SOUTH CAROLINA WATER RESOURCES COMMISSION

GEOLOGY - HYDROLOGY DIVISION

# SIX-MONTH INTERIM REPORT FOR SCWRC-USGS COOPERATIVE PROJECT:

# EVALUATION OF THE USE OF SURFACE GEOPHYSICS, GEOMORPHIC DATA, AND REMOTE SENSING METHODS TO PREDICT YIELDS OF GROUND WATER FROM PIEDMONT AQUIFERS IN SOUTH CAROLINA

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# INTRODUCTION

This interim report describes the work undertaken during the first 6 months (January - June 1988) of this cooperative project. Presented are preliminary findings, problems encountered and proposed or implemented solutions, and the proposed direction of work for the next 12 months.

## Purpose of Investigation

The project is being undertaken, as described in detail in the Project Proposal, Appendix 1, to evaluate ground-water exploration methods applicable in the Piedmont. Reasonable water supplies for public supply and industry can be obtained in the Piedmont if properly located. If successful and cost-effective exploration methods can be demonstrated, potential ground-water users could be encouraged to utilize that resource for their primary or back-up water supply.

## Objectives

The project objectives include:

- selection of a small drainage basin in which to test various ground-water exploration techniques and make low-flow studies of streams;
- inventory of wells in the basin;
- lithologic-geomorphic terrain analysis;
- remote sensing lineament mapping;
- surface geophysical surveys;
- analysis of the results;
- develop a ground-water availability map and test it with well-inventory data;
- evaluation of exploration methods.

## Acknowledgments

The authors acknowledge the cooperation and assistance of the following people during this portion of the project: U.S. Geological Survey personnell: Barry Smith, for his project coordination efforts with the Commission; J. C. Hare, for assistance in all aspects of the surface geophysical work; Larry Harrelson, for his work with the well inventory and field assistance in the surface geophysical surveys; Pete Haeni, for assistance in developing the surface geophysical applications for the project and the extensive training provided; Glenn Patterson, for helping shape the workplan; Sydney Poole and Ellen Satterfield for their well inventory work; the USGS in general for it's loan of the various surface geophysical instruments.

# DESCRIPTION OF WORK

The work described below was outlined in the workplan developed in December 1987 and listed in Appendix 2. Some of the objectives were met, but others, for reasons described in each section below, were not. The topics below are in the order presented in the workplan and are roughly in the order in which they were addressed in the study.

## DRAINAGE BASIN SELECTION

The first task of the project was the selection of the drainage basin in which to conduct the study. Since the project includes low-flow analysis of streamflow records, the geographic polygon of choice was a small drainage basin. Table 1 lists the 12 drainage basins considered, located on Figure 1, and the 14 areas of comparison. Also shown are a rating of each basin and a ranking of the top four basins.

The maximum drainage basin size considered was 25 $mi^2$ (square miles). Anything larger would make low-flow relationship with ground water baseflow contribution difficult to detect and make for very large and extensive surface geophysical surveys. As it turned out, the 8 $mi^2$ basin chosen was too large to survey completely, given the elementary stage of the staff's competence with the surface geophysical equipment.

The mere existence of a streamflow gage with 5 to 7 years of record did not insure good data. The U.S. Geological Survey staff responsible for streamflow gages were interviewed concerning the gages of interest and their records. The gage and the stream channel conditions were considered as well as the quality of the records. A mostly rural basin was considered to be better suited for analysis of natural streamflow response and detection of the ground-water component. Urbanized basins have greatly modified streamflow and thus are not acceptable for this study.

The terrain roughness and vegetative cover were important matters affecting the geophysical surveys. Steep terrain would adversely impact the surveys because results are best in flat terrain. Heavy vegetation would physically impede the surveys. It was learned during the surveys that sites clear of vegetation in January can become overgrown in June. Because of this and the heat, humidity, insects, and poison ivy, the best time to do surveys in South Carolina would be mid- to late fall and late winter to mid-spring. Late-fall to late winter could be too cold and wet.

Accessibility of the basin involved both the quality roads and distance from the office as well as access around and through the basin. A rural basin relatively close to Interstate 85 or 26 would allow the easiest access for a moderately distant basin. More than 15 miles of secondary or in-town roads would lessen a basin's desirability. A basin with little access around and through it would make it difficult to reach potential survey sites. Conversely, a high density of roads generally brought with it a higher degree of urbanization and its metallic and electronic interference to the surface geophysical equipment.

Property ownership was important to the study because of the need to access survey sites repeatedly. In the rural areas much of the open land was probably being used for agricultural, which could limit access to survey sites and possibly damage any survey flags set up for future surveys. Well drilling on private property could greatly complicate the process of conducting the study. State or federally owned property would pose fewer problems in this regard.

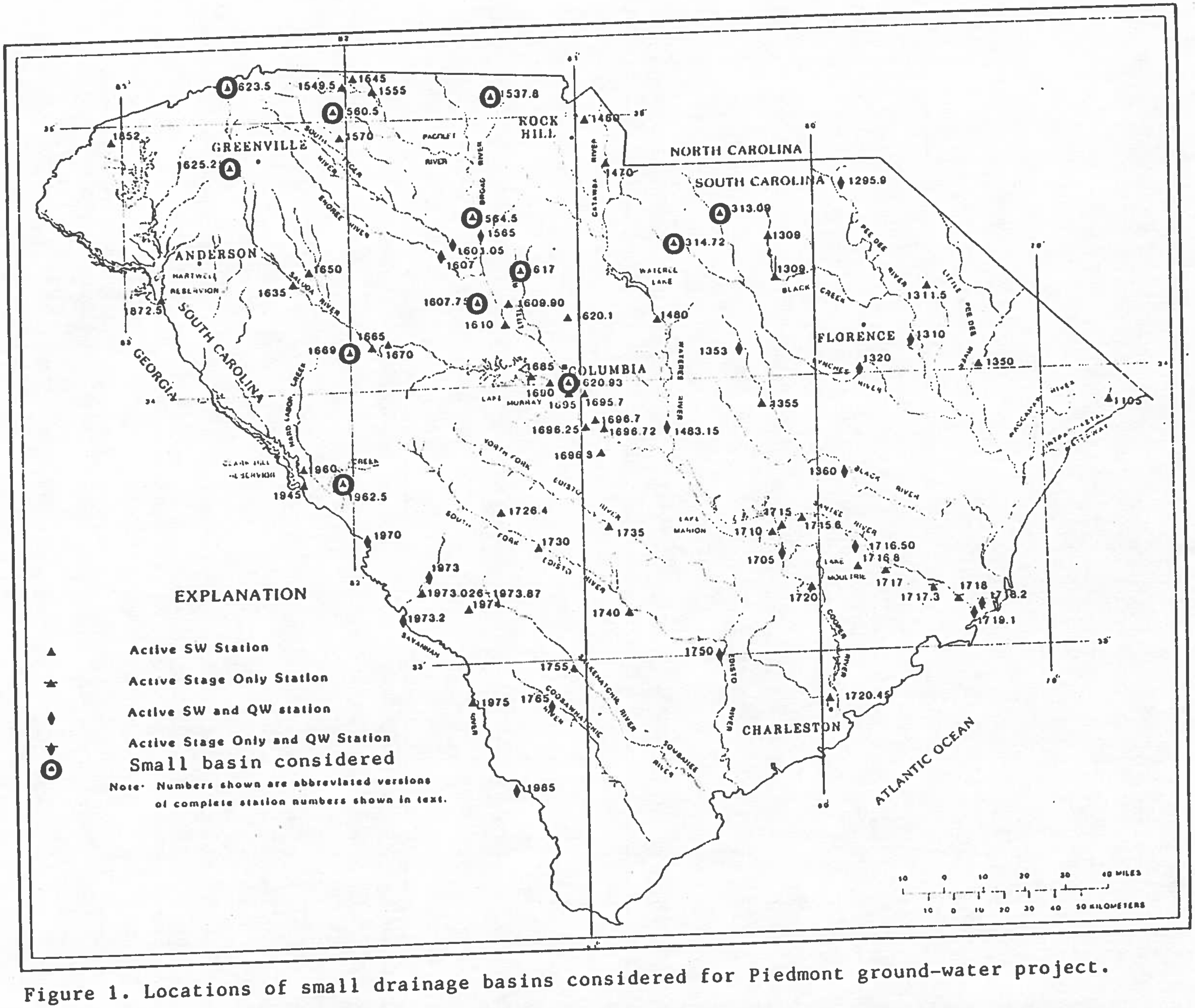


Figure 1. Locations of small drainage basins considered for Piedmont ground-water project.

1987-88 SCWRC - USGS PIEDMONT COOP PROJECT: Phase I Evaluation Table.

| RANK | GAGE NO. | GAGE NAME | DRAIN AREA (Sq.Mi.) | COUNTY | PERIOD of RECORD | YEARS | GAGE and RECORD NOTES | GEOLOGIC MAPPING |  | URBAN | ROAD MILES from OFFICE |  |  |  | ACCESSIBILITY | BASIN OWNERSHIP |  |  | AIR PHOTO COVERAGE | LANDSAT | SLAR | SPOT |  |  | PUBLIC SUPPLY | # OF WELLS | GRID | RATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  | Belt | Map Author and Date | % | Primary | Secondary | Cnty/City | Total |  | FED | STATE | PRIV |  | Path Row | Map | R | J | N |  |  |  | (* = detractions) |
| 3 | 20153780 | Clarks Fork nr Smyrna | 24.1 | York | 10/80 to CY | 7 | Good; no high end. | KMb | Horton, J. W., Jr., 1977<br>Horton and others, 1981<br>Butler and Siple, 1966 | 5 | 53 | 10 |  | 63 | Good; around and thru.<br>* heavy - mod woods. | 20 | 40 | 40 | BW; 4/81; 1:40,000;ASCS | 18 - 36 | Charlotte | 344(R) | 279 | 308 | None in Basin | Many; houses, trailors. | 35B | Good; mapping, access ownership, wells;<br>*woods |
| 4 | 20156050 | Lawsons Fork Creek nr Inman | 6.46 | Spartanburg | 10/79 to CY | 8 | Good; moderately urbanized, wastewater discharges. | IPb (MpCs) | Griffin, V. S., Jr., 1977<br>Bloxham and others, 1970<br>Goldsmith, R., 1981 | 60 | 16 | 7.1 | 3 | 26.1 | Good; many roads crossing<br>* Mod woods, some open |  |  | 100 | CIR; 5/81; 1:24,000;SCFC<br>BW; 1/77; 1: 4,800;SPCOPC | 19 - 36 | Knoxville | 344(L) | 280 | 308 | Inman-Campob.WD | Few; | 43-44C | Good-; Access, mapping, open area.<br>* urban, ownership |
|  | 20156450 | Neal Creek nr Carlisle | 12.3 | Union | 10/80 to CY | 7 | Fair to Good; backwater from Broad River. | Cb | Schaeffer, M. F., 1981<br>Wagener and Howell, 1973<br>O & B, 1965 | 5 | 4.8<br>20 | 58.2<br>38.5 | 4.8<br>4.8 | 67.8<br>63.1 | Fair; road around, few roads into basin.<br>* heavy - mod woods. | 95 |  | 5 | CIR; 5/81; 1:24,000;SCFS<br>BW; 2/81; 1:40,000;ASCS | 18 - 36 | (Spart) | 344(R) | 280 | 308 | Part-T of Union | Few; periphy | 36-37G | Fair-; mapping, ownership<br>* access, wells, woods, gage. |
| 1 | 20160775 | Hellers Creek nr Pomaria | 8.16 | Newberry | 10/80 to CY | 7 | Fair to Good; sandy bottom and shifting channel shape. | Cb | McCauley, J. F., 1961<br>O & B, 1965 | 5 | 59 | 6.1 | 0.8 | 65.9 | Good; around and thru.<br>* Mod woods, some open. | 90 |  | 10 | BW; 1/81; 1:40,000;ASCS<br>BW; 2/76; 1: 4,000;NEWCO | 18 - 36 | (Spart) | 344(R) | 281 | 308 | ? Part-NCWSAuth | Moderate; on roads. | 36K | Good; Access, mapping, ownership, gage, wells.<br>* channel, woods. |
|  | 20161700 | West Fork Little River nr Salem Crossroads | 25.5 | Fairfield | 10/80 to CY | 7 | Poor to Good; 2 channels, one gaged; main flow switches between two. | CSb | O & B, 1965 | 5 | 59 | 21.4 | 2.5 | 82.9 | Fair; road around, few roads into basin.<br>* Heavy - mod woods |  |  | 100 | BW; 1/81; 1:40,000;ASCS<br>BW; 3/76; 1: 4,800;FAIRCO | 18 36 | (Spart) | 273(L) | 281 | 309 | Part-Mid County W C | Moderate; around & up end. | 34I & J | Poor;<br>* gage, access, distance, ownership, mapping, wood |
|  | 20162093 | Smith Branch at N Main Street | 5.67 | Richland | 10/76 to CY | 10 | Fair to good; low flow gaging probs; highly urbanized. | CSb & K | Secor and Wagener, 1968<br>O & B, 1965 | 95 | 93 |  | 6 | 99 | Good; far from office, heavy road covering.<br>* urban, fences, etc. |  | 10 | 90 | CIR; 5/81; 1:24,000;SCFC<br>BW; 3/81; 1:80,000;USGS/NHAP<br>BW; 3/79; 1: 4,800;RICHCO | 18 - 36 | (Spart) | 273(L) | 282 | 309 | All-City of Columbia | Few; urban, cit | 300 | Fair-; Mapping, access.<br>* Urban, gage, distance, ownership, wells. |
|  | 20162350 | Middle Saluda R. nr Cleveland | 21 | Greenville | 10/80 to CY | 7 | Fair to good; flashy flows. | BR | Koch, Neil C., 1968<br>O & B, 1965 | 5 |  | 21.6 | 3.8 | 25.4 | Fair; steep terrain limit roads to valley; some tr<br>*steep, wooded; valley OK |  | 30 | 70 | CIR; 5/81; 1:24,000;SCPC<br>BW; 2/80; 1: 4,800;GRCO<br>BW; 3/79; 1:40,000;ASCS | 19 - 36 | Knoxville | 46(L) | 280 | 307 | none | Moderate; along valley. | 48-50B | Fair; distance, gage;<br>* terrain, access, owners mapping. |
|  | 20162525 | Hamilton Creek nr Easley | 1.6 | Pickens | 2/81 to 1986 | 5 | Poor to fair; discontinued. | IPb | Cazeau and Brown, 1963<br>O & B, 1965 | 80 |  | 8.1 | 3.6 | 11.7 | Good; many roads thru.<br>* open but urbanized. |  |  | 100 | CIR; 5/81; 1:24,000;SCFC<br>BW; 6/79; 1:40,000;ASCS<br>BW; 3/76; 1: 4,800;PICKEN | 19 - 36 | Greenville | 46(L) | 280 | 307 | All-Combined Utiliti | Few ?; urban. | 49E | Poor; distance, access.<br>* gage, urban %, mapping ownership, wells. |
| 2 | 20166970 | Ninety Six Cr. nr Ninety Six | 17.4 | Greenwood | 10/80 to CY | 7 | Fair; beaverdams downstream backwater gage. | KMb & Cb | Chalcraft and others, 1978<br>O & B, 1965 | 20 |  | 65.8 | 0.5 | 66.3 | Good; around and several roads through.<br>*much of basin open field |  |  | 100 | CIR; 3/81; 1:58,000;ASCS/NHAP<br>BW; 1/80; 1: 4,800;GREEN<br>BW;10/79; 1:40,000;ASCS | 19 - 36 | Grv/(Spa) | 344(L) | 282 | 308 | none | Mod-Many; around & through. | 42N,O | Good-; access, mapping, fields, wells ?.<br>*Ownership, gage?, dist?. |
|  | 20196250 | Horn Creek nr Colliers | 13.9 | Edgefield | 10/80 to CY | 7 |  | Kb & K | O & B, 1965 | ? |  | 84.4 | 9.4 | 94.2 | Fair; few roads thru, not completely around. |  |  | 100 | CIR; 3/81; 1:58,000;ASCS/NHAP<br>BW; 2/78; 1: 1,200;EDGE | 18 - 37 | (Augusta) | 344(R) | 282 | 308 | ? Edge Co W & S Auth | Mod ?; | 41-42S | Fair-;<br>* Distance, CP seds., access, wells?. |
|  | 20131309 | Fork Creek at Jefferson | 24.3 | Chesterfield | 10/76 to CY | 10 |  | K & CSb | O & B, 1965 | ? | 53 | 96.6 |  | 149.6 | ? |  |  | 100 | CIR; 4/82; 1:58,000;ASCS/NHAP<br>BW; 2/81; 1:40,000;ASCS | 17 - 36 | (Spart) | 202(L) | 281 | 310 | ? Town of Jefferson | Few ? | 23G | Poor;<br>* Distance, CP seds.; |
|  | 20131472 | Hanging Rock Cr. nr Kershaw | 23.9 | Lancaster | 10/80 to CY | 7 |  | K & CSb,gr | O & B, 1965 | ? | 53 | 80 |  | 133 | Good; around and several roads through. |  |  | 100 | CIR; 5/81; 1:24,000;SCFC | 18 - 36 | (Spart) | 273(R) | 281 | 309 | ? Town of Kershaw | Few ? | 26-27I | Poor;<br>* Distance, CP seds.; |

Hellers Creek in Newberry County was chosen as the basin to best fit the needs of both cooperators in the project, Figure 2. It had a streamflow gage with good records and acceptable channel; there was good accessibility to, around, and through the basin, its rural nature would pose few problems for the surface geophysical equipment sensitive to cultural interference; and it was thought that the entire basin is in a National Forest, which would allow much easier access to potential sites throughout the basin. It turned out that the U. S. Forest Service owns only a small portion of the basin, even though it is designated as a National Forest, Figure 3.

## SURFACE GEOPHYSICAL TRAINING

An important part of this first half-year's work was basic training in surface geophysical theory and techniques. Much of the remaining years' work will be heavily dependent upon a good understanding of the theory and applications techniques. Three phases of training took place during the 6-month period:

- A 1 1/2-day course in Columbia January 27-28, 1988.
- A class in Denver April 11 - 15,1988
- Use of equipment in the field March through June 1988.

Pete Haeni of the U. S. Geological Survey, Hartford, CT., conducted a 1 1/2-day course in Columbia January 27-28, 1988. This training introduced the project staff to surface geophysics and helped plant ideas on which equipment to try and how to experiment with the equipment, and it helped to establish some initial expectations of results.

Much of the class content reinforced many of the ideas and plans set forth in the project proposal the Piedmont Office staff submitted to the U.S. Geological Survey in January 1987 in response to Announcement 7217 (call for proposals) in the fiscal year 1987 Water Resources Research Program.

Prior to the April training course in Denver, CO, the first piece of equipment used was the Geonics EM-16/16R, a very low frequency electromagnetic instrument (VLF-EM). The study of the operations manuals, the use of the equipment, and the problems and questions that were generated prepared the two Staff attendees for the training course. Questions answered during or between the classes added to the information and training provided and solved or helped to solve problems encountered earlier.

The April training course was conducted at the Denver Federal Training Center in Lakewood, CO. The 4 days of classroom training with the 1 day of hands-on, field demonstration of the equipment provided a well-rounded second phase of our training. The class was taught mostly by U. S. Geological Survey staff with much experience in their specialties. Lectures were accompanied by references and case studies to provide background reading on the theory and applications. The topics covered included:

- Magnetics;
- Gravity;
- Electromagnetic methods ( VLF, Terrain conductivity, Transient EM, and airborne EM);

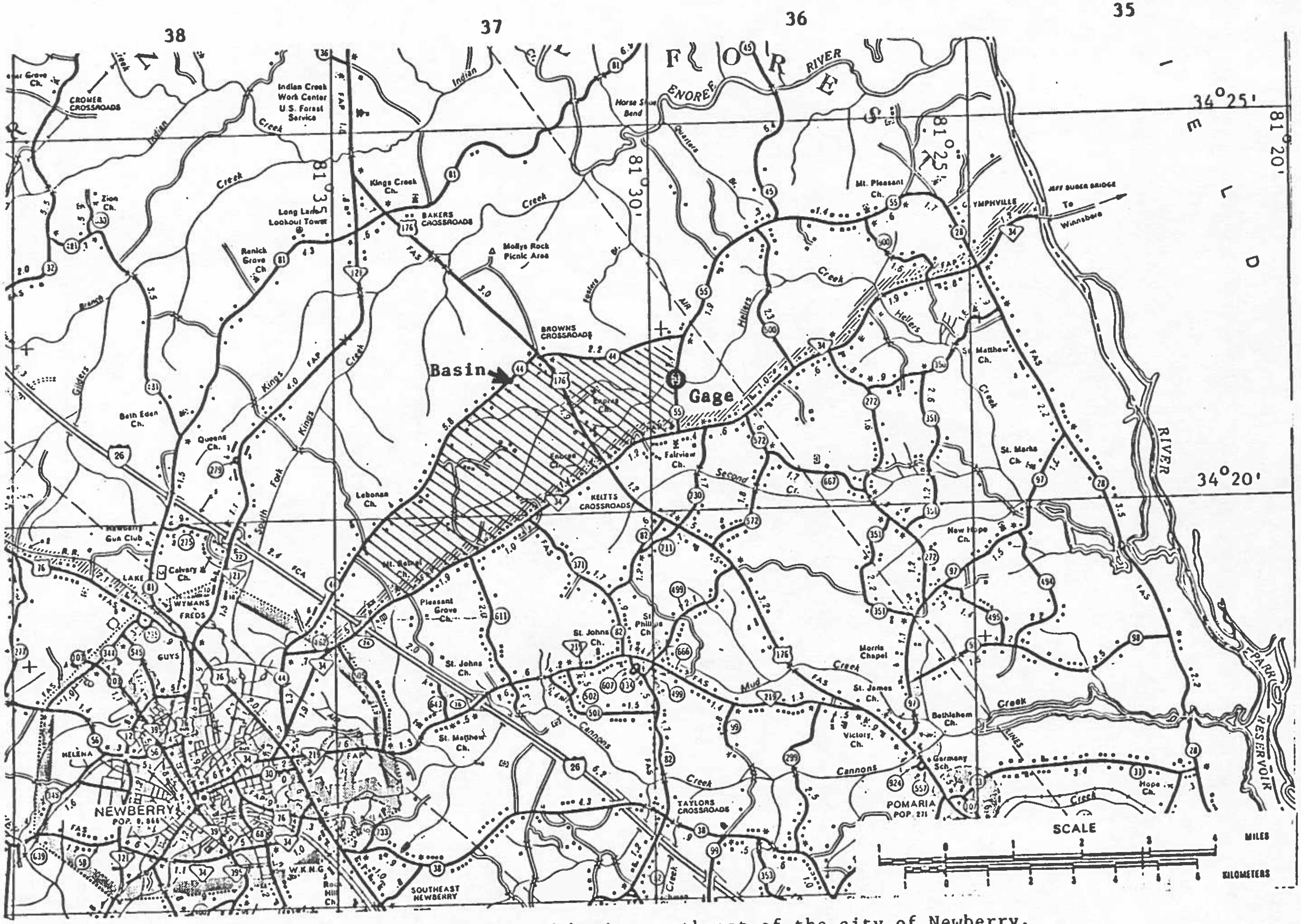


Figure 2. Location of Hellers Creek gage and basin, northeast of the city of Newberry.

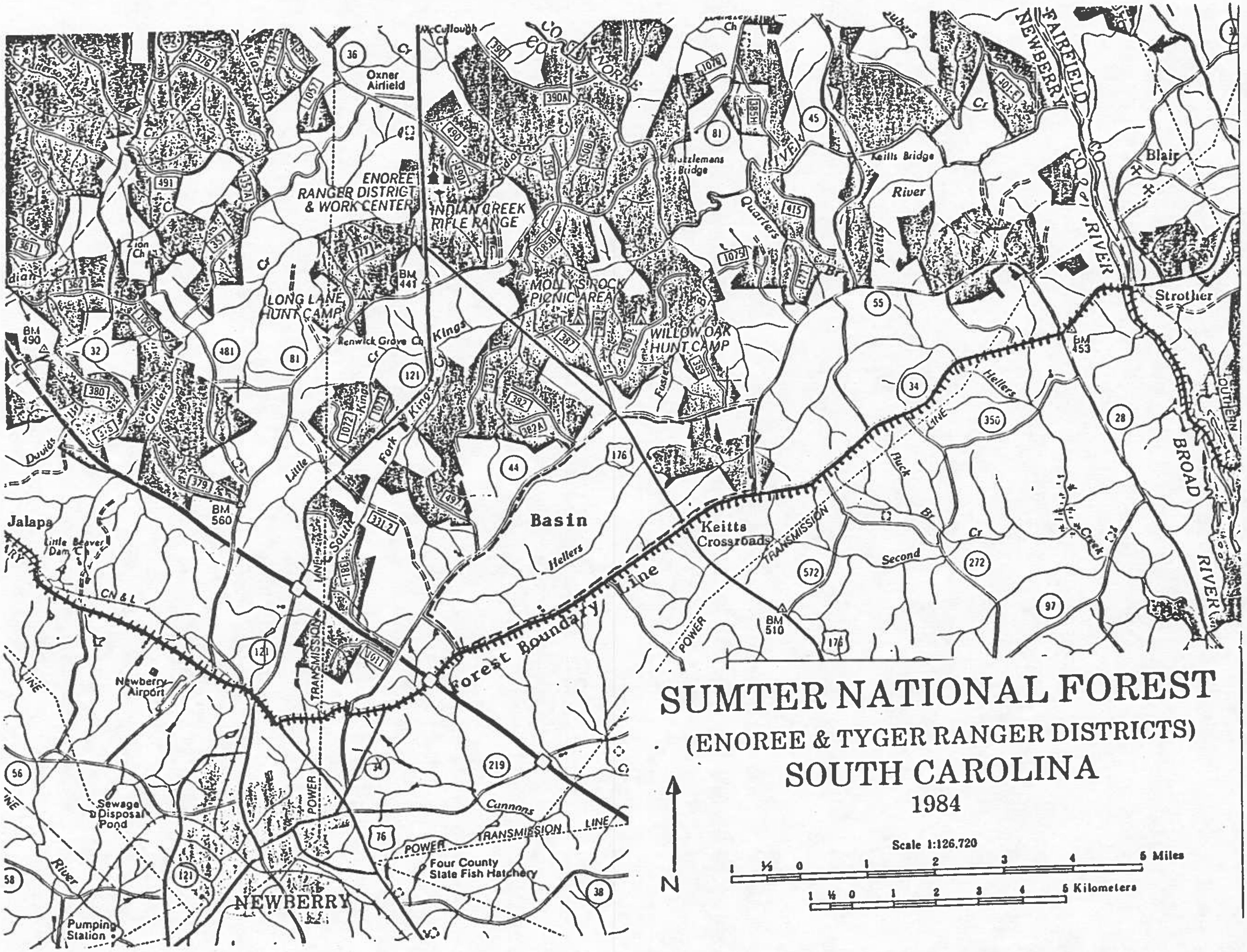


Figure 3. Location of Hellers Creek basin within Sumter National Forest, outlined by hachured line. Forest Service property shaded.

