6	-	0	-	1981	Waller	12Y040

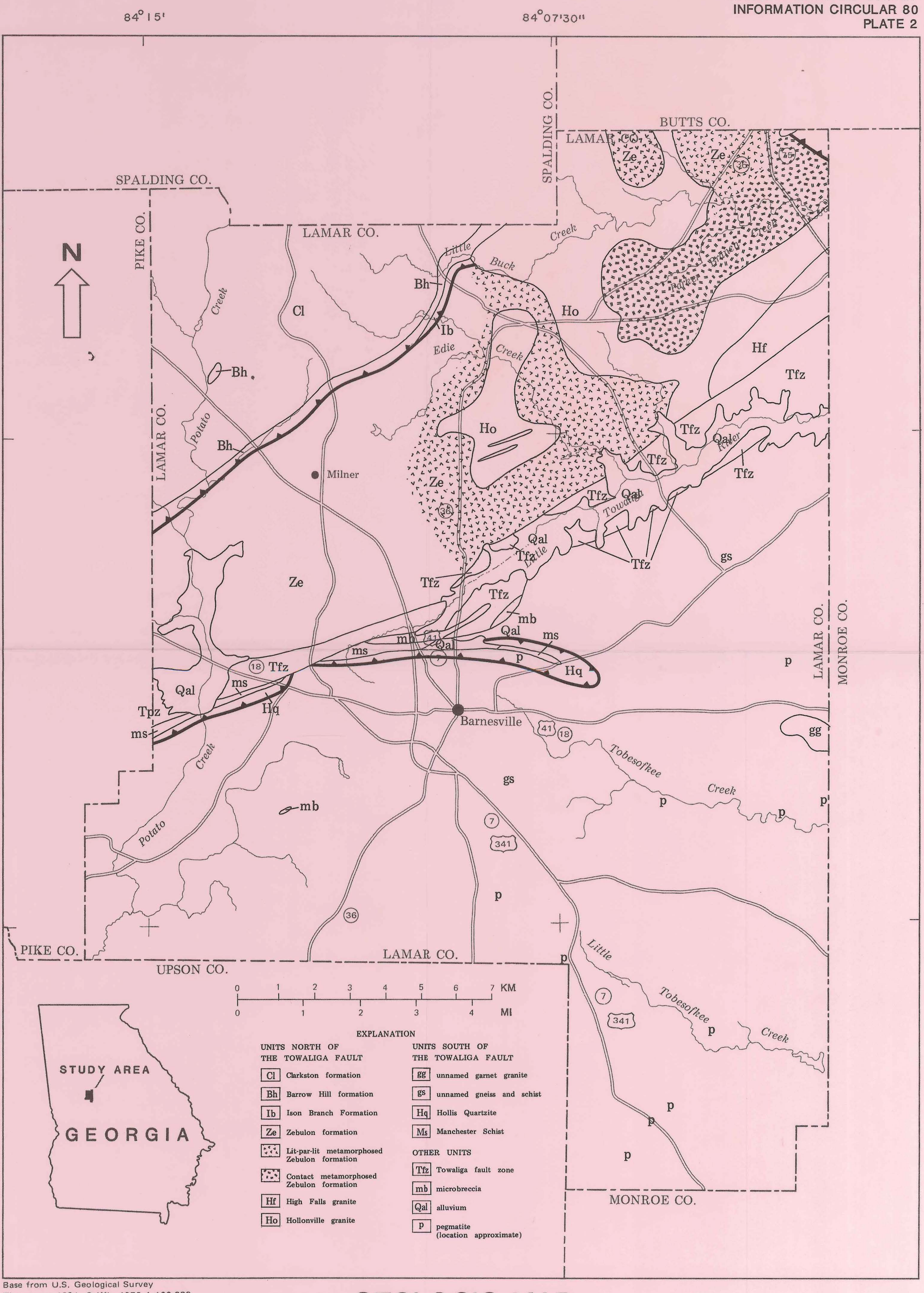
United States Geological Survey well numbers are included in the Appendix to enable cross referencing between the two sets of well numbers. The U.S. Geological Survey assigns well numbers based on their Index to Topographic Maps of Georgia. Each quadrangle is designated by a number and letter. Letters increase alphabetically northward with I and O omitted. Numbers increase eastward. Wells are numbered consecutively within each quadrangle. For example, well 12Y003 is the third well inventoried in the Barnesville quadrangle, and corresponds to inventory number 1 of this report.



Base from U.S. Geological Survey
Thomaston 1981, Griffin 1979 1:100,000

WELL LOCATION MAP

GEORGIA GEOLOGIC SURVEY
INFORMATION CIRCULAR 80
PLATE 2



Base from U.S. Geological Survey
Thomaston 1981, Griffin 1979 1:100,000

GEOLOGIC MAP