- Seismic refraction and reflection;
- DC resistivity;
- Complex resistivity;
- Ground penetrating radar;
- Marine seismic reflection and refraction.

At the conclusion of the class our questions (at the time) had been answered, and we were prepared to start with the next two pieces of equipment, the DC resistivity unit and the terrain conductivity meter (Geonics EM34-3). The instructors provided their phone numbers to allow class members to contact them at a later time with questions or problems.

Field experience with the equipment added firsthand training on how the equipment works as well as learning what problems each field situation presented and how to deal with them. Each piece of equipment had at least one problem not discussed in the training sessions or covered in the manuals. Consultation by phone with Pete Haeni or other U.S.G.S. personnel helped solve most of these problems. The problems encountered at times were frustrating but helped to open our eyes to the concerns we need to be aware of when planning future work.

Data interpretation in the next few months will add another phase of training - what can be learned about the study sites from the surveys and what we can apply to future applications of the equipment. The latter point may be the most important lesson learned.

Initial rough-cut analysis has shown that some of our initial expectations did not materialize. First, the saprolite is more resistive than anticipated. This may allow conductive fractures to be more readily "seen" at depth and may allow a greater probing depth. Second, the analysis of the data may be more detailed and complicated, and therefore more time consuming than first assumed. The experience of analysis itself may help speed up the process of future survey analysis.

## WELL INVENTORY

Records for only six wells in the vicinity of the basin were in Commission files, so a field inventory was made. Using a list prepared from county property maps and tax records, a field inventory of the wells was begun in March 1988. There were 291 property parcels listed in the basin or its vicinity, and most of the owners were visited in the field (some owners have more than one property).

The inventory was conducted by students working part-time who used an in-house developed inventory form and handed out a supplemental information sheet to the home owners they interviewed; both forms are shown in Appendix 3. At the same time a News Release was submitted to local newspapers, describing our work and its intent (Appendix 3). The Newberry County Sheriff was also contacted concerning our work (copy of letter in Appendix 3).

As listed in Appendix 4, 123 wells were inventoried, most of which are along the boundaries of the basin (along S.C. 34 and Newberry County Road 44) and across the center of the basin (U.S. 176), with some in the sparsely developed areas inside the basin. All wells that could be seen were noted, and it is believed that very few went uninventoried. Problems that prevented inventorying some wells were owner noncooperation or inaccessibility to well sites.

Owners or tenants were asked for standard information on their wells, such as well depth, casing depth, yield, name of driller, date well was drilled. They were also asked for permission to return at a later date, if necessary, for water level monitoring and water quality sampling. Well locations were plotted on aerial photographs (county property maps) and on USGS 7-1/2 minute topographic maps, and coordinates and elevations were determined.

The major problem encountered in the inventory was complete lack or scarcity of information on the wells. Only slightly more than half of the owners knew the depths of their wells, and some knew yields and casing depths (depth to bedrock is generally indicated by casing depth). Figure 4 indicates the location of all drilled, bored, and dug wells for which at least the depths are known. Wells for which more information is known are specially marked.

On the basis of the 75 (out of 129) wells for which we have this information (total depth), the following statistics are listed:

| | | |
|---|---|---|
| Drilled wells: | | |
| total depth, casing depth, yield | 5 | |
| total depth and yield | 12 | |
| total depth and casing depth | 2 | |
| total depth only | 39 | |
| Total drilled | | 58 |
| Bored and dug wells | | 10 |
| Unknown types, depths known | | 5 |
| Springs | | 2 |
| Grand total | | 75 |

Breaking these wells down by type and depth, and not including the two springs, the following table is presented:

| | Depth range (ft) | Number of wells | Average depth (ft) |
|---|---|---|---|
| Drilled Wells: | 0 - 60 | 1 | 60 |
| | 61 - 120 | 26 | 99 |
| | 121 - 180 | 18 | 153 |
| | 181 - 240 | 7 | 223 |
| | >240 | 6 | 388 |
| Bored and Dug Wells: | 0 - 60 | 10 | 40 |
| Unknown Type: | 0 - 60 | 5 | 42 |

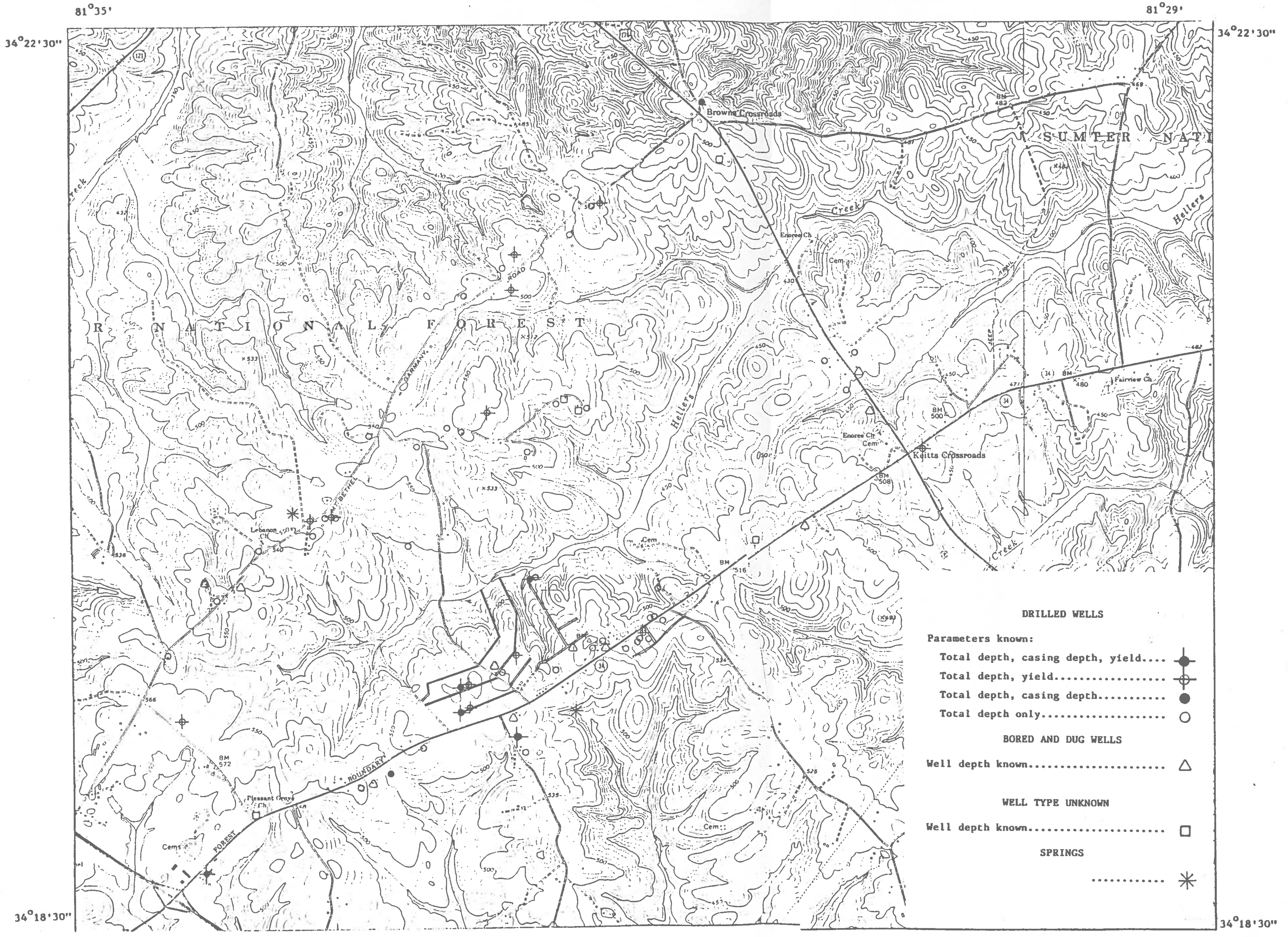


Figure 4. Well location map, Hellers Creek basin.

The largest group of drilled wells is in the 61-120 foot depth range, followed by those ranging in depth from 121 to 180 feet. Over 75 percent (44 of 58) of the drilled wells are between 61 and 180 feet. It is important to note that most of these wells are domestic and that their depths may be due more to economic factors (expense of drill hole per foot) than hydrogeologic factors. Unfortunately, so few wells in this inventory have yield data that it prevents analysis of the relationship between yields and factors such as depth, topography, lithoilogy, and distance from and orientation with respect to lineaments.

Bored and dug wells do not penetrate bedrock, and their maximum depth of 60 feet would seem to indicate bedrock at that depth. There are localities in the basin, however, that have much deeper bedrock (that is, thicker saprolite), as can be seen from some casing depths (in drilled wells) that are greater than 100 feet. The wells of unknown type, because of their depths, are most likely bored or dug.

Future efforts should include attempts to obtain more information on the wells inventoried, by checking back with owners and visiting local drillers. Areas where information is especially lacking should be targeted for direct measurement and geophysical logging of wells, if practical.

## LITHOLOGIC-GEOMORPHIC TERRAIN ANALYSIS

The lithologic-geomorphic terrain analysis, as described by Daniel and Sharpless (1983), involves the analysis of the geomorphology, including examination of drainage pattern and topography, well data, and geology. Compilation of this information for this project took longer and was more complicated than first anticipated.

### Geomorphic Analysis

The geomorphic analysis of Hellers Creek basin involved portions of the Newberry East and Pomaria 7-1/2 minute quadrangles, Figure 5. The drainage pattern is generally dendritic but with some rectangular characteristics. Several locations in the drainage basin display features suggesting geologic structural control such as very straight stream segments, abrupt 90 degree changes in channel direction, or a stair-step shaped channel segment.

The topographic lineament analysis is shown in Figure 6. Many linear features, or suspected ones, have been identified. Also shown is a rose diagram summarizing the alignments of the lineaments. The predominant alignment is N20-30$^{o}$W, which is perpendicular to the general trend of the Piedmont belts. According to Daniel and Sharpless, this orientation of lineament is generally more favorable for locating wells. Other orientations are N40-50$^{o}$W and N10-20$^{o}$E. Field mapping and verification of these lineaments have proven difficult owing to the few outcrops of usable size.

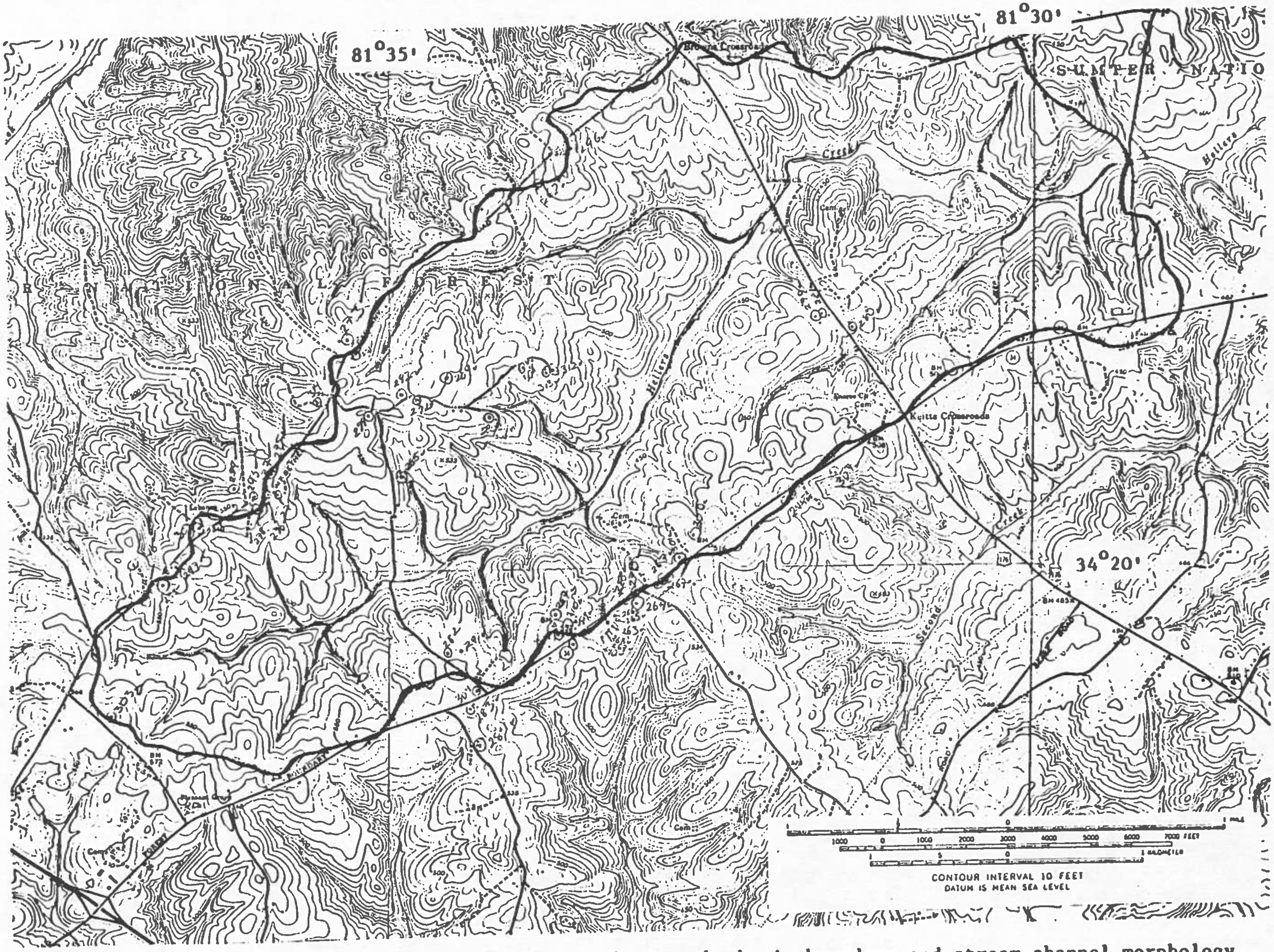


Figure 5. Topography of Hellers Creek basin, showing the basin boundary and stream-channel morphology.

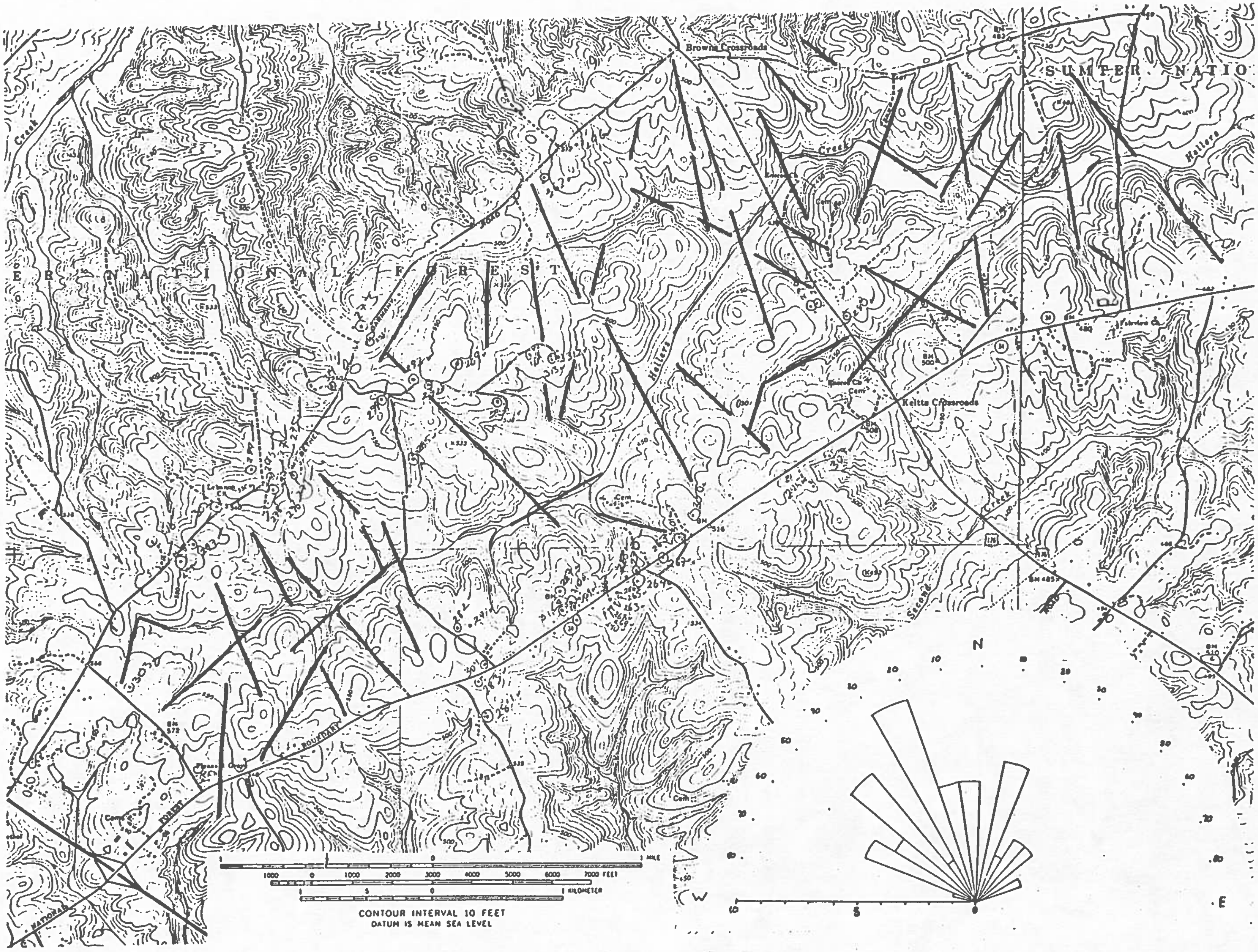


Figure 6. Topographic lineament map and lineament rose diagram, Hellers Creek basin.

### Well Analysis

Very few wells were in the Commissions Welltab data base for this area. The well inventory required completion before the analysis of the well data as suggested for this portion of the work. As was pointed out in the Well Inventory section, a low percentage of the inventoried wells had all of the critical data supplied, due to the lack of information on the owners' part. This may hamper the analysis, but the degree will be evaluated. This analysis will take place shortly and could be aided by the planned-for plotter and digitizer.

### Geologic Analysis

The geology of the basin is shown in Figure 7. This was compiled from three sources, as shown on the map. Many of the contacts are inferred or guessed at and the map may be oversimplified. The heavy vegetation and scarcity of outcrops mask the geology, making detailed mapping difficult.

Discussions with a local well driller indicated that in some locations the felsic biotite gneiss was partially weathered to depths greater than usual. This condition of the gneiss produced rocklike drilling but friable, sand-like water-bearing zones. These situations required well casing through this material. Thus several wells required casing of 100 feet or more, which is highly unusual. This knowledge of the deep partial weathering could not be used to help geologic mapping, due to the lack of wells with known casing depth.

It is speculated by the authors that the basin geology is much more complex than mapped, with more inclusions of the felsic gneiss throughout the Newberry complex. At various locations in the basin, pieces of the felsic gneiss were found as float, mostly in plowed fields, as well as pieces of quartz. The quartz ranged from massive microcrystalline fragments to masses of euhedral crystals 1/4-inch or larger in diameter.

With such an uncertain understanding of the geology it is impractical, for now, to assess best drilling sites on the basis of geology and its relationship to the geomorphology. Further work with the well inventory will be required to determine if particular areas, geology, or topographic locations are more favorable well sites. Consultation with Mr. Charles Daniel, USGS in North Carolina, will now be potentially useful and fruitful.

## REMOTE SENSING LINEAMENT MAPPING

According to the workplan this phase of the project was to be completed prior to the use of the surface geophysical equipment. The number of objectives scheduled for this first half-year of the project created a tight scheduling of events. The arrival of the air photos and remote-sensing images did not meet the schedule, as was suspected from the start, owing to the lead time required for the purchase of these products. As a result, older (February 1970), black-and-white air photos from the Map Library of the University of South Carolina were used to make an initial lineament map of the basin, see Figure 8.

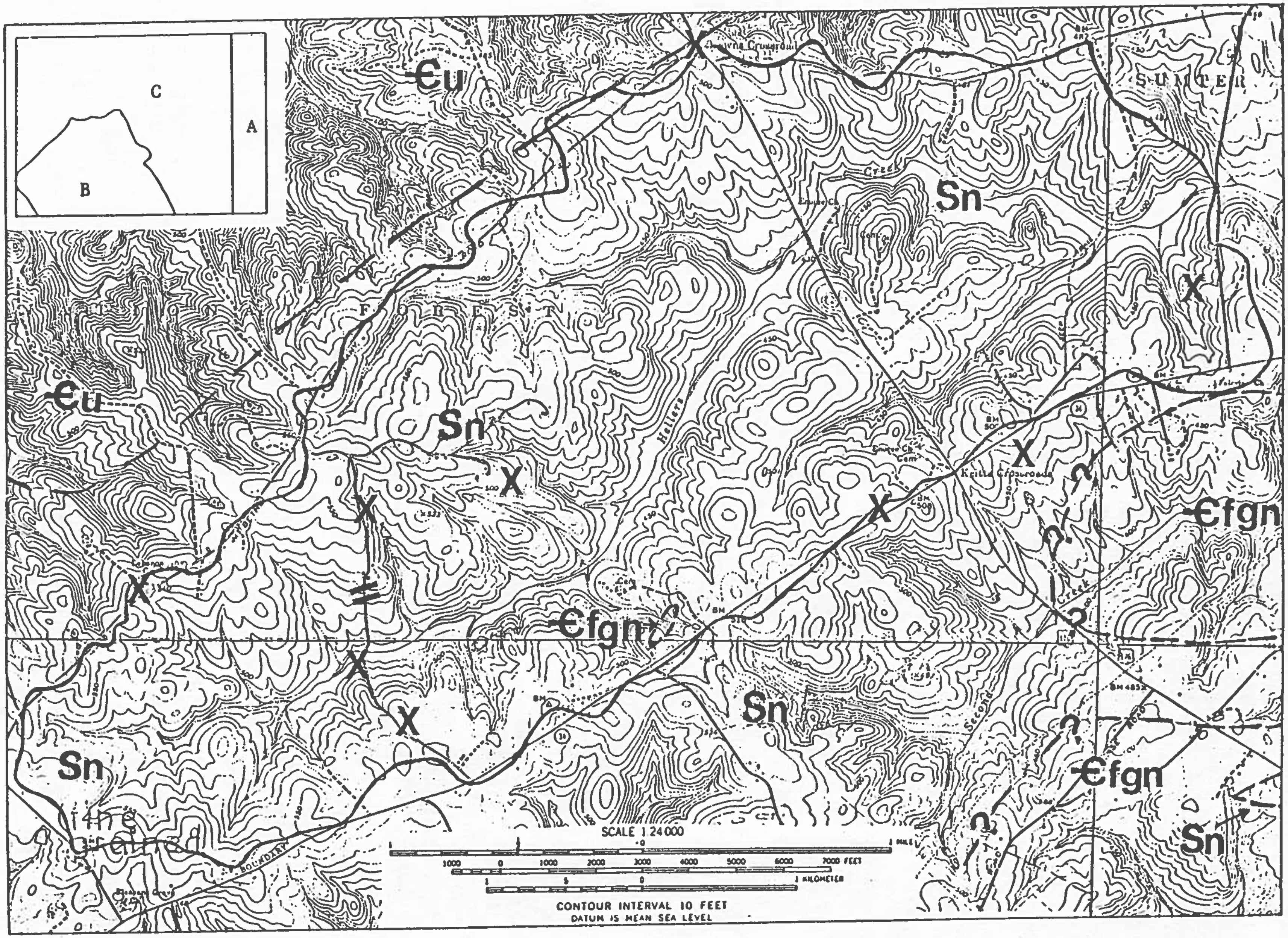


**Figure 7.** Geology of the Hellers Creek basin area. Geologic map after Pitcher, 1982 (A), Rawlins, 1986 (B), and Secor and others, 1987 (C). Heavy solid line is basin outline; heavy dashed lines are geologic contacts. Sn, Newberry plutonic complex (granitic); Єfgn, felsic biotite gneiss; Єu, undifferentiated paragneiss, schist, quartzite, and amphibolite. Observed in field in this survey: X, granitic outcrops; =, quartz-pegmatite dikes.

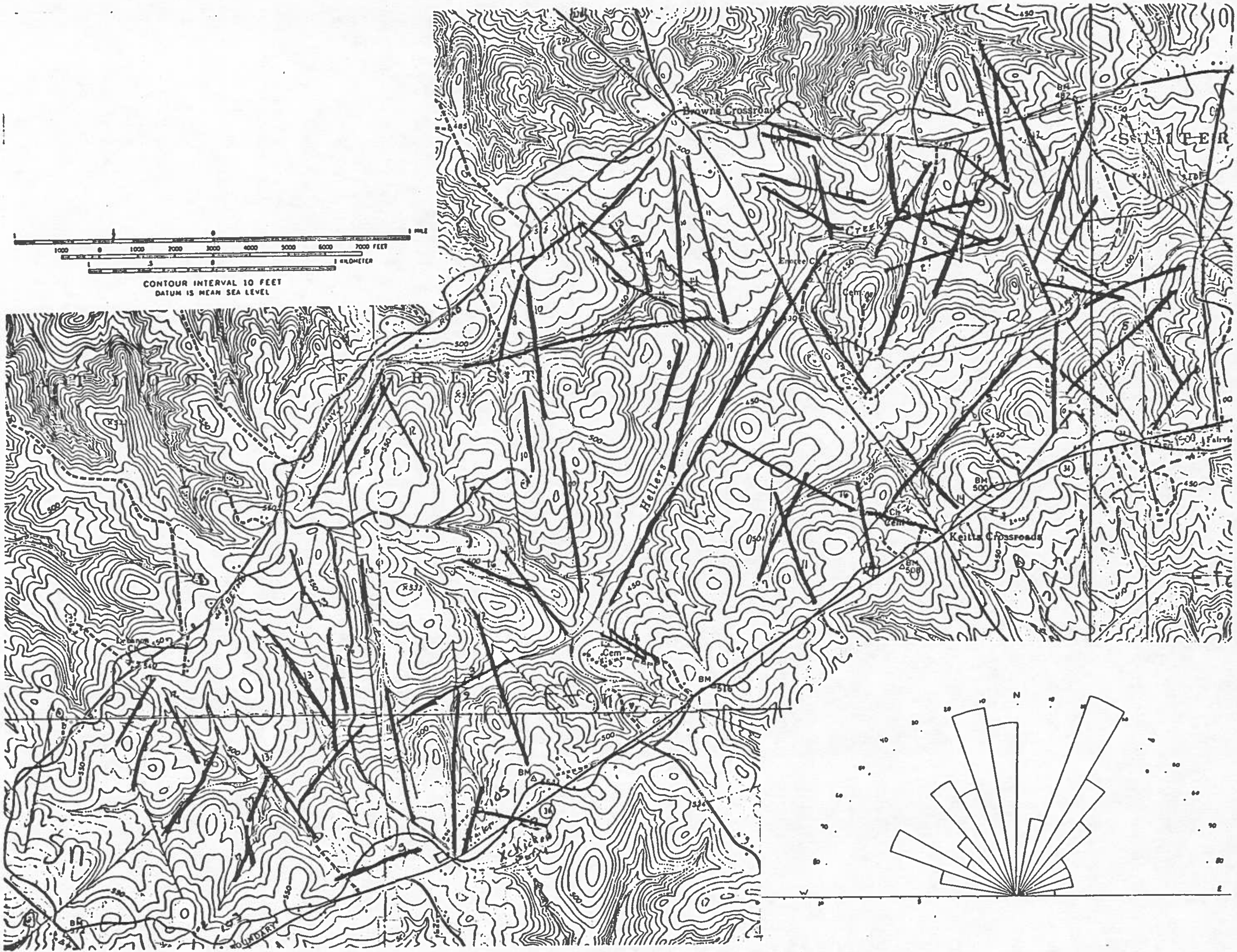


Figure 8. Air-photo lineament map and lineament rose diagram, Hellers Creek basin.

More lineaments were plotted on the air photos than on the topo sheet. Many of the lineaments from the two maps overlap, potentially confirming their existence. The rose diagram in the lower right of Figure 8 shows roughly the same preferred orientation as the previous map, Figure 6. The main difference being the N20-30$^{O}$E orientation is the most preferred direction on Figure 8.

Interpretation of the other images should shed more light on this lineament plot variation. The difficult logistic accessibility of the air photos used for the initial work inhibited cross checking.

An important lesson to be gleaned from this experience is that four to eight weeks may be required for the arrival of ordered air photos. The typical requests for ground-water resource development received in the Piedmont Office have a time frame of one to two weeks. This is obviously a much shorter time than the turnaround to order air photos. If remote-sensing lineament mapping is to be a serious option for the Piedmont, a set of images covering the Piedmont should reside in the Greenville Office or at another convenient upstate location, for the Commission staff and others. Most likely the imagery would not need frequent updating, at least for lineament mapping, since newer imagery would probably have more of the urbanization that detracts from lineament mapping.

An important aspect of this objective is the evaluation of various imagery different in scale, color, and sensing platform for their adequacy for lineament mapping. The imagery obtained includes:

1:20,000 scale Black and White 9"x9" paper air photos, 2-20-70; at USC Map Library in Columbia, SC;

1:40,000 scale Black and White 9"x9" transparencies, 1-25-81; coverage shown in Figure 9;

1:58,000 scale color IR 10"x10" NHAP transparencies, 2-15-84; coverage shown in Figure 9;

1:100,000 scale B&W 38"x38" SPOT imagery, 10-meter resolution; 5-10-87 and 12-30-87; coverage shown in Figure 9;

1:100,000 scale false-color 38"x38" SPOT imagery, 20-meter resolution; 5-10-87 and 11-13-87; coverage shown in Figure 9.

The coverage of the various imagery increases, obviously, with increase in the scale. Interpretive resolution decreases with the scale increase. It is hoped that a reasonable scale can be found that allows good lineament identification as well as economic areal coverage.

This imagery will be interpreted following the completion of this report. By the time the imagery arrived, the surface geophysical equipment had also arrived and had to be used before the loan time was up. As mentioned above, the 1:20,000-scale Black and White air photos were lineament interpreted to help in the selection of survey sites in the basin.

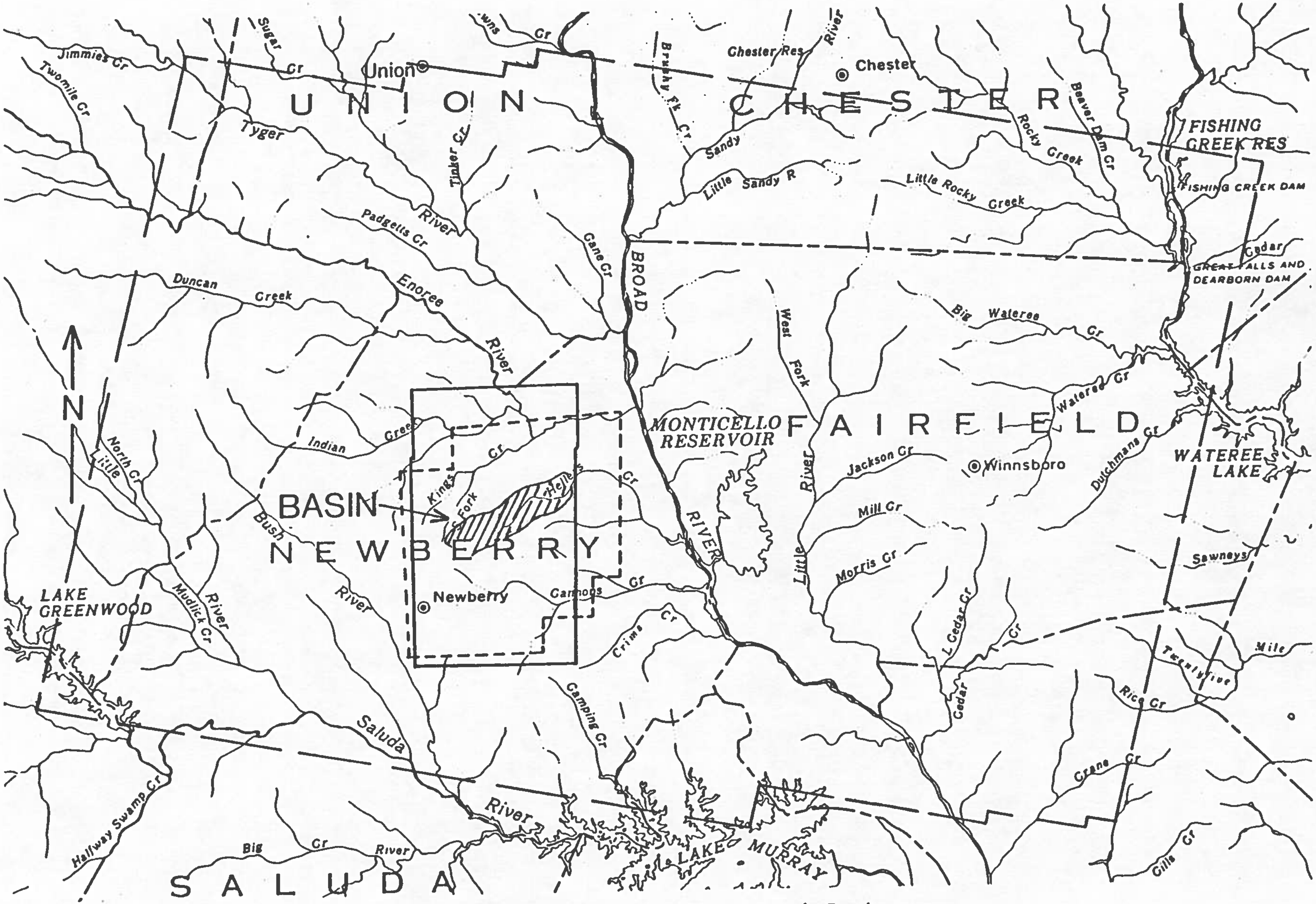


Figure 9. Airphoto and satellite imagery coverage of Hellers Creek Basin area.

– – – – – – – – ASCS 1:20,000-scale black & white photos

———————— NHAP 1:58,000-scale false-color photos

———— —— SPOT 1:54,000-scale black & white and false-color images

## SURFACE GEOPHYSICAL SURVEYS

The initial plan for this objective was to choose several sites throughout the basin in which to conduct the surface geophysical surveys. The choices were to be made on the basis of the exploration methods described above. These exploration methods were conducted but not to the degree nor quality initially desired, due to the problems described in the above sections.

The site selection was further narrowed by ownership and accessibility. Repeated access to the test sites would restrict or prevent use of the land by the owner, especially if survey lines were staked. Overland foot travel to test sites would reduce the volume of survey work possible during the limited time we had the equipment. Several sites were tentatively chosen and the most accessible would be worked in first.

Figure 10 shows the three locations where survey work was done, as well as four sites of minor work. The three survey sites are shown in more detail in Figures 11A, B, and C. Covering sites A and B consumed all of the month we had each piece of equipment. During the April 1988 training course, Pete Haeni stressed learning how to use the equipment and interpret the data this first 6 months. Once this was accomplished, more meaningful surface geophysical work could be pursued later.

Site 1, Figure 11A, is a grid containing 135 stations located in a U.S. Forest Service clear-cut area and covers one and possibly two lineaments. It consists of 9 parallel lines with 15 stations per line, and 20 meters between stations. The lines were oriented S47$^{o}$W to line up with the VLF transmitting stations, Figure 12, and the suspected lineament. Site 2, Figure 11B. is a traverse paralleling U.S. 176 and crosses a prominent linear feature.

Site 3, Figure 11C, is a private homesite where we gave technical assistance and ran 5 VLF-EM surveys. This contact was made during the initial stages of the geophysical work in the basin.

Three pieces of surface geophysical equipment were used between March and June 1988. Included were the Geonics 16/16R VLF-EM instrument, the Bison 2390 DC Resistivity unit, and the Geonics EM34-3 terrain conductivity meter. A fourth instrument, the WADI, a VLF-EM instrument, was experimented with in the grid site but the data were never analyzed or downloaded. The WADI data was later lost due to data management error and thus no results are available. More WADI surveys will be conducted during the next year of the project.

### VLF and Radiohm Meter

The Geonics 16/16R VLF-EM instrument was used in March 1988 and was the first piece of surface geophysical equipment employed. Much of the basic theory learned to date on surface geophysics was learned during this first month, because principles of resistivity/conductivity underlie all three methods used in this instrument.

The VLF instrument is a passive device, i.e., one that does not transmit signals but receives signals only. It uses the broadcast energy transmitted by very low frequency radio military stations from 14 locations around the world. The three stations used during the surveys are listed in Table 2.

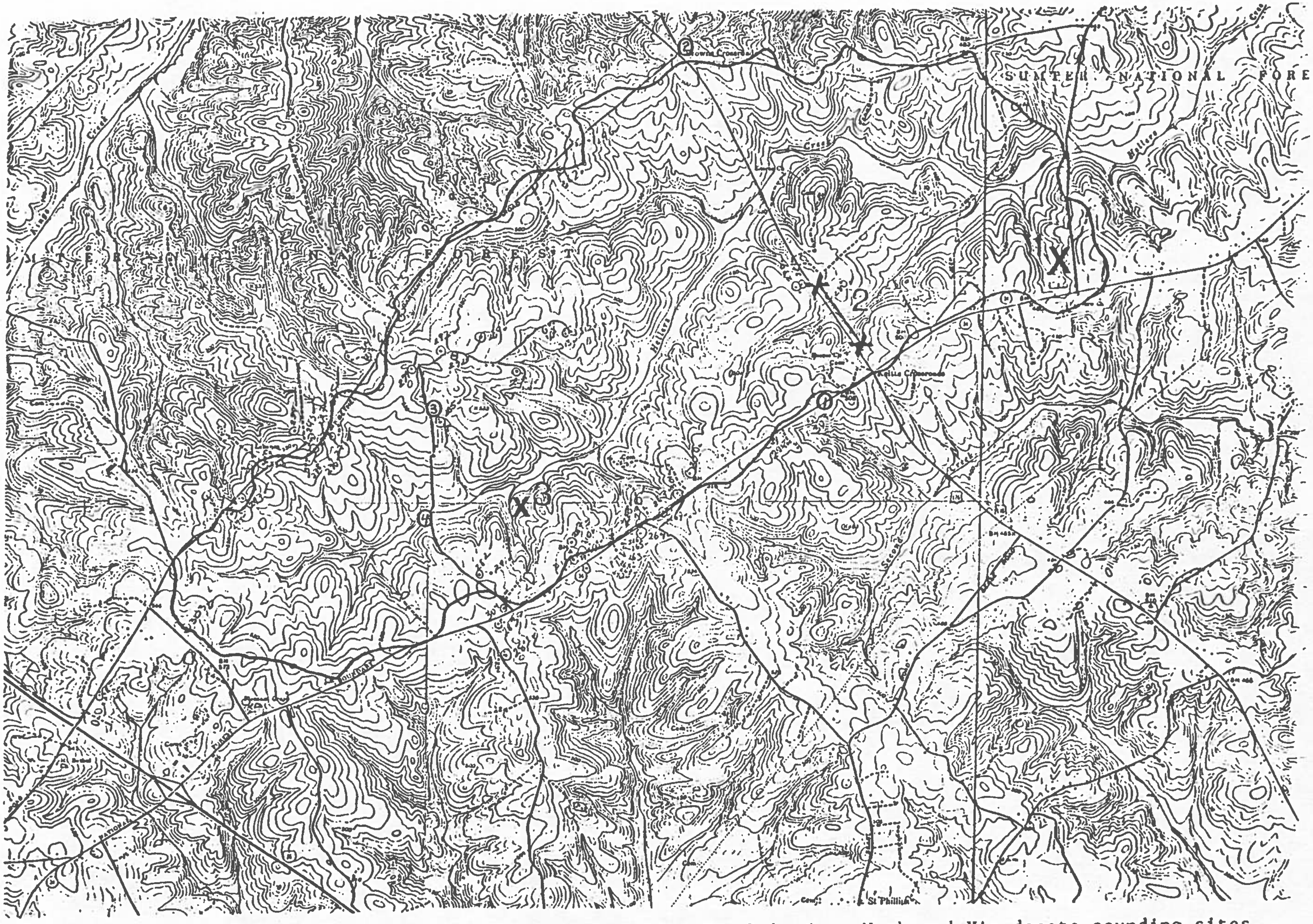


**Figure 10.** Surface geophysical survey sites in HellersCreek basin. Numbered X's denote sounding sites. Circled numbers 1 to 4 are simple measurement sites.

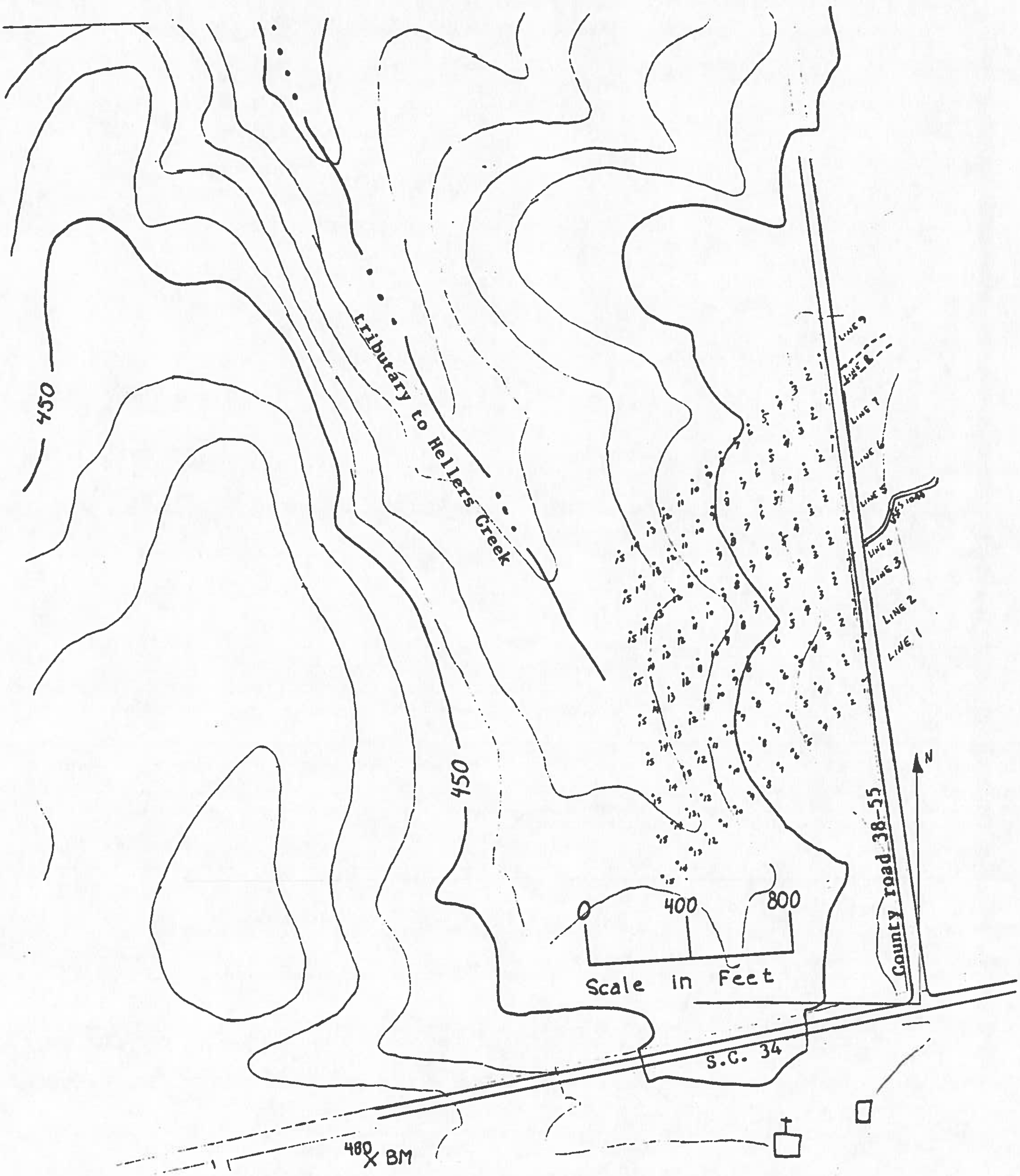


Figure 11A. Clear-cut grid site, SE corner of Hellers Creek basin.

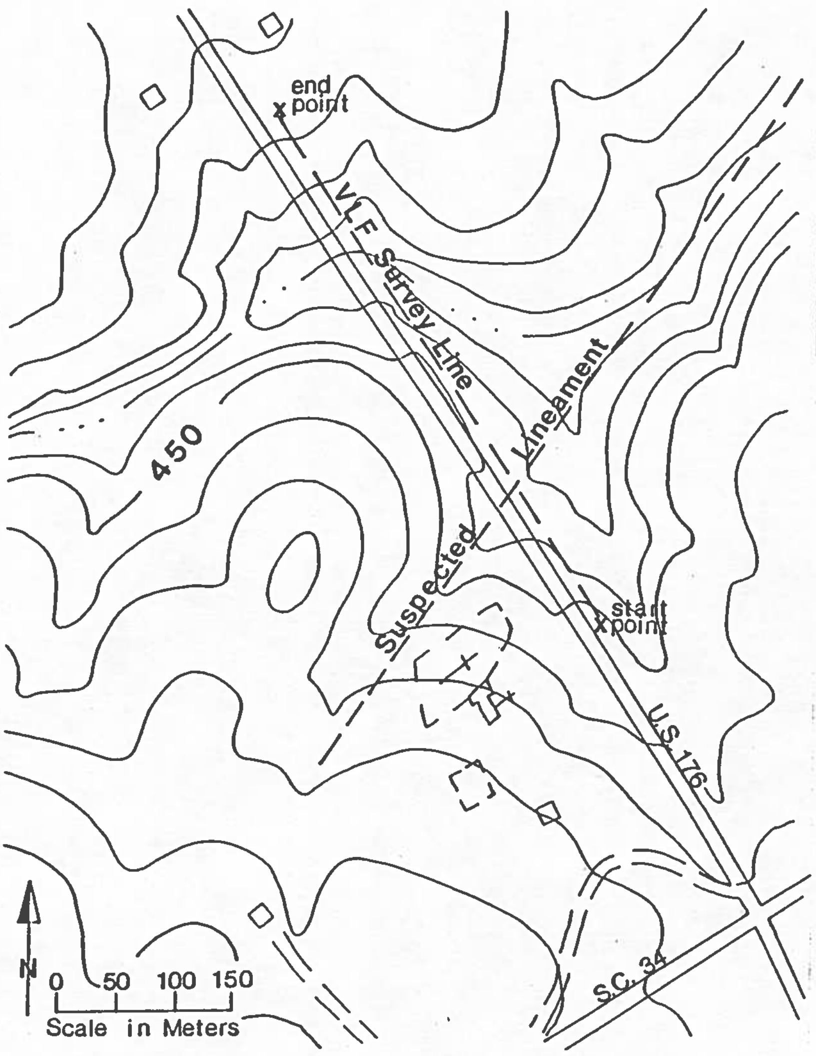


Figure 11B. U.S. 176 sounding/profile site.

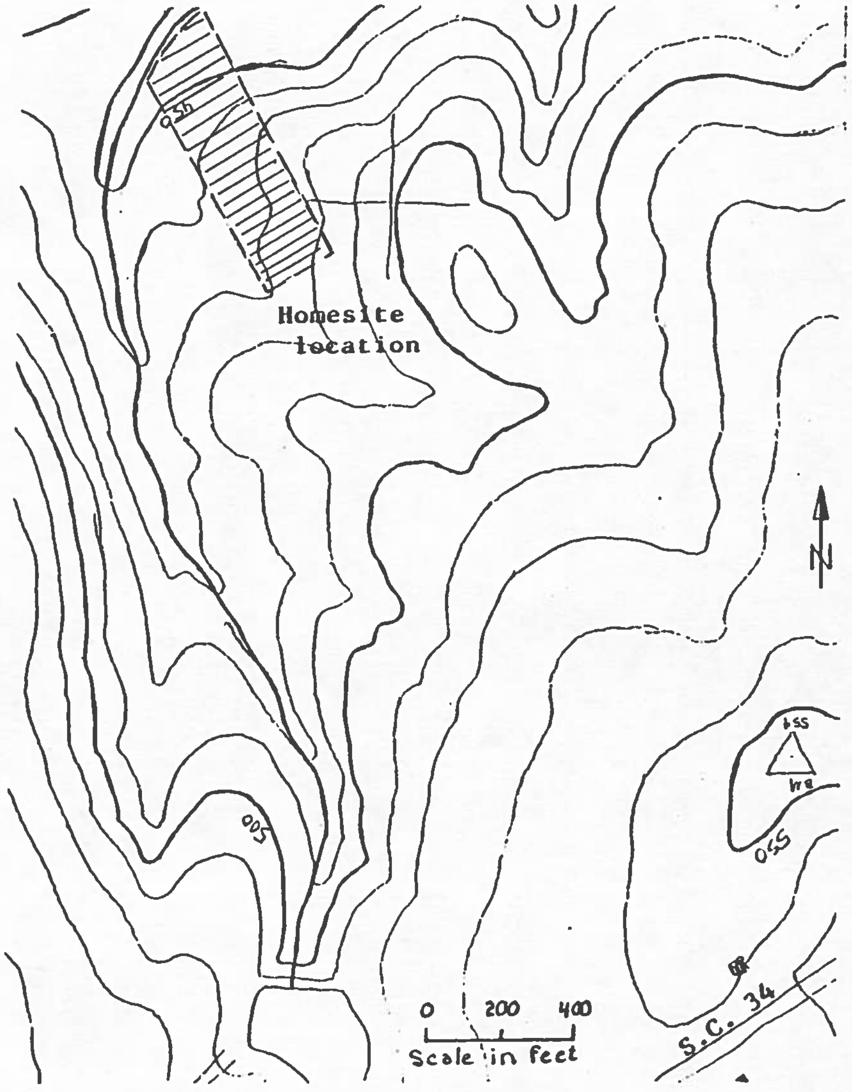


Figure 11C. Raymond Hatcher, Jr., homesite location.

TABLE 2

| ID | Location | Frequency | Power | Day | Time off |
|---|---|---|---|---|---|
| NAA | Cutler, ME | 17.8 kHz. | 1,000 kW | Mon | 0600-1400 |
| NLK | Jims Creek, WA | 18.6 kHz. | 300 kW | Thu | 1000-2300 |
| NSS | Annapolis, Md. | 19.0 kHz. | 100 kW | Tue | 0600-1400 |

Each of these stations have an off period every week for maintenance. Surveys had to be planned around these off periods since no readings can be made without the station broadcasting. As can be seen in Figure 12, Cutler, ME, and Annapolis, Md, are nearly identical in NE orientation to Hellers Creek. This made it possible to switch to the secondary station during the off time of the primary. Roughly perpendicular, or NW, to these stations is the Jims Creek, WA, station. Thursday was the only day surveys could not be performed, since both station orientations were used in the study.

The EM-16 can be operated in two modes:
- as a VLF instrument;
- as a radio-ohm meter, measuring apparent resistivity.

The latter mode requires an attachment that can be left attached during VLF measurements. This results in four measurements at each station for a particular broadcasting station.

The VLF instrument measures the horizontal magnetic component of the VLF radio waves. It also measures the secondary magnetic field generated by a conductive 'body' in the ground which interferes with the VLF radio signal. The 'body' could be a metallic sulfide deposit or a water-bearing fracture. Some of the factors that impact the operation of this instrument are depth to the fracture or target, resistivity of the earth material, strength of the radio signal, and cultural interference.

VLF mode

In the VLF mode two factors will directly impact the identification of a target, or fracture: contrast and attenuation. Sufficient contrast must exist between the resistivity of the fracture and that of the host rock to allow the fracture to be "seen". The resistivity contrast produces a conductive zone in which is generated the secondary magnetic field. Both magnetic fields are phase-shifted, the secondary field approximately twice as much as the primary field.

The deeper the target is located the greater the distance the signal will have to travel to the receiver. Attenuation of the signal increases with depth which could decrease the contrast sufficiently to make the fracture indiscernible. Less resistive (more conductive) intervening material increases the rate of attenuation. This attenuation factor limits the depth of penetration of the VLF unit in moderately conductive terrains. Preliminary evaluations of the Piedmont saprolite expected resistivity of 25 to 50 ohm-meters. Average measured resistivities were in the 100 ohm-meter range, allowing a deeper sensing penetration than originally anticipated.

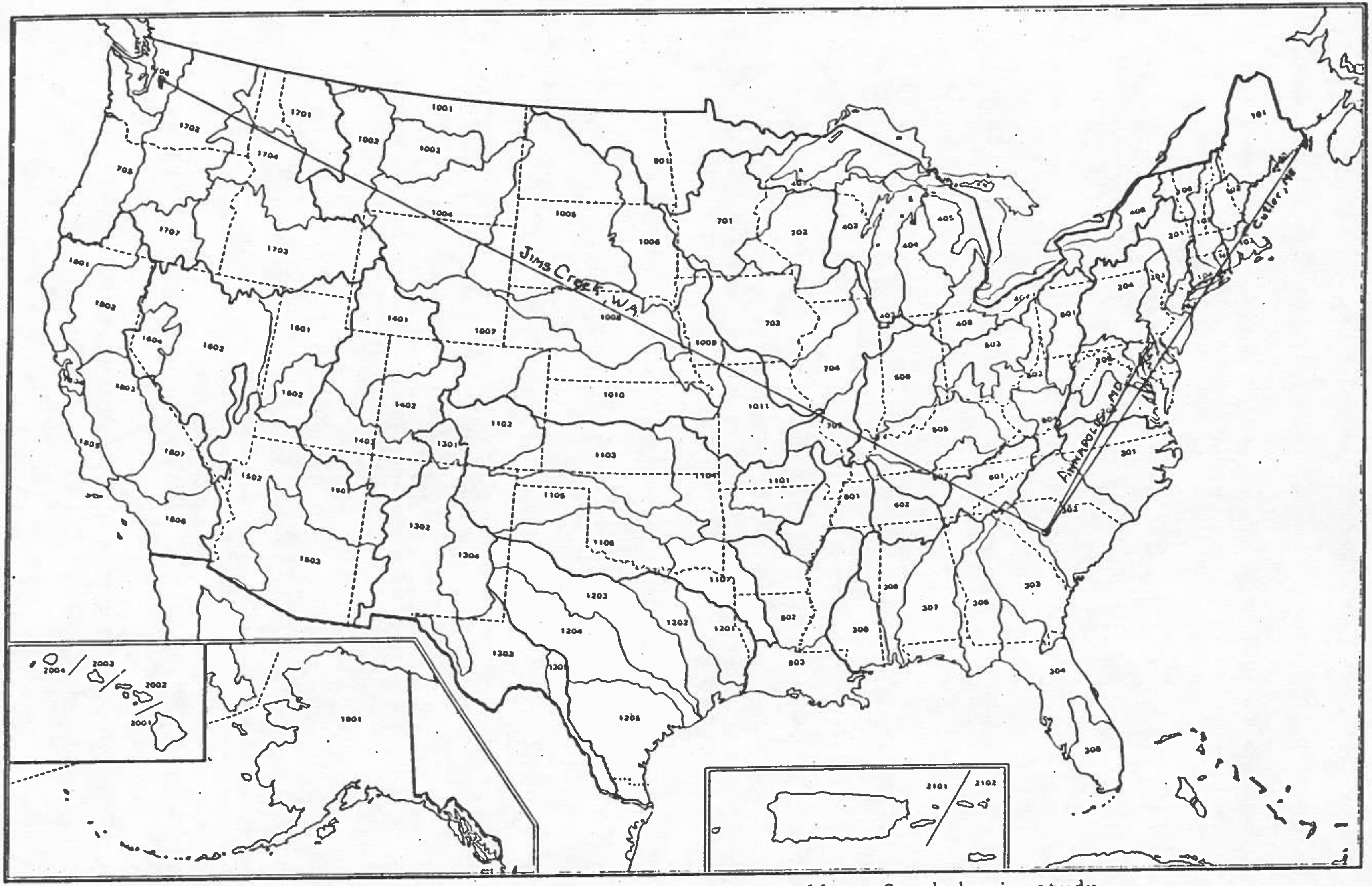


Figure 12. VLF military broadcast station sites used in Hellers Creek basin study.

This deeper sensing depth, or "skin depth", does not mean that any fracture at that depth will be detectable from the surface. Deeper targets require greater resistivity contrast for the target to be sensed. Water-filled fractures have only a limited contrast range with their host rock and thus have a limited detection depth. Part of next year's work will deal with defining that depth in the South Carolina piedmont.

In general, lower radiated energy from a VLF radio station or greater distance from the survey site results in lower energy level available for detecting subsurface features. Both of these factors attenuate the signal strength and both work concurrently.

Cultural interference includes power lines, either buried or suspended, metal fences, buried metal pipes, or other metallic objects. These can interfere with the received radio signal or produce anomalies that drown any naturally occurring geologic feature. Where these features exist, surveys may prove meaningless. If possible the survey lines should be move away from the interferring feature while still covering the desired target.

A few examples of VLF surveys, although not completely analyzed, are presented. Figure 13 shows the first two survey lines, oriented with north at top of page, in the clear-cut grid, Figure 11A. The solid line shows the "In-phase" component of the vertical magnetic field and the dashed line shows the quadrature component of the magnetic field. Nothing significant stands out from our limited analysis. Further analysis, such as running the results through a numeric filter, described by Frasier, 1969, and contouring of all nine lines of these data should improve the analysis capabilities.

Figure 14 shows the VLF profile along the southern quarter of U.S. 176 across Hellers Creek. Between stations 23 and 24 a zero-line crossover occurs very much like the textbook example for a conductive ore body below a conductive overburden. The assumed geologic model for the Piedmont is a resistive rock containing conductive water-bearing fractures overlain by conductive saprolite. This crossover coincides closely on the ground with the lineament identified by both topographic and air photo lineament mapping (Figure 11B).

Also of note is the asymmetry of the curves, with larger curves to the left (southeast) of the crossover than to the right. This is tentatively interpreted as indicating that the fracture dips to the southeast and intercepts the land surface, or saprolite, near the crossover point. If true the better well site would be southeast of the crossover point.

Figure 15 shows the five VLF profiles made at the homesite of Raymond Hatcher, Jr., site 3 in Figure 10. Figure 16 shows the approximate orientation of the profiles to the property and eventual well locations. The successful well, number 2, was drilled near station 5 on traverse 1. Nothing on the curve for traverse 1 suggests, so far, any fracture. Traverses 4 and 5 show crossovers near station 4, possibly dipping to the west. The well is located slightly to the west of the suspected fracture. If the fracture is oriented to the northwest it would parallel traverses 1 and 2 and would explain why they apparently show little evidence of an anomaly.

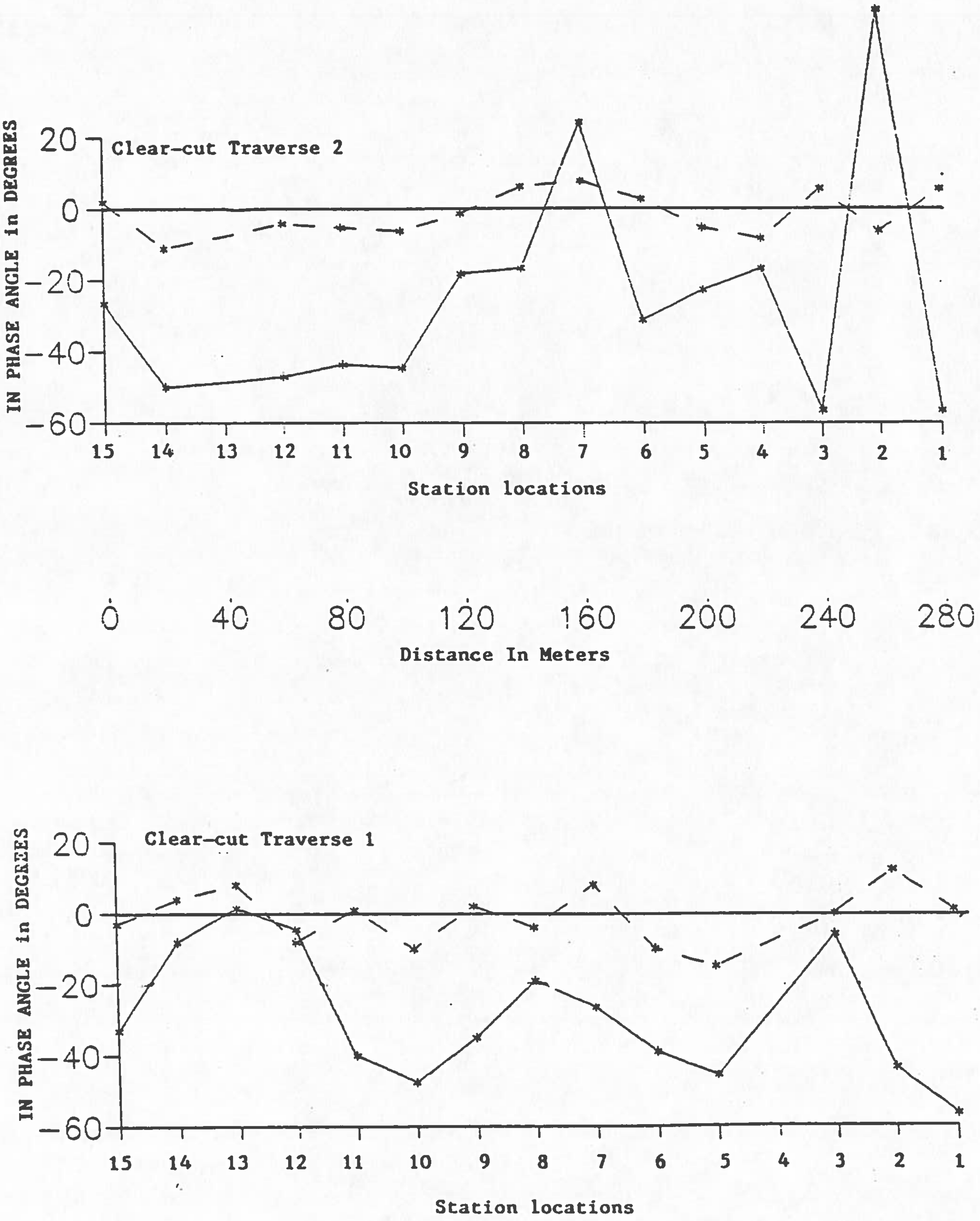


Figure 13. VLF plots of clear-cut traverses 1 and 2, Hellers Creek basin.

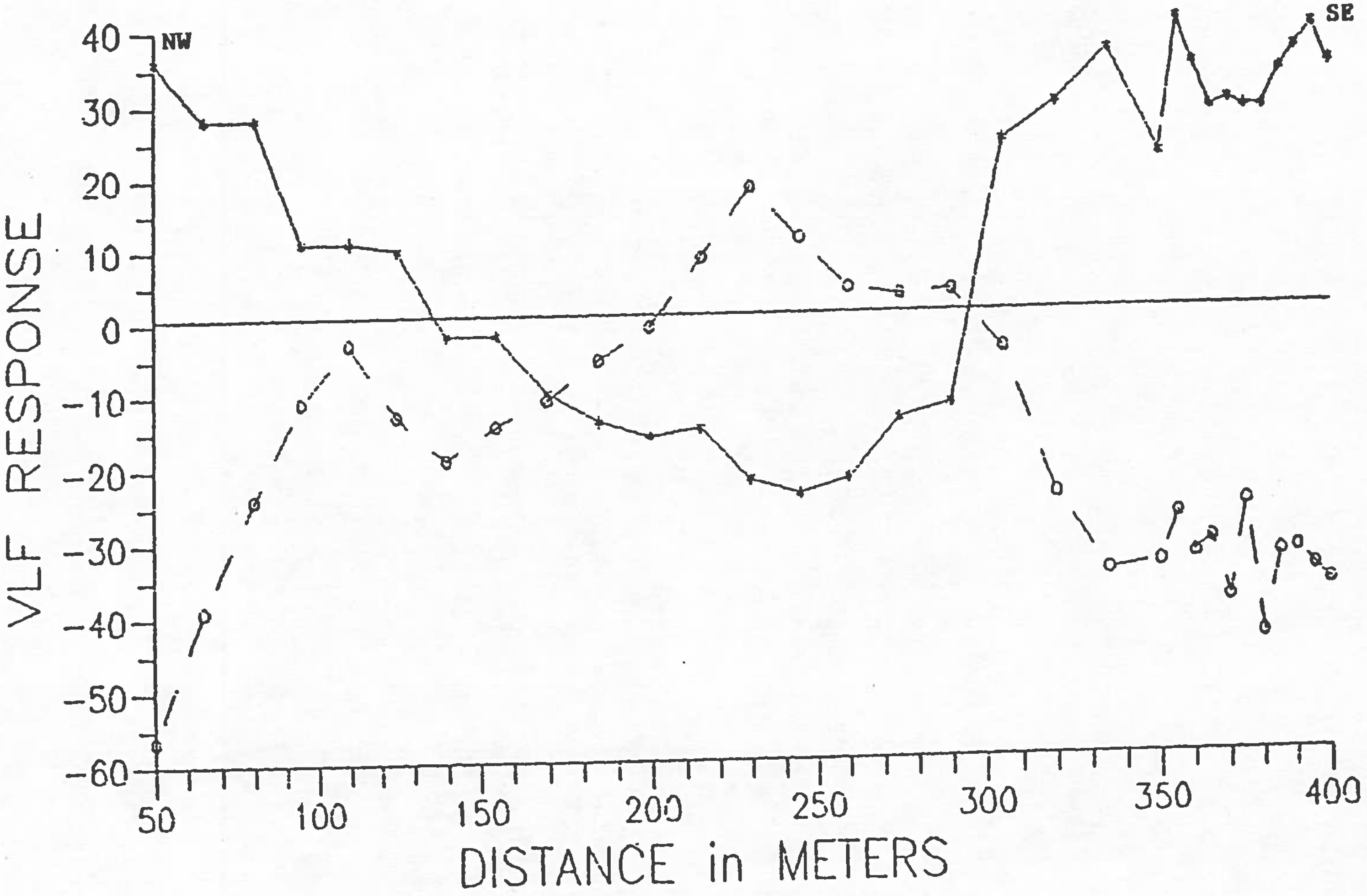


Figure 14. Plot of VLF survey along U.S.176, Hellers Creek basin.
—*—, Quadrature; - -o- -, Inclination.

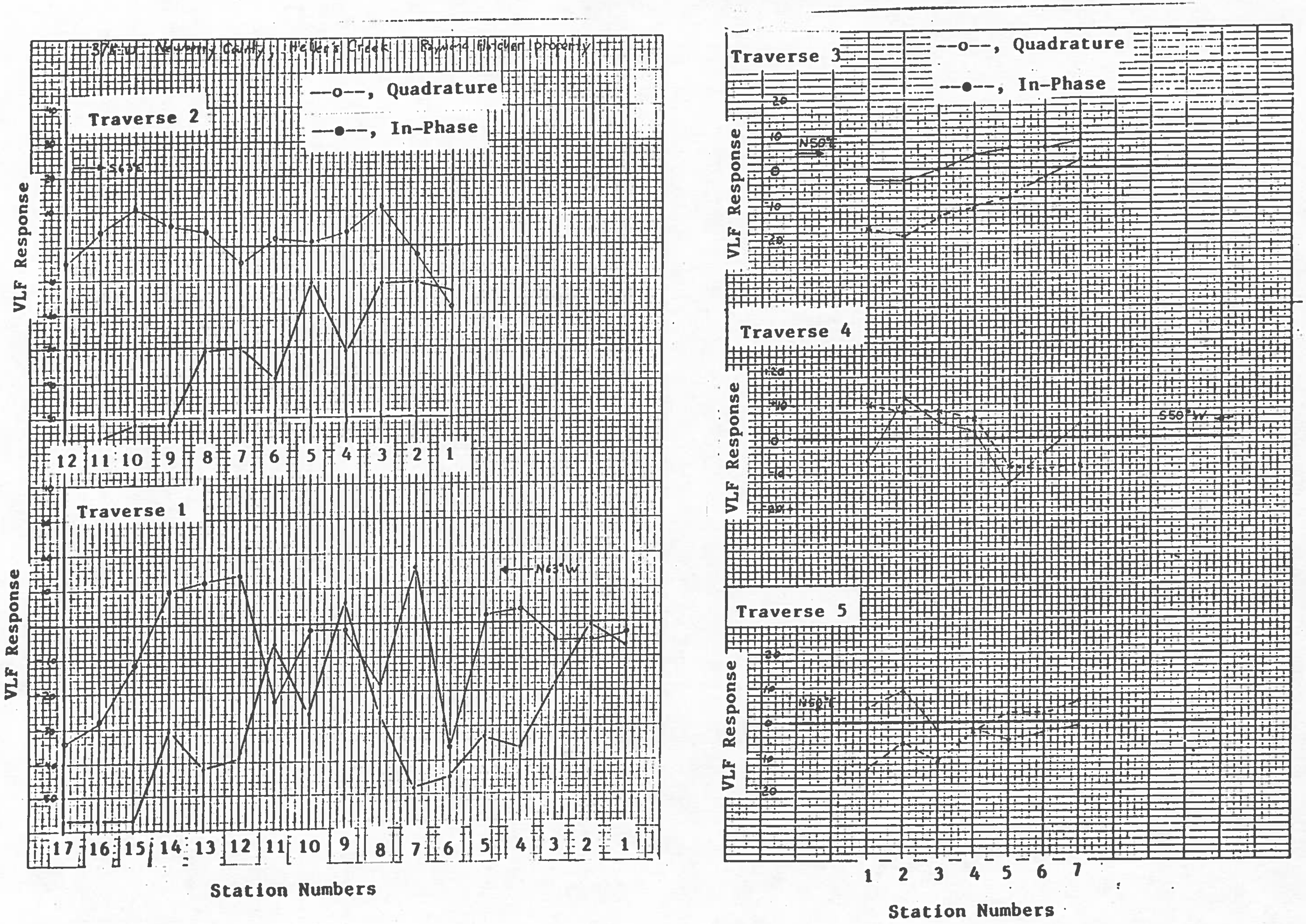


Figure 15. VLF plots of five traverses at Hatcher homesite, Hellers Creek Basin. Nine meters between stations.

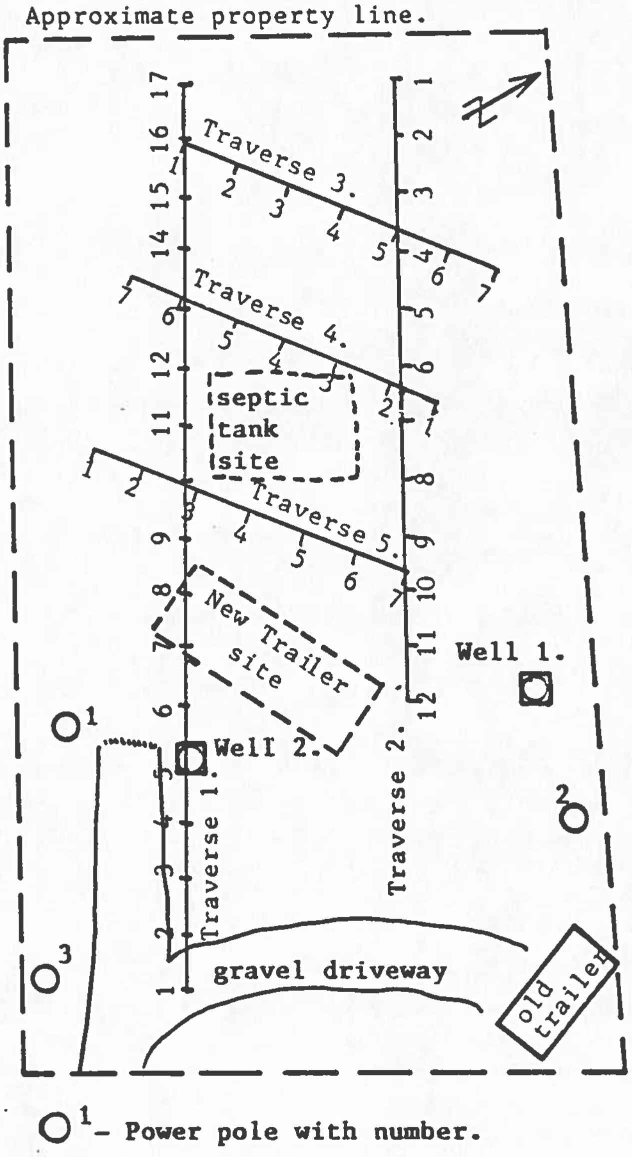


Figure 16. Layout of Hatcher homesite and VLF traverses, Hellers Creek basin.

Well 1 at the Hatcher site was not necessarily unsuccessful. The well was 115 feet deep and produced 30 gpm. The rock, however, was the partially weathered felsic gneiss. The water produced carried a significant suspended fraction which could clog the pump, thus making the well unusable. Well 2 required 105 feet of casing before solid rock was encountered and produced a reported 50 gpm.

### Radiohm meter mode

The radiohm meter, VLF-R, measures the resistivity of the earth volume down to the "skin depth". The VLF-R uses the same military radio stations as in the VLF-only mode. An attachment to the VLF instrument, with two cable-connected electrodes, allows the resistivity measurements. These electrodes are pressed into the ground, 5-meters in opposite directions from the instrument, oriented parallel to the radio station being used.

The VLF-R differs from the VLF in that it measures the ratio and the phase angle between the horizontal electric field and magnetic field of the VLF radio wave in order to measure the apparent resistivity of the ground. Apparent resistivity is the summed resistivity of two or more earth materials. The VLF-R allows the user to know if the underlying stratum is a single layer or two or more. A single-layer situation will give a phase angle reading of 45 degrees. A phase angle less than 45 degrees indicates a less resistive layer over a more resistive layer. A phase angle greater than 45 degrees indicates amore resistive layer over a less resistive one. In Hellers Creek basin nearly all phase angle measurements were less than 45 degrees, as expected.

The effective depth of penetration, or skin depth, depends mostly on the measured apparent resistivity and slightly on the radio frequency. Higher apparent resistivity allows deeper penetration whereas lower values decrease skin depth. For example, an apparent resistivity of 100 ohm-meters measured with the Cutler, ME, station has a skin depth of 33 meters (108 feet).

The same factors affecting VLF detection of fractures at the skin depth apply for VLF-R. Since the resistivity of the entire earth volume below the instrument to skin depth is measured, the fracture must be of significant contrast to be detectable. In most cases water-filled fractures will not be detectable at skin depth. A more reasonable expectation may be one-half skin depth.

Additional information must be available to allow reasonable interpretation of the apparent-resistivity measurements, particularly in the two-layer situation. The resistivities of the two layers must be known, as well as the thickness of the upper layer. This information can be used in the forward model computer package to interpret the VLF-R resistivity measurements. If some of these earth values are not known, trial-and-error can be attempted. So far our experience has not been good in trial-and-error.

In an attempt to supply some of these unknowns, various sites of suspected homogeneous subsurface situations were measured. Table 3 lists four outcrop sites, plotted on Figure 9, where VLF-R measurements were made.

TABLE 3

| Location | Resistivity | Phase angle | Radio Station |
|---|---|---|---|
| 1. | 450 | 23° | Cutler, ME. |
| | 410 | 28° | Jims Creek, WA. |
| | 410 | 22° | Jims Creek, WA. |
| 2. | 4250 | 44.5° | Jims Creek, WA. |
| | 18800 | 26° | Cutler, ME. |
| 3. | 500 | 29° | Jims Creek, WA. |
| | 320 | 62.5° | Cutler, ME. |
| 4. | 2000 | 20° | Jims Creek, WA. |
| | 4500 | 27° | Cutler, ME. |

Nearly all these measurements had phase angles less than 45 degrees, indicating more resistive material below less resistive surface layer. This is believable for stations 1 and 3 but most likely not for station 4, and especially not for station 2. The nearly 45 degree phase-angle measurement at station 2 was made on a large outcrop at an abandoned monument factory. The Jims Creek station measurement was made across a single fracture in the outcrop. The Cutler station measurement was made parallel to the fracture and was the highest measurement recorded. The low phase angle associated with this high resistivity could reflect incomplete instrument nulling, since something more resistive than 18,800 ohm-meters is unlikely.

No sites were found that were totally saprolitic to skin depth. No borehole geophysical logs exist in the vicinity which could possibly show saprolite resistivity values. Working against this alternative is the fact that electrical-resistivity borehole logs require saturated conditions. The long- and short-normal log tools require a 50-foot leader line which also must be submerged. This results in most logs in the Piedmont bypassing the saprolite.

At the Hatcher well site the unused well, well 1, was logged the day after it was drilled, using the 10-foot lateral electric-log tool that does not require the leader. Figure 17 shows the suite of logs that were obtained from that well. As can be seen, the logs go to only 50 feet, because of well collapse. It is interpreted that the typical saprolite extends down to 25 feet, and below that is the partially weathered felsic gneiss. This is based on the gamma log showing higher counts above 25 feet than below. If this is true then the partially weathered felsic gneiss has resistivity of approximately 1,000 ohm-meters, right in Figure 17. Above this, which is also above the water table, is the saprolite where no measurements were obtained.

It should be kept in mind that the lateral log measures the resistivity of a 10-foot cube of earth as the tool moves up the borehole. In many cases it is actually recording apparent resistivity. The Commission's geophysical logger operator is now working with using the single-point tool in the Piedmont. Initial results look very promising.

Logs obtained from wells drilled into the basement in the Coastal Plain were used to evaluate the buried-saprolite resistivity. The resistivity values for four examples range from 25 to 200 ohm-meters. One of the objectives for next year is to measure saprolite resistivity at many sites throughout the Piedmont and evaluate its variation with rock type.

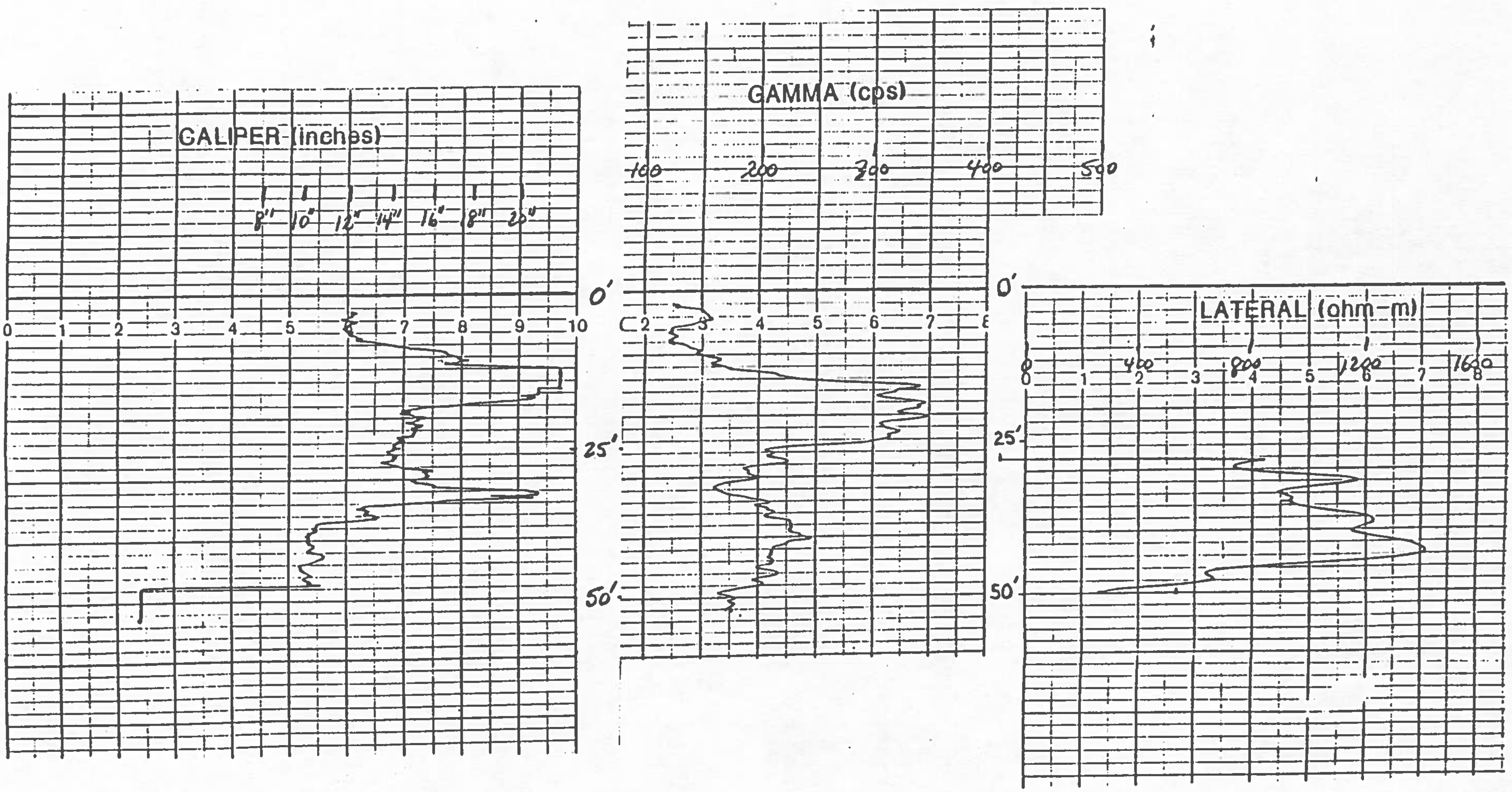


**Figure 17.** Borehole geophysical logs obtained from well 1, Hatcher homesite, Hellers Creek basin.

With the need for resistivity and saprolite thickness data in mind some results of the VLF-R unit are shown in Figures 18 and 19. Figure 18 shows the apparent resistivity measured at each grid point using the Cutler, ME, station. Resistivity highs occur in the north-northeast corner and in the south corner. Granitic outcrops were located adjacent to the northern high, but off the grid. The highs may indicate bedrock close to the surface. In the middle of the grid are resistivity lows. this could be a thicker layer of saprolite or it could be a fracture zone.

Figure 19 shows the apparent resistivity measured in the grid, using the Jim's Creek, WA, station. Resistivity highs are located in the northwest corner, the southeast corner, and in the southern section. A resistivity low is again identified in the middle. It is hoped that further analysis and massaging of all the VLF-R data will clear up some of the current variations in the results. Possibly the contouring of the absolute value of the difference in apparent resistivity may be significant. Phase-angle data will also have to be analyzed.

One persistent problem encountered throughout these surveys, primarily in the VLF mode, involved the audible nulling. Three steps were involved in making VLF measurements:

> The instrument must be aligned with the station. This was accomplished by nulling the audible sound as the antenna pointed at the station;
>
> Tilting the instrument until it further nulls the signal;
>
> Further nulling the signal with the Quadrature knob on the instrument.

It was our experience that the best station for the NE orientation was the Annapolis station, NSS. This station nulled only partially in the first step, allowing clearer and therefore easier nulling in the later steps. The Cutler station, and the Jims Creek station to a lesser degree, would almost completely null in the first step. The next two steps, especially the second, were very difficult to complete. The radio-ohm mode did not have this problem.

Consultation with the manufacturer, concerning the use of a meter instead of a sound, did not solve the problem. According to Geonics, a 'VU' meter has an inherent delayed response which may complicate the zeroing in on the correct alignments. They further stated that their studies showed that the human ear was more sensitive than the meter. An earphone was used but did not prove satisfactory. Measurements were made as best possible in light of the situation.

## Direct Current (DC) Resistivity

The Bison 2390 Signal Enhancement Earth Resistivity System was used during May 1988 to make profiles of resistivity soundings at the two test sites. We had it reserved for the month of April also but did not receive it due to its use in the training course in Denver the same month.

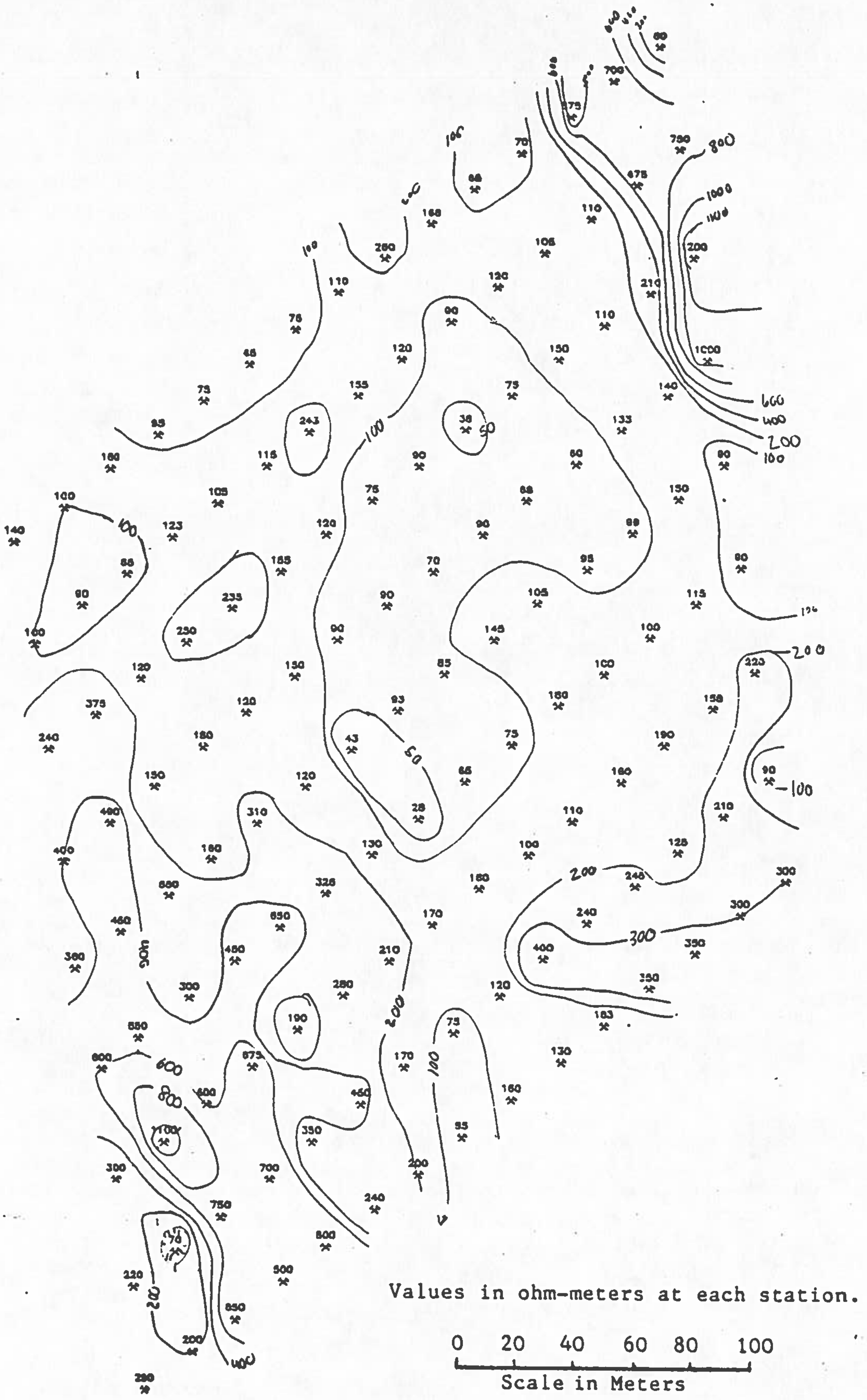


**Figure 18.** VLF-R apparent resistivity contouring at clear-cut grid, SE corner of Hellers Creek basin, for Cutler, ME, station.

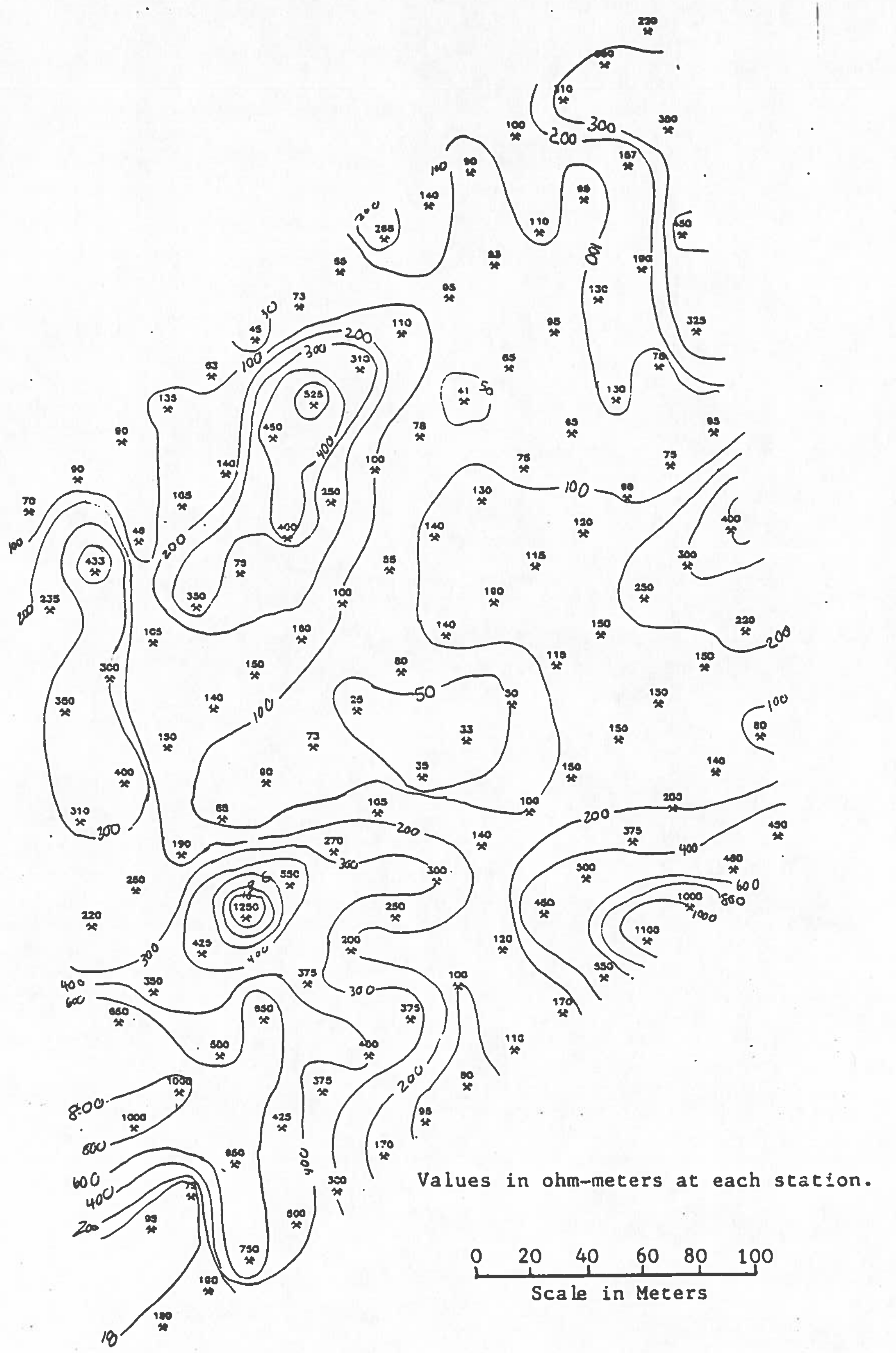


**Figure 19.** VLF-R apparent resistivity contouring at clear-cut grid, SE corner of Hellers Creek basin, for Jims Creek, WA, station.

The 2390 system has several more features than a typical DC Resistivity unit. The signal-enhancement feature stacks the continually received electrical measurements, producing a better reading. The system also includes a BOSS (Bison Offset Sounding System) unit, which greatly simplified the potential electrode switching. A chart recorder is also used to make sure the proper signals, square waves, are being received. This is primarily a double-check feature to allow the user to detect improper signal reception, and possibly erroneous data, in the field.

This system involves much more equipment than the VLF unit (requires three large wooden boxes weighing 450 pounds), and it takes longer to set up, but its measurements can be analyzed by computer and stand alone, initially. The results must be interpreted by an experienced hydrogeologist and correlated with borehole data.

The measurements are made with two sets of electrodes, a transmitter and a receiver. An electrical current is transmitted into the ground through two current electrodes. These electrodes are steel stakes driven into the ground a known distance apart. The current is received in two other steel stakes, or potential electrodes. The receiver displays values in millivolts which are converted by formula to apparent resistivity.

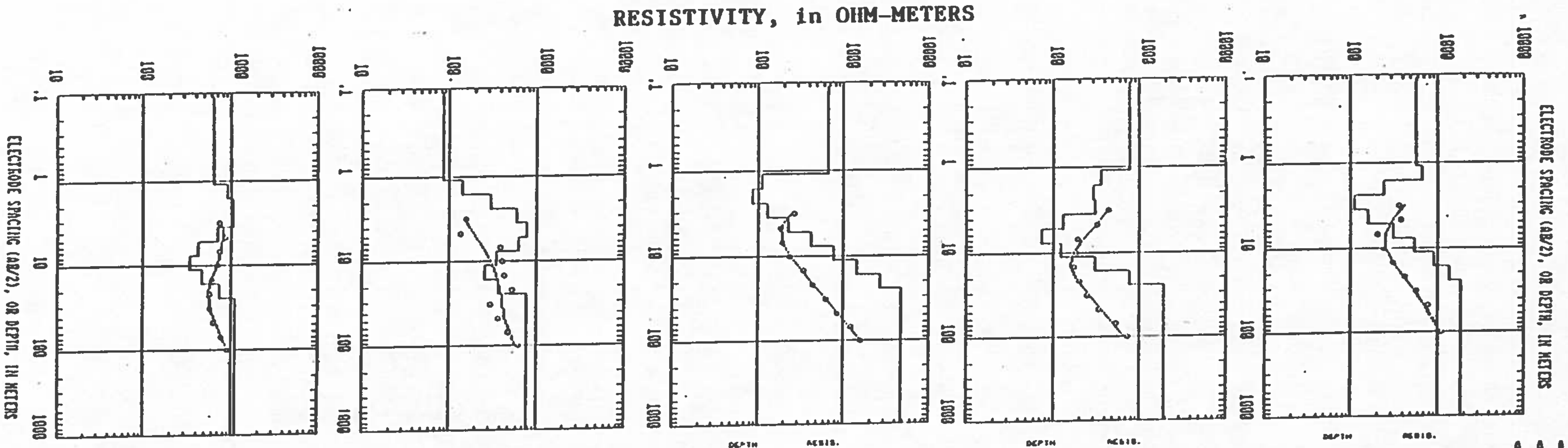
For the purposes of this study the electrodes were arranged in a Schlumberger array. This array has two sets of electrodes spread along a straight line, equally spaced from the center. The current electrodes are farthest from the center and the potential electrodes are located within one-fifth to one-tenth the distance to the current electrodes.

The current electrodes are labeled A and B and the potential electrodes are labeled M and N. Since the electrode arrangement is identical on either side of the center point, most workers discuss the electrode spacings in terms of one side of, or one half, the arrangement, such as AB/2 or MN/2.

Electrical soundings were conducted at seven locations in the clear-cut grid and five locations along U.S. 176. A sounding is the measuring of apparent resistivity for successively wider electrode spacings from the center point. The wider electrode spacings measure apparent resistivity deeper into the ground. The maximum electrode spacing used in most cases was AB/2 = 100 meters resulting in an assumed sensing depth of 33 meters (108 feet).

Most of the data gathered have not been analyzed, due to the fact that as soon as we turned in the DC Resistivity unit the next equipment arrived and we were in the field again. Figure 20 shows the computer inverse model output for the five soundings along U.S. 176, oriented northwest on left to southeast on right.

Below the model outputs is an interpreted section from the resistivity data. Two features stand out. Below sounding station 2 is a deepening of lower resistivity, indicating a potential fracture zone. This also lines up with the VLF profile crossover in Figure 14. Below stations 4 and 5 is a 400 ohm-meter zone, sandwiched between more resistive zones, that does not connect with the rest of the section. One possible explanation is that the left side is underlain by unfractured Newberry granite and the right by the felsic gneiss, with a fracture under station 2.



| DEPTH | RESIS. |
|---|---|
| 1.106797 | 623.9438 |
| 1.624556 | 893.9300 |
| 2.384522 | 1074.803 |
| 3.5 | 1027.647 |
| 5.137297 | 714.5375 |
| 7.540521 | 417.6119 |
| 11.06797 | 340.629 |
| 16.24556 | 452.9337 |
| 23.84522 | 723.0576 |
| 99999 | 1132.914 |

| DEPTH | RESIS. |
|---|---|
| 1.106797 | 86.11839 |
| 1.624556 | 140.4992 |
| 2.384522 | 311.9109 |
| 3.5 | 306.144 |
| 5.137297 | 775.5620 |
| 7.540521 | 634.7343 |
| 11.06797 | 368.6818 |
| 16.24556 | 266.3443 |
| 23.84522 | 349.2498 |
| 99999 | 765.6291 |

| DEPTH | RESIS. |
|---|---|
| 1.106797 | 680.3269 |
| 1.624556 | 110.515 |
| 2.384522 | 83.80938 |
| 3.5 | 131.3328 |
| 5.137297 | 227.0593 |
| 7.540521 | 417.7411 |
| 11.06797 | 783.8434 |
| 16.24556 | 1454.21 |
| 23.84522 | 2626.83 |
| 99999 | 4682.719 |

| DEPTH | RESIS. |
|---|---|
| 1.106797 | 763.8187 |
| 1.624556 | 364.3109 |
| 2.384522 | 280.0799 |
| 3.5 | 315.4594 |
| 5.137297 | 127.8954 |
| 7.540521 | 73.90601 |
| 11.06797 | 125.0643 |
| 16.24556 | 203.1452 |
| 23.84522 | 760.6335 |
| 99999 | 1967.672 |

| DEPTH | RESIS. |
|---|---|
| 1.106797 | 344.760 |
| 1.624556 | 675.8444 |
| 2.384522 | 233.6036 |
| 3.5 | 111.1632 |
| 5.137297 | 136.2492 |
| 7.540521 | 366.8424 |
| 11.06797 | 334.16 |
| 16.24556 | 910.1020 |
| 23.84522 | 1243.334 |
| 99999 | 1826.616 |

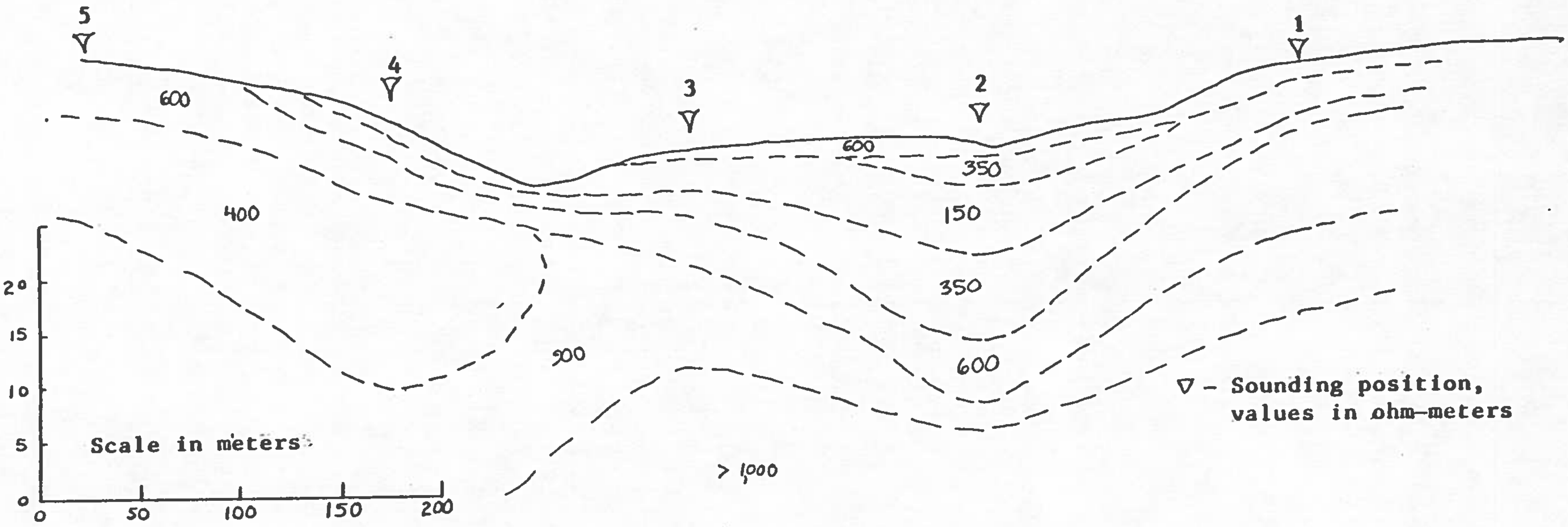


Figure 20. DC Resistivity sounding profile along U.S.176, Hellers Creek basin.

With further analysis it appears that several layers can be discriminated from ground surface down:

| Layer | Resistivity range, in ohm-meters |
|---|---|
| Dry saprolite | 350 - 600 |
| Saturated saprolite | 80 - 200 |
| Fractured bedrock | 400 - 600 |
| Solid bedrock | > 1,000 |

This is a preliminary analysis and much work is needed here, as well as with the clear-cut grid data.

Several equipment problems were encountered during the month, which cost field time but provided useful training also. The first was a novice-user problem; we didn't know how to correctly connect the equipment. No wiring diagram was provided and the manuals were not clear. When the correct wiring scheme was determined, a wiring diagram was drafted and added to the user manual.

One of the charging devices did not connect well, resulting in some equipment not being charged and more lost field time. The transmitter was not transmitting a current even though the battery check showed a sufficient charge. Where we could drive the truck to the sounding station, the truck battery was connected with special jumper cables. Inaccessible sites required a deep-charge marine battery to be carried to the sounding station. This problem further reduced the overland transportability of the system.

The bulk and weight of this particular equipment would make profiling prohibitive. Much information can be gained with soundings and making profiles from them. For this equipment to be time effective for use in identifying fractures it may have to be used in a profiling mode. It is planned to estimate in the next year's work some array spacings that would prove useful for identifying fractures, such as AB/2 of 8 and 40 meters. Lighter and less cumbersome equipment is available and may suit profiling well. The user, however, will need to know if poor data are being recorded, since many of the fail-safe devices of the USGS equipment will not be included.

## Terrain Conductivity

The Geonics EM34-3L is an electromagnetic device like the VLF instrument discussed above. A major difference between the two is that the EM34-3L is an active device; it transmits radio signals from its transmitter that are picked up by the receiver. This device measures terrain conductivity (reciprocal of resistivity), using a transmitted sinusoidally varying magnetic field to electromagnetically induce currents in the ground. This is done in such a manner that current amplitude is linearly proportional to the terrain conductivity. The magnitude of these currents is determined by measuring the magnetic field that they, in turn, generate.

This is done without ground contact, which greatly speeds up measurements of conductivity that can easily be converted to resistivity. Measurements are made by using two wheel shaped coils, one transmitting and one receiving, in both a horizontal position (vertical dipole orientation) and a vertical position (horizontal dipole). Three cable spacings are used, each with a specific transmitting frequency, which allows a stepwise estimated depth of penetration range from 7.5 to 60 meters. This is roughly the depth range covered with the DC Resistivity unit, which took 2 hours per sounding. Only 20 minutes were required with the EM34-3L.

The EM34-3L was used in June 1988. It is an easy device to use but it took some time to learn how to speed up making measurements. The receiver has two VU meters, one to indicate conductivity and one to indicate coil spacing. Locating the coils at their required 10-, 20-, or 40-meter spacing must be exact and is the most time consuming task. A data logger can also be connected to the receiver to automatically record the measurement.

Only the clear-cut site was surveyed, not U.S. 176, because of initially slow measurement. The coils, whether vertical or horizontal, were required to be parallel in orientation, and accomplishing this proved trying, especially in rolling and uneven terrain.

Two points of field technique helped to speed up the procedure. Using the 40-meter cable, with markings at 20 and 10 meters, allowed all six measurements to be made with one pass over the stations. Previously it was thought that each cable had to be used for each spacing. Centering the coil spacing with the coil in the vertical position was much easier than in the horizontal position. Employing these two techniques speeded up the surveying from 45 minutes per station to 20 and sometimes 15 minutes per station.

To date, none of the data gathered with the EM34-3L have been analyzed. Much can be done with the data, such as to manipulate it with the forward modeling software provided by USGS and plot the profiles of the data from station to station. Contouring of all the data in the grid may also prove useful.

Alkaline batteries were used in the transmitter, receiver, and data logger. All of them seem to have been drained within 3 weeks of when they were loaded, which is a shorter life than expected. Of particular concern was the battery drain in the data logger. The batteries drained quickly, and upon changing them all recorded data were lost. The downloading software was also lost and could not be transferred from the Commission's PC computers to the data logger. The latter could be a communications-cable problem and will be investigated shortly. This device will have to be checked into further before the authors trust it.

## WADI

As was mentioned in the beginning of this section, the WADI, a VLF instrument, was not used by any of the Commission staff during this first 6-month period. The WADI was purchased during this period but did not arrive until the other surface geophysical equipment was already being used. A USGS technician experimented with the WADI in the clear-cut grid but the data were not downloaded. A data-management error resulted in the measurements being lost in the WADI.

The WADI is a VLF instrument and works identically to the Geonics EM-16; however, many of the functions are automated such as all the nulling routines, the major operational problem we had with the EM-16. The readings are stored also for downloading in various ways, for manipulating with the WADI, and for display on its screen. Preliminary work with the WADI have shown it to be a very rapid instrument in use. Further work this next year should define its capabilities and applicability to Piedmont hydrogeology.

## DATA ANALYSIS OF SURFACE GEOPHYSICAL SURVEYS

To date, only initial analysis of the data has been possible because of the tight scheduling of the equipment. The analysis work that has been attempted has been discussed above in the appropriate sections. Further analysis and cross correlation between results will be part of the next year's work.

## CONSULTATION WITH CHARLES DANIEL,III

Because of the problems encountered in the geologic portion of the Lithologic-Geomorphic Terrain analysis, Charles Daniel was not consulted. We talked with him briefly at a conference in Atlanta, Ga, in May 1988. We intend to meet with Mr. Daniel in the fall of 1988 to discuss our findings, as well as our problems.

## Second-Year Objectives

1. Interpret surface geophysical data obtained during the first 6 months.

   Most of the data remain to be analyzed and interpreted. Because this is the first time we have been involved in such analysis, it will most likely take more time than future analysis.

2. Remote-sensing lineament mapping with comparison of success and economics.

   As discussed earlier in the report, the various imagery will be lineament mapped and the results will be compared in regard to lineament identification success, time involved, size of lineament identified, and cost of imagery.

3. Analyze well data for geomorphic statistics.

   Compile statistics concerning the wells, analyze the plotted wells for correlations of yield, depth, and other characteristics in relation to location and topography.

4. Establish water quality and water level monitor wells in the Hellers Creek area.

   Develop a set of wells in and around Hellers Creek basin with which to make water level measurements and collect samples for water analysis. These data will be used in conjunction with the ground-water flow model being developed for the basin by USGS.

5. Conduct EM34-3L surveys throughout the Piedmont to determine saprolite resistivity and conductivity.

   Because the saprolite turned out to be more resistive than at first anticipated, it was decided to try to determine saprolite resistivity at many sites throughout the Piedmont. Sites will be chosen to reflect the varyious geology of each belt. A map and supplemental report could be developed from this work.

6. Review areomagnetic data for the Piedmont and evaluate its usefulness for ground-water exploration. Compare with results obtained in Objective 5.

   Various scales of aeromagnetic maps have been produced, ranging from statewide coverage to 7-1/2 minute topographic maps at various locations. The results obtained in Objective 5 will be compared, where possible, for any correlations that may prove useful for fracture identification.

7. Conduct seismic, magnetometer, and WADI surveys at established test sites.

   These additional pieces of surface geophysical equipment will be evaluated for their potential in locating water-bearing fractures.

8. Locate and drill wells in Hellers Creek basin to add to interpretive knowledge at test sites. Also establish ADR wells, a rock well, and a saprolite well near it.

   No monitoring well data dealing with the correlation between the saprolite and fracture water levels exist in the Piedmont. This will provide an excellent opportunity to start this as well as provide data for the ground water model for the basin.

# APPENDIX 1

## Project Proposal

PROJECT PROPOSAL SC87f

PROJECT TITLE AND LOCATION:

Evaluation of the use of Surface Geophysics, Surface-Water data, Geomorphic data, and Remote Sensing Methods to Predict Yields of Ground Water from Piedmont Aquifers in South Carolina.

## PROBLEM, NEED, AND HYDROLOGIC CONDITIONS

The nature of ground water ocurrence in crystalline rock terrain makes it difficult to assess its flow and yield potentials. This hinders the correct analysis of a crystalline rock aquifer's potential to yield economically significant volumes of water as well as its susceptibility to pollution and contamination.

Ground water flows through the faults, fractures, joints, and bedding or foliation planes in crystalline rock. Outside of these high porosity zones ground water flow through the rock is virtually nonexistent. In most instances, the rock is mantled by a layer of in-place weathered rock called saprolite. This saprolite is the principal ground-water recharge reservoir to the water-bearing zones. Thicker saprolite provides a larger reservoir but also masks surface evidence of the water-bearing fracture zones.

Detection of these zones at the surface is difficult and requires the interpretation of indirect manifestations of the subsurface features. The ground-water exploration methods to be investigated in this project are intended to help overcome the hindrances to locating these water-bearing zones. These exploration methods need to be systematically evaluated for their success, reliability, and cost-effectiveness in locating high-yield ground water supplies in the crystalline rock Piedmont.

Contaminants move along the same pathways as water. In the Piedmont rocks these pathways are the faults, fractures, joints, and bedding or foliation planes. Successful employment of these exploration methods will also allow the delineation of these flow pathways for the identification of actual or potential contaminant transport. This would be very helpful in the siting of landfills and industries which handle hazardous materials.

Many towns, rural communities, and most rural domestic residents in the Piedmont Province of the Southeastern United States depend on ground water for their water supplies. Many of these water users not only faced difficulties in locating their ground water supply initially but some planning is needed for future water demands. These additional supplies are necessary to meet short-term, peak water demand in the event of a drought, as experienced during 1986, as well as projected increased demand for public supply, commercial, and industrial growth.

Extremely low precipitation during the winter, spring, and most of the summer of 1986 resulted in a severe drought in much of the Southeastern United States. Extremely high temperatures exacerbated the problem. Both of these factors caused an increase in demand for water from municipal, industrial, and household water supply systems, which were also being stressed by drought-lessened water supplies. Water supply managers and homeowners were forced to reassess their water resources situation.

It is popular belief that only small volume users can depend on ground water resources in crystalline rock areas. There are several instances, however, in which wells in crystalline rock have proven to be adequate for large supplies. For example, this past summer the South Carolina Water Resources Commission successfully located a municipal well site, which produced a 250 gpm well in the Inner Piedmont geologic belt. It should be noted that this site was not the primary choice, as the optimum well site chosen was unavailable for use since it had already been designated by the town for a future sewage treatment plant. The exploration method applied involved the analysis of the site geology, and an assessment of the topographic map for linear features, similar to the method described by Daniel and Sharpless (1983).

The above example demonstrates the successful application of improved ground water exploration methods. It also demonstrates one of the problems faced in the development of municipal or industrial water supplies in crystalline rock terrain. Ground water wells cannot be located for convenience; they need to be located in the water-bearing fractures, wherever that may be in the community or on the industrial or homeowner's site. Successful exploration methods will allow existing and potential ground water users to assess where they will be able to develop future supplies and make appropriate plans.

A variety of techniques, some old and some new, are available to evaluate ground-water resources in fractured rock overlain by saprolite. The need that will be addressed in this project is for a systematic combination of the available techniques in an environment that permits evaluation of their effectiveness. The project will make use of advances in surface geophysics, surface-water data analysis, geomorphic and geologic data analysis, remote sensing, and geographic information systems to delineate the ground-water flow system in a test basin, estimate a water budget, and evaluate well yields. Some well-yield data will be withheld during the evaluation, to be used as a check on the ability to predict yields.

A systematic approach was developed for the analysis of crystalline rock for locating high-yield ground-water wells (Daniel and Sharpless, 1983). This procedure involves the analysis of the topography, particularly the drainage pattern, as it relates to the underlying geology.

Linear features, such as segments of stream channels and saddles in ridges, that align in close proximity to each other are believed to be the surface manifestation of fracture traces in the underlying rock. The orientation of these lineaments is related to the geologic structure which may control the local drainage. This allows the assessment of recharge to given points along the lineament and helps in selecting the most desirable well site.

An important element to include in the selection of the potential well site is the thickness of the overlying saprolite. The saprolite stores the majority of the ground water that recharges fractures and the bedrock. Areas with thin saprolite are considered poor sites. In general, the thickest saprolite indicates the best recharge reservoir and therefore the best well site.

The use of stereo air photo interpretation for mapping lineaments (fault-, fracture-, and joint-traces) has been quite successful (Lattman, 1958, and Gold, 1977). In conjunction with this, the techniques for locating ground-water wells in crystalline rock terrains by their relationship to fracture traces (Lattman and Parizek, 1964) has been employed successfully for some time.

These photo interpretation techniques will be employed for locating lineament traces in each of the test sites. Once identified, these lineaments will be field checked to verify their geologic character as opposed to man-made features. It is the intent of this investigation to test and compare the applicability of this ground-water exploration method in the igneous and metamorphic terrains of the Southeastern Piedmont.

The concept of using radio signals for mineral exploration has been known since the turn of the century, when measurements of attenuation and polarization were conducted by Hack in 1908 and Feldman in 1933 (Paterson and Ronka, 1969). Electromagnetic methods using radio waves from portable transmitters were employed as early as the 1930's for prospecting and geological mapping. Mapping of coal seams and exploration of base-metal ores using radio-frequency methods continued in Europe, and, in the Soviet Union, radio-shadow techniques in drill-holes successfully explored and mapped sulfide ore bodies (Paterson and Ronka, 1969)

Electromagnetic techniques were not used routinely until 1964 when passive VLF (very low frequency) equipment became available. This technique uses signals from powerful naval transmitters across the world (Paterson and Ronka, 1969). Since then VLF and other EM systems have gained widespread use in geologic mapping and mineral exploration.

Earlier use of VLF techniques for geologic exploration was difficult because of noise generated by the relatively high frequency used. Fraser (1969) developed a data manipulation technique which filtered the noise and rendered data suitable for contouring. This technique was particularly successful in exploration for near-surface ore bodies because of their high conductance (Fraser, 1969). Shallow geologic structures were mapped near Ottawa, Canada, using VLF. The information obtained from this survey agreed well with other geologic data (Telford and others, 1977). While this VLF survey was useful in locating subsurface anomalies such as faults, it did not provide much information on the nature of the rocks surrounding an anomaly, and had to be supplemented with apparent resistivity data. Thus the VLF method was noted as a "useful qualitative supplement to field geology mapping" in "simple structures" but also a technique subject to errors of interpretation from lateral changes in overburden resistivity or abrupt changes in overburden thickness (Telford and others, 1977).

More recently VLF techniques have been used to map fracture zones of a granitic pluton in the Canadian Shield at the site of a planned underground nuclear waste laboratory. While highly conductive overburden limited the use of VLF data in mapping deep bedrock, the trends of major vertical fracture zones detected with the technique agree well with mapped fracture traces and resistivity surveys (Soonawala and Dence, 1981).

A VLF (apparent resistivity) instrument was used for mapping a massive sulfide prospect in the MacKenzie District of Canada's North West Territories. The area is underlain by permafrost and exhibited wide variations in resistivity, but the data was adequate to map the complex geology (Scott, 1974).

Exploration for ground water using direct current resistivity techniques has been a common practice more than 50 years, and is probably the most favored method still in use. Electromagnetic surveying techniques, however, were developed primarily for geologic mapping and mineral exploration. Even though electromagnetic techniques for ground water prospecting were first demonstrated in Sweden in 1933, these methods have not been extensively applied in the past (Paterson and Bosschart, 1987). In the last few years, however, electromagnetic techniques have been used in a wide variety of ground-water problems.

Electromagnetic techniques were used in Pre-Cambrian rocks of Burkina Faso in a ground water exploration and development program (Palacky and others, 1981). The geology of this area of West Africa is characterized dominantly by crystalline rock, overlain by a residual weathered layer, usually 15 to 40 m thick. The weathered layer is generally permeable but because of the region's aridity it is often dry. Water can be found at its base in a transition zone, which, however, is usually of insufficient thickness to be a viable aquifer. Weathering is deeper in fracture zones and these generally form excellent aquifers. It is these narrow fracture zones that must be drilled into for an adequate water supply. Missing these zones by even a few meters may produce only a dry hole (Palacky and others, 1981).

The generally dry weathered layer contrasts with the water-bearing fracture zones beneath it and their differences in conductivity are detected easily by VLF techniques. These techniques were used very successfully in locating these fractures. It is also important to know which of the two dominant lithologic types (granite/gneiss suite and metamorphosed volcano-sediments) underlie the weathered layer, as the metamorphosed volcano-sediments usually weather more deeply than do the granite/gneiss suites. HLEM responses vary for the weathered layer depending on the residual lithologies, and the two major rock types are easily distinguished from each other (Palacky and others, 1981).

Combining data from VLF and EM surveys produced very good results in ground water exploration. During the 1980 field season, 23 out of 24 wells drilled were successful. Another major advantage in using the VLF and EM techniques was the speed, ease, and accuracy over conventional resistivity methods (Palacky and others, 1981).

Dirks and others (1983) report similar results using EM techniques in hard rock areas in West Africa, again by locating narrow fracture zones in the bedrock. In southern India, a VLF survey successfully located ground water in a geological setting similar to that of West Africa, but with a different hydrological system (Poddar and Rathor, 1983). The major aquifer is a weathered rock layer which overlies a granite-gneiss basement in one area, and overlies basalts and dolerites in another. In the granitic area, the weathered layer is permeable and very conductive because of its high water content, which generally masks effects on the VLF of the underlying bedrock. Anomalies in VLF measurements are therefore attributed to the weathered layer itself. The data is interpreted as thickness of the weathered layer (depth to bedrock).

The basaltic area is similar in response but also has a thin clay layer between the weathered layer and bedrock. This clay layer almost completely prevents the bedrock resistivity from being measured. In general, therefore, for both areas the VLF instruments are used for interpreting resistivity and thickness of the weathered rock layer, the major aquifer (Poddar and Rathor, 1983). In both cases, VLF surveys provided a fast and inexpensive tool for mapping the weathered layer, after calibration of the equipment in a few resistivity soundings (Poddar and Rathor, 1983).

In regional tests with the techniques in Sweden, not only has the VLF been demonstrated to be an excellent locator of fractured water-bearing zones, but quantitative analysis can be performed from the data, in which given similar geologic regimes, a stronger VLF anomaly represents a larger amount of water available (Mullern and Eriksson, 1982).

EM techniques have been used at a hazardous-waste landfill site in Minnesota to evaluate fluid flow through fractured bedrock (Technos, 1985). The EM techniques detected increased conductivity in the fracture zones, and conductivity was increased (and EM detection enhanced) if the water was contaminated.

In the Netherlands, ground-water pollution plumes were mapped from a waste disposal site in sedimentary rocks, using VLF and EM (Ritsema, 1983). Besides being quicker and less expensive than conventional resistivity methods, the results of the newer techniques were in agreement with resistivity and borehole data (Ritsema, 1983).

Paterson and Bosschart (1987) list several advantages of EM methods over standard resistivity techniques:

1. Em methods require no contact with the surface, as do resistivity measurements.

2. EM methods can be done by "parametric" sounding in which readings are made at different frequencies at one station for a complete depth and conductivity survey, whereas conventional resistivity methods are "geometric", which require physically moving electrodes several times at increasing distances for each sounding.

3. A better profile resolution can be achieved with EM methods because EM data readings can be spaced much closer together. This high resolution is especially important in narrow bedrock fracture aquifer systems.

4. EM methods combine sounding and profiling in one operation while conventional methods require separate and more time-consuming operations.

5. EM measurements can be carried out from moving platforms such as aircraft.

Electromagnetic (EM and VLF) methods have been shown to be useful in locating fracture zones and in estimating weathered layer thickness and lithologies, and doing so in a time- and cost-effective manner. The techniques are less labor-intensive than traditional resistivity surveys and more economical, and can therefore cover larger areas for a smaller investment in time and finances.

While electromagnetic surveys have been conducted in many parts of the world, no such survey is known to have been done in the southeastern Piedmont of this country. The geology of this region is very similar to that described for Burkina Faso (Dirks, 1983; Palacky and others, 1981; Paterson and Bosschart, 1987) and southern India (Poddar and Rathor, 1983), where EM and VLF techniques have been successful in locating ground water supplies.

However, there are major differences in the hydrology. The West African crystalline rock sites, being in arid and semi-arid climates, are dependent on narrow fracture zones for their ground water supply. The tropical southern India sites, also in crystalline rock, are more dependent on their weathered rock layers for ground water. The Southeastern Piedmont, on the other hand, is a temperate climatic zone in which water is found in both the weathered layer (saprolite) and fracture zones. If large water supplies are needed, however, only the fracture zones will be adequate.

The difficulties in interpreting Piedmont hydrological systems lie in differentiating between the highly conductive weathered layer and the highly conductive fracture zones. The fracture zones need to be located without the interference on EM and VLF measurements by the weathered layer. In the West Africa prospect sites the relatively dry weathered layer permitted underlying fractures to be located; in the southern India study area the saturated weathered layer hindered fracture locating but this was not critical since the major water supply there is the weathered layer.

Information on the distribution of streamflow in space and time, particularly during periods of low flow, can be useful in understanding ground-water flow and availability. Low-flow duration statistics indicate the rate of dependable flow discharging from aquifers into a stream. Simultaneous streamflow measurements at different locations along the stream identify ground-water discharge rates associated with various geologic features in the basin. Combining streamflow data with well yields and meteorologic data permits estimation of a water budget for the basin.

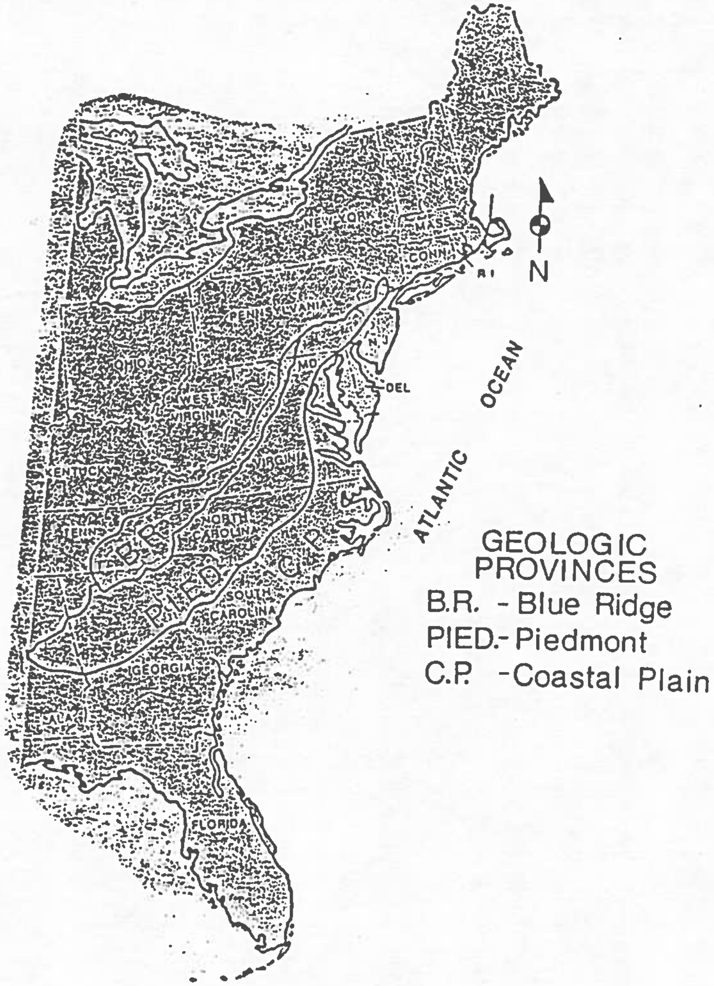


Figure 1. Map of the Eastern United States showing the orientation and distribution of the Piedmont Geologic Province.

The various techniques to be applied in this project will lead to a data base containing many different kinds of information, most of which will be associated with specific geographic locations. A geographic information system will be developed to store, manipulate, and display the data in forms that will further the objectives of the project.

The Southeastern Piedmont therefore presents the challenge of combining techniques used in other areas to interpret its hydrogeological framework and enable accurate locating of important water-bearing fracture zones. The aquifer system of the Southeastern Piedmont is dependent on both the overlying weathered layer (saprolite) and the fractured bedrock as a whole. The development of a practical field methodology, interpretation technique, and exploration models in the use of EM and VLF for ground water evaluation will greatly enhance current efforts in improving water supply and quality in the region.

## PURPOSE AND OBJECTIVES

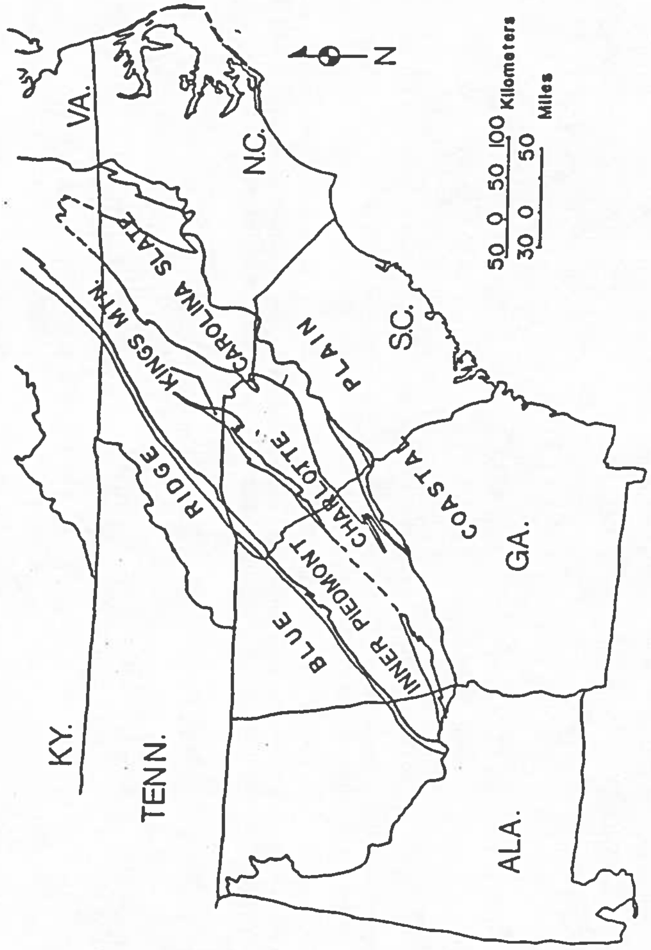
The purpose of this project is to evaluate the utility of combining a variety of techniques for assessing availability of ground water in the South Carolina Piedmont. Specific objectives include:

A. Select a study basin based on criteria of size, land use, geology, and availability of data on streamflow and well construction and yields.
B. Collect and analyze data on geology, soils, topography, land use, geomorphology, and hydrology.
C. Withhold well yield data for later checking of well yield predictions.
D. Perform fracture-trace analysis of air photos and other remotely sensed data such as LANDSAT, and SLAR of the study area.
E. Conduct surface geophysical surveys using electromagnetic surface conductivity (EM), very low frequency EM (VLF-EM) and, if possible, other techniques such as resistivity, ground-penetrating radar, and seismics.
F. Develop a geographic information system to store, manipulate, and display the combined data.
G. Use a relation between the various parameters determined for the basin to construct a map showing relative availability of ground water in the basin.
H. Test the map using the withheld well-yield data.
I. Present an evaluation of the methods, along with results of the investigation, in a report.

## APPROACH

### Study Basin Selection.

The Piedmont crystalline rock province of the Eastern United States extends from New Jersey and Pennsylvania in the northeast to Alabama in the southeast, crossing through Maryland, Virginia, North and South Carolina, and Georgia (Figure 1). This province is bordered to the northwest, for most of its length, by the Blue Ridge province. To the east and southeast, this province is bordered by and underlies the Coastal Plain Province made up of Cretaceous age and younger sediments.



Modified from: Hatcher, 1974

Figure 2. Map of the Southeastern United States showing the location of the geologic belts within the Piedmont Geologic Province.

The Piedmont rocks originated as sedimentary rocks, being deposited in the late Pre-Cambrian through Paleozoic time (Overstreet and Bell, 1965) in an island arc environment. Following the deposition the plate collision between North America and Africa subjected the sediments to metamorphism and syn- and post-kinematic igneous plutonism.

This metamorphism produced a series of parallel rock belts, running roughly the entire length of the Piedmont Province. In the Southeastern Piedmont the major belts are, from northwest to southeast: Inner Piedmont belt, Kings Mountain belt, Charlotte belt, and Carolina Slate belt (Figure 2). Each of these belts differ by metamorphic grade and rock assemblage.

A study basin encompassing one or more of these rock types will be selected for the initial focus of the project. Ideally, later phases of the project will incorporate additional study basins in different rock types.

The selected basin will have some streamflow and well-yield data available. It will be large enough to represent a range of geologic and topographic features, and small enough to permit field surveys of surface geophysics. Land use will be predominantly rural, which will afford a straightforward relation between surface water and ground water.

Four small drainage basins currently under consideration as shown in Figure 3, are:

1. Hellers Creek near Pomaria, South Carolina, in Newberry County, containing 8.16 $mi^2$ of drainage area, 7 years of streamflow records, a part of the Broad River basin, and underlain by Charlotte belt rocks;
2. Hamilton Creek near Easley, South Carolina, in Pickens County, containing 1.60 $mi^2$ of drainage area, 6 1/2 years of streamflow records, a part of the Saluda River basin, and underlain by Inner Piedmont belt rocks;
3. Lawsons Fork Creek at Dewey Plant near Inman, South Carolina, in Spartanburg County, containing 6.46 $mi^2$ of drainage area, 8 years of streamflow records, a part of the Broad River basin, and underlain by the Inner Piedmont belt rocks;
4. Neals Creek near Carlisle, South Carolina, in Union County, containing 12.3 $mi^2$ of drainage basin, 7 years of streamflow records, a part of the Broad River basin and underlain by Charlotte belt rocks.

<u>Basin analysis.</u>

The selected basin will have a complete background data compilation and assessment. The resulting conceptual model of each site will include:

A. Geologic model:
   - mapping and digitizing of site geology and structure;
   - analysis of existing borehole geophysical data;
   - inventory of existing wells and analysis of well data;
   - digitization of existing soil survey maps.

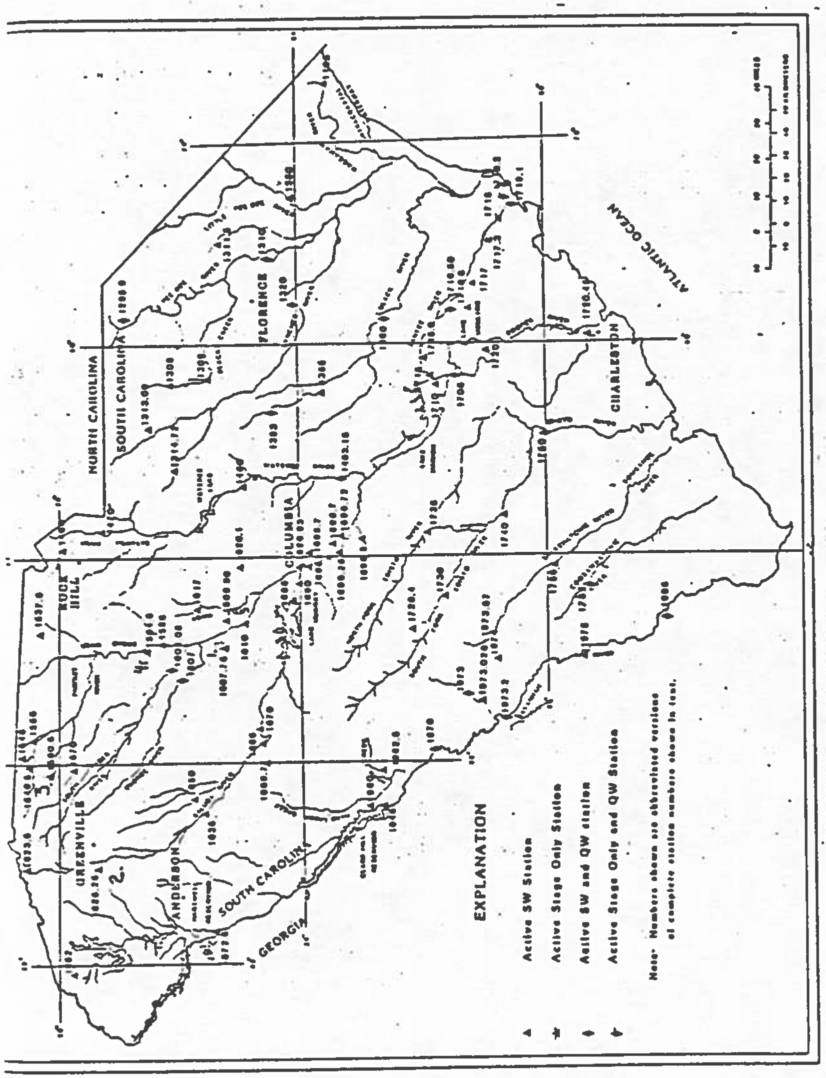


Figure 3. Proposed study basin locations.

B. Hydrologic model:
- drainage basin delineation;
- surface water low-flow analysis and seepage run for estimation of ground water recharge and discharge;
- existing ground-water level data;
- local rainfall-runoff relationship, and

C. Climatologic model:
- annual and monthly precipitation statistics for the basin;
- assessment of current situation through the use of cumulative departure from normal plots.

### Lithologic and geomorphic terrain analysis.

A site selection procedure for locating high-yield wells in the Piedmont terrain by Daniel and Sharpless (1983) will be pursued. This involves a geomorphic terrain analysis of surface drainage patterns relative to the underlying geology and reconnaissance mapping for areas of thick regolith and high water table.

### Air Photo interpretation for mapping of photo lineaments.

Stereo air photo interpretation will be conducted at scales of 1:40,000 for regional analysis and 1:9,000 for detailed site analysis. Photo lineaments will be transferred to a base map and digitized for later analysis of preferred orientation, length, and frequency of occurrence. These photo linears will be field checked to eliminate man-made features.

Other remotely sensed images will be investigated for their applicability to lineament mapping. Side-Looking Airborne Radar (SLAR), National High Altitude Photographs, and aeromagnetic surveys will be reviewed. However, their small scale may make them unsuitable.

### VLF-EM Water evaluation.

Basically, the electrical conductivity of a substance is a measure of the ease with which an electric current can be made to flow through it. It is generally electrolytic and takes place through the moisture-filled pores and passages which are contained within the insulating matrix. The minerals in sand and silt soils are electrically neutral and generally excellent insulators. Completely dry clay is also an insulator, but if moistened it changes its properties radically. Rocks because of their very small primary porosity are insulators too except where secondary porosity has developed.

When porewater is not particularly saline, the soil and rock electrical properties may be strongly influenced by the lithology and geologic structure. If these geological features (joints, fissures, fractures, etc.) are saturated, they become good conductors and are responsible for anomalies encountered during resistivity surveys. The interpretation and understanding of such irregularities could be used to delineate and locate potential aquifers in crystalline rock, such as those of the Southeastern Piedmont.

Surface Resistivity. surface resistivity methods mainly will be applied to obtain background information and to calibrate EM equipment. To calibrate the EM instrument, the conductivity in a region of very resistive ground is obtained from a set of resistivity soundings. The reciprocal observed resistivity values subsequently are used to set the instrumental zero of the EM meter. The Wenner array consisting of four equally spaced electrodes is used for this purpose because calculation of apparent resistivities (and therefore conductivities) is simple, and portable, low current instruments can be used.

For purposes of comparison, at least two resistivity profiles will be conducted across each site using Schlumberger arrays. Zohdy and others (1974) present a number of arguments in favor of Schlumberger soundings, as opposed to Wenner array soundings, including less time and manpower and relatively less sensitivity to stray currents. Most importantly, lateral variations in resistivity are more easily recognized, and therefore more effective for the identification of vertically oriented fresh-water bearing fractures zones while profiling.

For correlation to topographic and photometric observations and VLF and EM surveys, Schlumberger profiles will be conducted along lines coincident with two of the profile lines of the VLF and EM surveys. The appropriate electrode spacing is determined from soundings and use of a two-layer interpretation (assuming low resistivity saprolite and high resistivity bedrock) and the profile is obtained by moving the array along lines normal to the fracture trace. If arrangements to obtain a more powerful unit succeed, an AB array might be applied in areas where sufficient space exists. The AB array uses current electrodes spaced at distances of 3,000 ft or greater while the potential electrodes are moved along the middle third of the array.

Very Low Frequency Electromagnetic Techniques. The VLF-EM evaluation methods relay on the measurement of a secondary field generated by conductive bodies in the ground when subject to a primary EM (electromagnetic) signal. Under certain conditions the apparent resistivity of these bodies can be estimated from measurable components of the fields. The primary field can be generated either from a remote station or from within the instrument. The remote stations are powerful military radio transmitters that operate at VLF (very low frequency) to communicate with submarines.

The radio waves penetrate the ground and are disturbed by electrically conductive bodies. These bodies may be rocks containing significant amounts of conductive minerals (magnetite, hematite, graphite, etc.), or water-bearing fracture zones (Mullern, 1982). These perturbations can be recorded with VLF-EM instruments and analyzed to determine the potential of these fracture zones as aquifers, or the occurrence of ground water with higher electrical conductivity due to contamination (Dirks and others, 1983).

The principal advantages of the inductive EM technique over conventional resistivity are the speed and accuracy with which lateral changes of terrain conductivity can be measured. This technique can also be used to measure vertical variation of conductivity by expanding the intercoil spacing in a manner analogous to that in conventional resistivity sounding techniques. However, it is limited to only three frequencies.

### Interpretation of EM (electromagnetic) Data.

The interpretation of EM data is possible by assuming models representing the natural system. The earth is represented by homogeneous layers of different conductivities and thicknesses. In reality, each layer evidences inhomogeneities in both thickness and conductivity complicating the analysis of data. Several techniques have been developed to consider the departure from horizontal uniformity by using suitable phasor diagrams (Poddar and Rathor, 1983, p.527).

A conceptualized profile of the crystalline rock consists of the following segments (see Figure 4, top to bottom): a crust of residual quartz- and organic-rich soil several inches thick (A horizon); a zone of completely weathered rock from 1-4 feet thick (B horizon); and a zone of active weathering from 4-100 feet (C horizon).

1. The aquifer in the weathered zone (C horizon) has a low hydraulic conductivity, is subject to seasonal variations, and because of its proximity to the surface is very susceptible to contamination.

2. The aquifer in the fractured zones (below C horizon) is excellent because of the high hydraulic conductivity (high secondary porosity), and considerable saturated thickness of the overlying material. Drilled wells in these aquifers have a substantial yield and are less subject to seasonal variations and contamination.

An adequate physical model to represent the weathered profile of the crystalline rock would be a three-layered model of which the upper layer represents soil, the middle layer weathered rock, and the lower layer unweathered rock. Current research in igneous and sedimentary rock of other continents suggests that the upper soil layer has a low conductivity and could be ignored (Poddar and Rathor, 1983). The physical model could therefore be reduced to a two-layer model comprising a weathered layer resting on fresh bedrock (see Figure 5).

In situations where the weathered rock zone does not behave as a horizontal layer, Palacky and others (1981) suggested the use of a more realistic model. This is the valley discontinuity model, in which the fracture zone is approximated by a valley-shaped increase in the thickness of the weathered zone. Theoretical responses and phasor diagrams for this model have been published by Villegas-Garcia (1979).

When using the EM in its apparent resistivity mode, a layered system also needs to be assumed. The two-layer model has three unknowns, which are depth and resistivity of the upper layer, and resistivity of the lower layer. One of the variables needs to be known or assumed in order to use phasor diagrams to solve the other two variables. An algorithm was developed by Grissemann and Reitmayr (1978) that given the resistivity for the upper layer, the thickness of the upper layer and the resistivity of the lower layer are calculated.

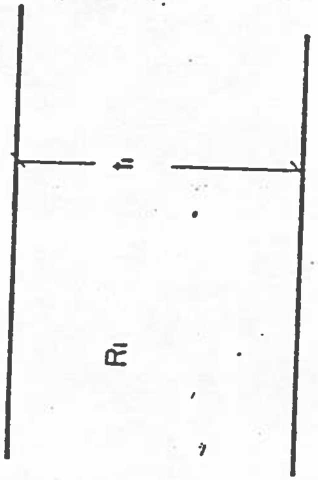


Figure 5.

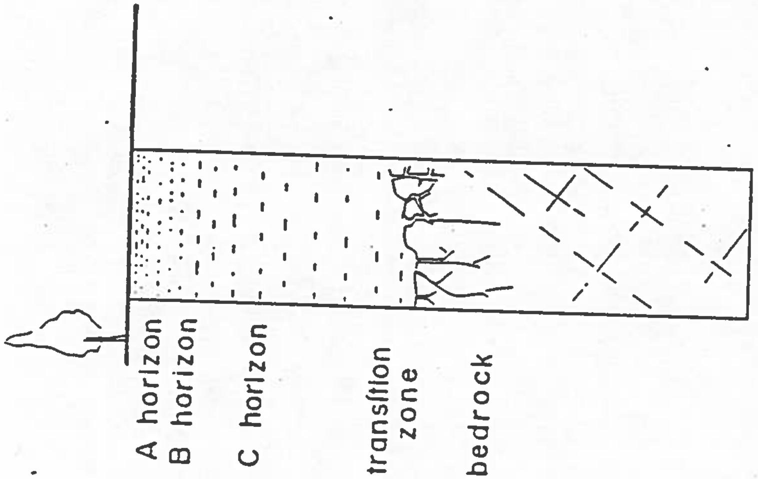


Figure 4.

A three-layer model has five variables, three of which are unknown and need to be assumed before the remaining two can be determined. Phasor diagrams were developed for the solution of a three-layer model (Poddar and Rathor, 1983).

While the depth of exploration using the EM can be severely restricted for very conductive weathered rock, it should be adequate for the weathered igneous and metamorphic rock of the Piedmont Provinces. Common values of resistivity for weathered rock (Engalenc, 1978, West Africa) are used here to compute the following penetration depts for the EM:

| | Resist. (ohm-m) | Conduct. (mmho/m) | Frequency kHz | Penetration (meters) | Depth (feet) |
|---|---|---|---|---|---|
| Weathered granite | 25-50 | 40-20 | 25 | 16-23 | 52-75 |
| | | | 15 | 21-29 | 69-95 |
| Weathered schist | 10-30 | 100-33 | 25 | 10-17 | 33-56 |
| | | | 15 | 13-23 | 43-75 |
| Weathered amphibolite | 5-15 | 200-67 | 25 | 7-13 | 23-43 |
| | | | 15 | 9-16 | 30-52 |

The weathered zone of the crystalline rock of the Piedmont averages between 30-50 feet in thickness. These values are within the penetration depth range of the EM16R, suggesting that despite the conductive upper layer, valuable information could be obtained about the weathered zone and the bedrock.

Poddar and Rathor (1983) studied the weathered layer of the Pre-Cambrian granite-gneiss of southern India using a Geonics EM16/16R. A two-layer model, a weathered layer resting on fresh bedrock, was used successfully to map an inhomogeneous weathered layer. They found that even though a three-layer model would more closely resemble the system, it did not yield significant additional information.

<u>Analysis of survey line spacing and orientation.</u>
After the field surveys, results will be analyzed and compared. Minimum spacing requirements necessary for the appropriate skin depth and for maintaining resolution will be determined. The survey lines for the EM will be oriented to several VLF radio transmitter stations. Each of these lines will be analyzed in its capacity to detect linear features such as water-bearing zones. Anomalous linear features are best detected when they trend parallel to the direction of the station. There are probably four transmitters available to reception in the Southeastern USA. The Jim Creek station signal (Washington State) is expected to best show the linear features striking to the northwest-southeast.

<u>Development of Geographic Information System.</u>
The geographic data and associated attributes will be incorporated into a geographic information system to facilitate storage, manipulation, comparison, superimposition, and display of the data.

Prediction of well yields.

An attempt will be made to use the combined data base to construct a map showing the relative availability of ground water throughout the basin. The map will be checked using the withheld well-yield data.

Prediction method effectiveness assessment.

The results of the exploration methods will be assessed individually and in various groupings to determine their individual or corporate degree of field-, time-, and cost-effectiveness.

## PRODUCTS

The following products are expected to result from this project:

A. A report on the effectiveness of the methods, individually and combined, and a presentation of results,
B. A map showing availability of ground water in the study basin,
C. The GIS data base.

## TIME FRAME

It is anticipated that this project will have a duration of 3-4 years, and will be expanded to encoumpass additional study basins with different geology and land use during the second and third years. A report on the first study basin will be published during the third year.

## PERSONNEL

The project will be a cooperative effort between the South Carolina Water Resources Commission and U.S. Geological Survey, in terms of both funding and personnel. Personnel to be assigned to the project during the first year include:

Geologist/geohydrologist,
Water Resources Commission, 12 months

Geohydrologist GS-12,
Geological Survey, 12 months

Supervisory geohydrologist,
Water Resources Commission, 3 months

Supervisory hydrologist, GS-13,
Geological Survey, 3 months

Cartographic technician GS-7,
Geological Survey, 5 months

Hydrologic technician GS-6
Geological Survey, 8 months

Graduate students (2)
Clemson University
(Summer employment) 3 months

The Geological Survey will have primary responsibility for surface water hydrology and the geographic information system. The Water Resources Commission will have primary responsibility for fracture trace analysis and direction of the field effort. The rest of the tasks will be shared.

## FUNDING

Funding for the first year of the project will be provided as follows:

| Agency | Funds | Direct Services | Total |
|---|---|---|---|
| S.C. Water Resources Commission | $ 50,000 | $ 50,000 | $100,000 |
| U.S. Geological Survey | 100,000 | 50,000 | 100,000 |
| Totals | $150,000 | $100,000 | $200,000 |

It is anticipated that similar funding will be provided for successive years.

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# APPENDIX 2

## First Year Workplan

# SCWRC-USGS PIEDMONT CO-OP PROJECT

WORK PLAN: December 11, 1987

Below are summaries of the various tasks for the surface geophysics and other ground water exploration methods investigation. These tasks correspond with the various elements on the two time-lines which precede this section.

## I. Data Gathering for Basin Selection

Several Piedmont drainage basins will be investigated to determine the best basin in which to pursue the main work of the project. The preliminary investigation will look at the following data elements:

1. Small gaged drainage basins, less than 25 mi$^2$ area, with at least 5 years of record; analysis of gage site and discharge records will be provided by U.S. Geological Survey staff.

2. Available geologic mapping: Overstreet and Bell, 1965 will be primary map but more recent and larger scale mapping will be utilized where available.

3. Availability and usefulness of various air photo and other remote sensing images:
   - Determine and log what available;
   - Make cursory lineament mapping appraisal from SLAR or NHAP products to see if images show lineaments.

4. Topographic analysis of surrounding drainage: Make sure ground water (water table) drainage basin reasonably matches the surface water drainage basin (i.e., groundwater basin divide lines up with surface water divide):
   - cursory lineament analysis from topography;
   - work in coordination with USGS staff.

5. Determine potential population of wells in each basin by various methods such as analyzing census data vs. public supply distribution lines. The well inventory will be used in the study for:
   - obtaining water levels;
   - obtaining yield and construction information;
   - locating unused wells for geophysical logging and possibly ADR site;
   - verifying prospecting methods as to yield vs. proximity to lineaments, etc.

6. Proximity of weather stations with sufficient period of record.

7. Availability of soils data.

8. Drive through drainage basins to determine:
   - degree of urbanization
   - things that may hinder surface geophysics such as power lines, large water tanks, etc.
   - accessibility.

9. Locate any aerial geophysical surveys of compatible coverage in the basins of interest for possible use in this project.

OUTPUT PRODUCT - Detailed tabular summary of each data element for each basin. Additional explanations attached as required.

Completion date: January 15, 1988
Time required: 40 days.

## II. Surface Geophysical Training

1. Early in project meet with Pete Haeni, USGS, to learn how surface geophysical equipment works, how applicable it is in the Piedmont, how it will work with our project and how to set up investigation sites before the equipment is leased. Meetings dependent on his schedule.

2. Literature research on various surface geophysical methods and applications and interpretations by other researchers.

3. Participate in whatever ongoing demonstrations that could help us gain field application experience with the equipment and interpretation of output.

4. Up to one week of training, total, on the various pieces of equipment as they are leased.

OUTPUT PRODUCT - Summary report describing which pieces of equipment will be used, when they are scheduled for use, and what results or problems may be expected from each type of survey equipment.

Completion date: Variable, dependent on schedules of instructoers.
Time required: 20 days.

## II. Well inventory:

Once the basin is selected, a detailed inventory of wells will be needed to supply basic ground water information for several aspects of the project. The information obtained in the 'Data Gathering for Basin Selection' phase will hopefully indicate how many wells are potentially in the basin of choice. Consultation with local well drillers will also be pursued.

Based on this, it will be decided whether to inventory all wells in the basin or a given percentage. Since very little is known about wells in the various basins of study, no recommendations will be made now concerning the criteria to guide well inventory other than total number. At this point, a sample of 100 wells throughout the basin seems reasonable.

A. Background information:

- well construction information: depth, diameter, saprolite thickness, pump size, etc;
- water levels;
- well yields;
- topographic location information;
- problems expressed by owners;
- water quality data (chemical analyses).

B. Data gathering sites:

- locating wells for borehole geophysical logging for correlation with surface geophysical surveys;
- locating wells for possible pumping tests;
- possible wells for ADR or inclusion in a water level run;
- possible wells for inclusion in a water quality run.

C. Exploration methods testing wells:

- Verifying results of various ground water exploration methods employed in project.

OUTPUT PRODUCT - Map of basin with inventoried wells and computerized database for each well in the Well Tab database format.

Completion date: March 15,1988
Time required: 40 days.

## IV. Lithologic-Geomorphic Terrain Analysis

This procedure involves an analysis of the bedrock lithology as it relates to the local topography and geomorphology in order to locate ground-water yielding fractures. The bedrock lithology will be interpreted by its type, age (as it relates to periods of deformation), and its structure and fabric.

This interpretive information will then be used in concert with a geomorphic analysis of the terrain. Together, these analyses will yield information leading to a delineation of possible water-bearing fractures and a possible prioritized list of well sites locally. This will be done throughout the basin.

OUTPUT PRODUCT - Map showing prioritized areas of potential well yields: low, medium, and high.

Completion date: February 12, 1988
Time required: 20 days.

## V. Remote Sensing Lineament Mapping and Field Truth

Visually interpret various types of remote sensing images for locating lineaments of ground water-yielding fractures. Black and white and/or color aerial photographs will be the principal images used. Other images, however, will also be employed to determine if they are as sensitive to detection of the lineaments as air photos.

Most of these other images are at a smaller scale than the air photos and thus may not show all of the lineaments. On the other hand, their medium sensed, or frequency used, may be more attuned to detecting the lineaments and thus prove to be better tools.

Side-Looking Airborne Radar (SLAR), high altitude air photography, and Landsat images will be investigated. It may be determined that some pre-processing of the Landsat imagery, such as low-pass or high-pass filtering, may enhance the lineament detection.

Finally, field checking, or ground truth, will be performed on the results from the lithologic-geomorphic terrain analysis and the remote sensing lineament mapping techniques. This will verify whether the supposed lineaments are fracture-produced or a man-made artifact.

OUTPUT PRODUCT - Map of plotted lineaments with ground truth notes added. Also a summary of notes on air photo lineament mapping and ground truth experiences.

Completion date: March 11, 1988
Time required: 20 days.

## VI. Surface Geophysical Surveys

The surface geophysical surveys will be conducted in various areas of the selected basin after the two preceding steps are completed. First, training with the various pieces of equipment will be necessary to help make the actual surveys more reliable. Second, the other two ground water exploration methods will need to be done to help locate the sites on which to conduct the surface geophysical surveys.

Since the basins of interest range in area from 1,024 to 16,300 acres, conducting surface geophysical surveys over an entire basin would be impractical in both time and cost. Several sites, 5-10 acres in size, will be selected throughout the chosen basin. Most of these will be areas with good indication of the presence of fractures. One site will be chosen that shows no indication of fractures.

The surface geophysical equipment to be investigated and probably used in this project will be:

VLF - very low frequency electromagnetics
EM34 - electromagnetics (apparent resistivity)
Direct current (DC) resistivity
possibly seismic, magnetic, radar, and gravity surveys.

Borehole geophysical surveys will be run at this time for any tie-in required.

OUTPUT PRODUCT - Detailed report on surface geophysical surveys conducted during investigation. Will include summary of survey work, sample copies of equipment output, and map showing survey lines marked to identify the type of equipment used.

Completion date: May 6, 1988
Time required: 40 days.

## VIII. Data Analysis of Surface Geophysical Surveys

The results obtained from the actual surveys will need to be analyzed as the output medium dictates. These interpretations will then be compared with the remote sensing and lithologic-geomorphic techniques for compatibility. All three will be compared with actual well data for reliability and success of prospecting.

No new wells are planned to be drilled. The actual comparison of the methods may be more difficult if no wells are constructed in the potentially high yield zones. This is a situation that will need to be addressed after the well inventory and ground water exploration surveys.

OUTPUT PRODUCT - A detailed report to be prefaced with the preceding reports described above. It will include a discussion of the survey results interpretations, a map showing prioritized well locations based on surface geophysical surveys and other methods, and a discussion of concurrence of the results of the various methods used in this project. Finishing the report will be recommendations concerning the ground water exploration methods and project results.

Completion date: June 30, 1988
Time required: 40 days.

## IX. Consultation with Charles Daniel, III

Charles Daniel has been involved in crystalline rock ground water hydrology and exploration for several years in North Carolina. His knowledge and experience could well benefit this project's investigations. Once and hopefully twice during this project Mr. Daniel will be consulted. First in the basin selection/data gathering period and a second time prior to the conducting of surface geophysical surveys.

The second meeting will hopefully include a survey visit of the basin as well as review of results of the remote sensing lineament mapping and lithologic-geomorphic analysis.

Completion date: Variable, as our need and Mr. Daniel's schedule dictate.
Time required: 5 days.

# APPENDIX 3

## Miscellaneous Well Inventory Items

State of South Carolina
# Water Resources Commission

DATE: ____________
FIELD #: ____________
PROPERTY #: ____________
FIELD CHECK BY: ________

## WATER WELL INVENTORY FORM

1. Home/Well Owner Name: ______________________________ Phone: ____________

2. Address: ______________________________________________

3. Well Driller Name: ______________________________________

4. Well Depth: ____________ Feet 5. Well Diameter: ____________ Inches

6. Date Well Drilled: __________(m-d-y) 7. Date Pump Installed: ____________

8. Open Interval: Top __________ Feet B G S Bottom __________ Feet B G S

9. Type of Pump: ______________________________ (Submersible, Jet, etc)

10. Pump Size: _______(H.P.) 11. Motor Type: ____________(Electric, gas, etc)

12. Pumping Rate: ____________(GPM) 13. Pump Setting Depth: __________ feet

14. How Well Used: ______________________________________

15. Problems ? :
Quality- ______________________________________________
______________________________________________

Quantity- ______________________________________________
______________________________________________

Drought related- ______________________________________________
______________________________________________

16. Latitude: ____________ 17. Longitude: ____________ 18. Elevation: ______ Ft.

19. Grid: ____________ 20. Topog: ____________ 21. Hydro Unit: ____________

22. Water Level: ____________ Feet B MP 23. Date: ________________

24. Measuring Point Description: ______________________________

25. Any SPRINGS in area? : ______________________________
______________________________

26. OK to take Water Level? Y or N 27. OK to take QW sample? Y or N

SKETCH HOME SITE AND ROAD INTERSECTION MAP ON BACK.

# EVALUATION OF GROUND WATER EXPLORATION METHODS
# IN THE HELLERS CREEK AREA
# NEWBERRY COUNTY, SOUTH CAROLINA

Various new and existing ground-water exploration methods will be employed in the Hellers Creek area of Newberry County. This is a cooperative effort between the USGS (U. S. Geological Survey) District Office in Columbia and the Piedmont Regional Office of the SCWRC (South Carolina Water Resources Commission). Work involved in this project will include gathering ground water basic data, analyzing existing streamflow and weather data, and evaluating the special ground water exploration techniques and their results. The first phase of this project is scheduled for completion in the summer of 1988.

An understanding of the local ground water resources is essential to this project. Much information will be obtained from local well owners and well drillers. Project staff will be contacting the Hellers Creek area residents concerning their wells. These data will be analyzed by computer and compared with local geology.

The USGS will evaluate the streamflow data gathered for Hellers Creek since October 1980 to determine the ground water component of the lower flows. Weather data from nearby stations will be analyzed to determine the rainfall pattern and its impact on streamflow and ground water recharge. The streamflow and weather data will also be utilized to develop a water budget for the basin.

Ground water exploration methods to be evaluated will include: remote sensing lineament mapping, geomorphic terrain analysis, and surface geophysical survey techniques such as seismic, DC resistivity, and electromagnetic (low frequency radio wave) sensing. Each of these methods will be investigated for its effectiveness in locating ground-water yielding fractures in the Piedmont of South Carolina.

Ground water flows through fractures in crystalline rock, and these fractures must be intercepted by water wells for the wells to successfully deliver water. Locating these fractures on the ground is difficult at best. These exploration methods have been successful in other regions of the world but have not been applied in South Carolina. The heavy vegetative cover and extensive weathered rock mantle (saprolite), characteristic of the Piedmont, as well as highways, powerlines, and pipelines, will make ground water exploration especially challenging. The methods will be evaluated for their effectiveness in terms of cost, time, and manpower involvement, and to ascertain if any two or more will complement one another.

Success of these new techniques will make it possible to survey and better understand the hydrogeology of certain areas and greatly increase the likelihood of successful water prospecting in the Piedmont.

For further information contact the Commission's Piedmont Regional Office at:

South Carolina Water Resources Commission
Green Gate Office Park, Suite 702
25 Woods Lake Road
Greenville, SC 29607. (803) 233-2982

NEWS RELEASE

SOUTH CAROLINA
WATER RESOURCES
COMMISSION

*Louisa D. Mincey*
**Executive Assistant**
**for Public Affairs**

FOR IMMEDIATE RELEASE

March 3, 1988

# GROUNDWATER STUDIES NOW UNDERWAY IN THE HELLER'S CREEK AREA

The South Carolina Water Resources Commission (Commission) is looking for a better way to find groundwater in the Piedmont area. The Commission began work in the Heller's Creek area of Newberry County last month and hopes to complete the project's first phase this coming summer.

Joe Harrigan, Project Coordinator, stated, "In order to gain a better understanding of the Heller's Creek groundwater resources, project staff will collect data from local well owners and well drillers. This will involve surveying local residents to obtain information on their wells." Once this information is gathered, it will be compared with local geology by computer analysis.

Groundwater flows through fractures or cracks in crystalline rock below the earth's surface. Successful wells must intercept these fractures to deliver water in useful amounts. Mr. Harrigan noted that locating these fractures from above ground is often difficult, therefore various exploration methods that have been successful elsewhere will be examined. These techniques will be evaluated for their cost, time and manpower involvement, and to determine if any two complement each other.

. . . continued

1201 Main Street, Suite 1100, Capitol Center, Columbia, S.C. 29201/(803) 737-0811

The area's heavy vegetative cover and extensive weathered rock mantle, which is characteristic of the Piedmont, make groundwater exploration especially challenging. This challenge is further compounded by the many highways, powerlines, and pipelines in the area.

The project involves four phases. First, background groundwater data must be gathered. The next step involves analysis of existing streamflow and weather data prior to conducting studies on various groundwater exploration techniques. Finally, these results must be evaluated to determine the best methods for locating the resource.

Commission staff from the Piedmont Regional Office in Greenville and the U. S. Geological Survey's (USGS) Columbia office will conduct the study. The USGS will look at streamflow data gathered for Heller's Creek since October 1980 to determine groundwater's effect on streams during dry periods. Rainfall patterns and their effects on streamflow and groundwater recharge will also be examined.

The Commission hopes that these investigations will assist in a better understanding of the hyrogeology of such areas and result in more successful water prospecting in the Piedmont.

For further information, contact:

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25 Woods Lake Road
Greenville, SC  29607
233-2982

# APPENDIX 4

## Well Inventory Data Listing

| SCWRC GRID# | COUNTY NUMBER | OWNER | LAT | LONG | ELEV | U | WT | TD | CD | DIA | GPM | SWL | SWL DATE | DATE COMP | DRILLER / REMARKS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36K-y001 | NEW-0319 | Fairview Church | 342055 | 812931 | 465 | IS | D | -1 | -1 | 6 | 5 | -1.00 | | | | |
| 37K-e001 | NEW-0298 | Ruby Wilson | 341958 | 813410 | 555 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | | | |
| ● 37K-l001 | NEW-0238 | Olin & Janel Thomas | 342209 | 813142 | 515 | DO | O | 89 | 47 | -1 | -1 | -1.00 | 10/24 | 1964 | W. C. Norris | occas. quant. prob. |
| 37K-q001 | NEW-0252 | Beth Folk | 342101 | 813315 | 530 | DO | D | -1 | -1 | -1 | -1 | -1.00 | | 1973 | | |
| 37K-q002 | NEW-0253 | Caroline Fulmer | 342103 | 813307 | 530 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | | | drilled 33 yrs ago? |
| ○ 37K-q003 | NEW-0262 | Furman E. Epps | 342134 | 813323 | 495 | DO | O | 125 | -1 | 6 | -1 | -1.00 | | 1938 | driller from Saluda | well serves 2 houses |
| 37K-q? | NEW-0322 | C. Wingard Price | | | 0 | DO | O | 200 | -1 | 8 | 6 | -1.00 | | 9/75 | Thad Coleman | pump at 160' |
| ⊕ 37K-r001 | NEW-0243 | C. E. Harshaw | 342142 | 813214 | 510 | DO | D | 160 | -1 | 6 | 25 | -1.00 | | 1987 | Coleman | spring in wet weathr |
| ⊕ 37K-r002 | NEW-0245 | Harold Epps | 342129 | 813240 | 520 | DO | D | 120 | -1 | 4 | 4 | -1.00 | | 1958 | Norris | has unused b. well |
| ○ 37K-r003 | NEW-0246 | Donald Warren | 342142 | 813216 | 520 | DO | D | 180 | -1 | 6 | -1 | -1.00 | | 1982 | | depth may be 180'? |
| ⊕ 37K-r004 | NEW-0247 | Eakie McCullough | 342119 | 813242 | 505 | DO | D | 140 | -1 | 6 | 40 | 35.00 | | 1069 | Coleman from Saluda | |
| ○ 37K-r005 | NEW-0248 | Bob Epting | 342118 | 813256 | 505 | DO | D | 110 | -1 | 4 | -1 | -1.00 | | 1963 | Norris | |
| ○ 37K-r006 | NEW-0249 | Bob Epting | 342125 | 813244 | 505 | UN | D | 200 | -1 | 6 | -1 | -1.00 | | 1985 | | 2 b. wells not found |
| 37K-s001 | NEW-0236 | New Enoree Bapt. Ch. | 342125 | 813110 | 415 | IS | H | -1 | -1 | -1 | -1 | -1.00 | | | | large dia. dug well |
| □ 37K-s002 | NEW-0241 | Ben Hamilton | 342154 | 813136 | 492 | DO | C | 60 | -1 | -1 | -1 | -1.00 | | 1968 | | |
| 37K-s003 | NEW-0242 | Richard Bookman | 342143 | 813121 | 460 | DO | D | -1 | -1 | 8 | -1 | -1.00 | | | | |
| ○ 37K-s004 | NEW-0279 | W. Rutherford | 342101 | 813103 | 475 | DO | D | 150 | -1 | 6 | -1 | -1.00 | | 1976 | | owner says >150ft |
| 37K-s005 | NEW-0281 | David Rutherford | 342101 | 813101 | 470 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | 1968 | driller from Pomaria | |
| 37K-t001 | NEW-0144 | Willie Elkins | 34210- | 81305- | 470 | DO | D | 310 | 103 | 6 | 5 | 27.00 | 08/06 | 8/86 | Gowan | see NEW-0321 |
| ○ 37K-t002 | NEW-0237 | Mrs. Louis Caldwell | 342103 | 813054 | 470 | DO | D | 168 | -1 | 6 | -1 | 35.65 | 30388 | 1973 | Tom Lewis | 2 houses use well |
| ○ 37K-t003 | NEW-0321 | Willie Elkins | 342103 | 813053 | 470 | DO | D | 300 | -1 | 6 | -1 | -1.00 | | 1971 | | see NEW-0144 |
| △ 37K-u001 | NEW-0240 | Beachie Lyles | 342047 | 813049 | 460 | DO | B | 18 | 18 | 36 | -1 | 12.50 | 31988 | 1963 | | small spring nearby |
| △ 37K-u002 | NEW-0280 | Yancy Dawkins | 342058 | 813052 | 455 | DO | B | 32 | 32 | 24 | -1 | -1.00 | | 1970 | Hawkins from Union | |
| 37K-u003 | NEW-0307 | unoccupied house | 342022 | 813057 | 505 | UN | H | -1 | -1 | 24 | -1 | -1.00 | | | | |
| ⊕ 37K-u004 | NEW-0317 | Judy Graham | 342037 | 813033 | 475 | DO | D | 115 | -1 | 6 | 5 | -1.00 | | | | |
| 37K-u005 | NEW-0318 | Wayne Ringer | 342042 | 813030 | 475 | DO | D | -1 | -1 | 6 | 15 | -1.00 | | 1968 | | |
| ○ 37K-u006 | NEW-0320 | Mrs. Gener | 342055 | 813056 | 455 | DO | D | 100 | -1 | 4 | -1 | -1.00 | | 1963 | Norris | |
| □ 37K-v001 | NEW-0215 | Daisy Chaplin | 342014 | 813125 | 520 | UN | O | 40 | -1 | -1 | -1 | -1.00 | | 1958 | | depth 40? |
| 37K-v002 | NEW-0216 | Daisy Chaplin | 342013 | 813142 | 520 | DO | O | -1 | -1 | -1 | -1 | -1.00 | | 1987 | Dave's Pump Service | from Prosperity |
| ⌽ 37K-v003 | NEW-0217 | Cindy Crumpton | 342000 | 813155 | 500 | UN | D | 60 | -1 | 6 | -1 | -1.00 | | 1968 | Lewis ? | |
| △ 37K-v004 | NEW-0295 | Sarah Glymph | 342017 | 813109 | 535 | DO | H | 8 | 8 | -1 | -1 | -1.00 | | 1948 | | depth may be > 8'? |
| 37K-v005 | NEW-0300 | Leroy Cooper | 342008 | 813138 | 520 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | 1978 | Tom Lewis | |
| 37K-v006 | NEW-0301 | Faye Eargle | 342003 | 813142 | 500 | | H | -1 | -1 | -1 | -1 | -1.00 | | | | owner not home |

|  | SCWRC GRID# | COUNTY NUMBER | OWNER | LAT | LONG | ELEV | U | WT | TD | CD | DIA | GPM | SWL | SWL DATE | DATE COMP | DRILLER / REMARKS |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ○ | 37K-w001 | NEW-0219 | Raymond Hatcher, Jr. | 342004 | 813235 | 445 | AB | D | 130 | -1 | -1 | -1 | -1.00 |  | 4/88 | Gowan | logs of uncased well |
| ⊕ | 37K-w002 | NEW-0220 | Raymond Hatcher, Jr. | 342003 | 813236 | 450 | DO | D | 150 | 103 | 6 | 50 | 26.00 | 3/23 | 3/88 | Gowan |  |
| □ | 37K-w003 | NEW-0225 | unoccupied house | 342051 | 813225 | 525 | UN | D | 30 | -1 | -1 | -1 | -1.00 |  |  |  | info: Marilyn Harris |
|  | 37K-w004 | NEW-0259 | Freddie M. Cook | 342038 | 813247 | 535 | UN | D | -1 | -1 | -1 | -1 | -1.00 |  |  |  | uoccupied house |
| ○ | 37K-w005 | NEW-0272 | Keith Dominick | 342042 | 813257 | 550 | DO | D | 90 | -1 | 4 | -1 | -1.00 |  |  |  |  |
| ⊕ | 37K-w006 | NEW-0289 | J. H. Dates | 342047 | 813249 | 550 | DO | D | 165 | -1 | 6 | 15 | -1.00 |  | 1980 | Coleman |  |
| ○ | 37K-w007 | NEW-0294 | Ronnie Morris | 342037 | 813237 | 525 | DO | D | 125 | -1 | 6 | -1 | -1.00 |  | 1968 |  |  |
| ○ | 37K-w008 | NEW-0308 | Ronald Mills | 342049 | 813227 | 525 | IR | D | 225 | -1 | 6 | -1 | -1.00 |  |  |  |  |
| ○ | 37K-w009 | NEW-0312 | Marilyn Harris | 342048 | 813218 | 525 | DO | D | 95 | -1 | -1 | -1 | -1.00 |  | 1966 |  |  |
| □ | 37K-w010 | NEW-0313 | John Leopard | 342048 | 813220 | 530 | UN | D | 60 | -1 | -1 | -1 | -1.00 |  |  |  |  |
|  | 37K-x001 | NEW-0250 | Gerald Green | 342039 | 813315 | 560 | DO | D | -1 | -1 | 6 | 15 | -1.00 |  | 1980 | driller retired |  |
|  | 37K-x002 | NEW-0251 | Carolyn Brigman | 342053 | 813315 | 550 | DO | D | -1 | -1 | -1 | -1 | -1.00 |  | 1963 |  |  |
|  | 37K-x003 | NEW-0254 | Nell Caldwell | 342014 | 813301 | 520 | DO | D | -1 | -1 | 6 | -1 | -1.00 |  | 1978 | driller from Saluda |  |
|  | 37K-x004 | NEW-0260 | Robert Hill | 342024 | 813340 | 550 | DO | D | -1 | -1 | 6 | -1 | -1.00 |  | 1968 |  | drilled >20 yrs ago |
|  | 37K-x005 | NEW-0261 | Ann Kennerly | 342030 | 813335 | 550 | DO | D | -1 | -1 | 6 | -1 | -1.00 |  | 1987 | Gowan |  |
| ○ | 37K-x006 | NEW-0271 | Jesse Johnson | 342019 | 813337 | 545 | DO | D | 156 | -1 | 6 | -1 | -1.00 |  | 1972 | Lewis | spring:woods to left |
|  | 37K-x007 | NEW-0273 | Charles Price ? | 342056 | 813317 | 545 | DO | G | -1 | -1 | -1 | -1 | -1.00 |  | 1982 |  |  |
| ○ | 37K-x008 | NEW-0274 | Larry Creekmore | 342038 | 813312 | 555 | DO | D | 120 | -1 | 6 | -1 | -1.00 |  | 1980 | Thad Coleman | picks up sand |
| ⊕ | 37K-x009 | NEW-0275 | Waters Duffie | 342019 | 813338 | 545 | DO | D | 153 | -1 | 6 | 5 | -1.00 |  | 1963 | H.Z. Duffie |  |
|  | 37K-x010 | NEW-0276 | Mrs. J. S. Watters | 342018 | 813341 | 545 | UN | B | -1 | -1 | -1 | -1 | -1.00 |  |  |  |  |
| ○ | 37K-x011 | NEW-0277 | Mrs. J. S. Watters | 342019 | 813340 | 545 | UN | D | 100 | -1 | -1 | -1 | -1.00 |  |  |  |  |
| ○ | 37K-x012 | NEW-0278 | Mrs. J. S. Watters | 342016 | 813344 | 550 | LS | D | 300 | -1 | 6 | -1 | -1.00 |  |  | Gould |  |
|  | 37K-x013 | NEW-0285 | Terry Green | 342023 | 813302 | 510 | DO | D | -1 | -1 | -1 | -1 | -1.00 |  | 1973 | Coleman | did not see well |
| ○ | 37K-x014 | NEW-0292 | Thomas Bradley | 342043 | 813302 | 540 | DO | D | 205 | -1 | 4 | -1 | -1.00 |  | 1982 | from Lexington |  |
| ⊕ | 37K-x015 | NEW-0293 | Paul Schealy | 342018 | 813345 | 545 | DO | D | 120 | -1 | 6 | 5 | -1.00 |  | 1981 | Gowan |  |
| ✳ | 37K-x016 | NEW-0299 | James W. Johnson | 342020 | 813350 | 515 | DO | * | -1 | -1 | 24 | -1 | 999.99 | 62088 |  | * SPRING * |  |
| ○ | 37K-x017 | NEW-0305 | Jack Lominick | 342012 | 813314 | 495 | DO | D | 175 | -1 | 6 | -1 | -1.00 |  | 1980 | Coleman | water not clean in first well |
| ○ | 37K-x018 | NEW-0306 | Cindy Lominick | 342012 | 813314 | 495 | DO | D | 200 | -1 | -1 | -1 | -1.00 |  | 1986 | Gowan |  |
| ○ | 37K-x019 | NEW-0314 | Richard Lominick | 342041 | 813326 | 550 | DO | D | 90 | -1 | 8 | -1 | -1.00 |  |  |  | owner says 90'? |
| △ | 37K-y001 | NEW-0297 | Pearl B. Ruth | 342002 | 813407 | 555 | DO | B | 22 | 22 | 24 | -1 | -1.00 |  | 1940 | Ted McDowall | low in summer |
| ○ | 37K-y002 | NEW-0302 | Lebanon Meth. Church | 342011 | 813400 | 545 | IS | D | 65 | -1 | 6 | -1 | -1.00 |  | 1963 | Zack Kinard | drilled 4 holes |
| △ | 37K-y003 | NEW-0316 | Ruth Stoudemire | 342003 | 813419 | 560 | UN | B | 50 | 50 | 24 | -1 | 25.00 |  |  |  | 25-30 ft of water |
| ○ | 37L-b001 | NEW-0218 | Plato Gray | 341953 | 813157 | 510 | DO | D | 87 | -1 | 6 | -1 | -1.00 |  | 1971 | Lewis |  |
| ○ | 37L-b002 | NEW-0264 | Andrea Mathis | 341951 | 813154 | 505 | DO | D | 100 | -1 | 6 | -1 | -1.00 |  | 1972 | driller: Prosperity | depth about 100 ft |
| ○ | 37L-b003 | NEW-0265 | Lee Mozee | 341947 | 813159 | 525 | DO | D | 100 | -1 | 6 | -1 | -1.00 |  | 1973 |  | depth about 100 ft |
|  | 37L-b004 | NEW-0267 | Diane Eigner | 341957 | 813147 | 515 | DO | D | -1 | -1 | -1 | -1 | -1.00 |  |  |  | well next door? |
|  | 37L-b005 | NEW-0270 | Charles Simms | 341954 | 813154 | 500 | DO | D | -1 | -1 | -1 | -1 | -1.00 |  | 1974 |  | spring at hill bott. |
| ○ | 37L-b006 | NEW-0288 | Willie Ruff | 341952 | 813157 | 510 | DO | D | 85 | -1 | -1 | -1 | 45.00 |  | 1972 |  | 40' of water reptd. |
|  | 37L-b? | NEW-0255 | J. D. Cromer |  |  | 0 | DO | D | 220 | -1 | 6 | -1 | -1.00 |  | 1978 | Gowan |  |

| SCWRC GRID# | COUNTY NUMBER | OWNER | LAT | LONG | ELEV | U | WT | TD | CD | DIA | GPM | SWL | SWL DATE | DATE COMP | DRILLER / REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ⊕ 37L-c001 | NEW-0157 | Newb'y Park Est. MHP | 341934 | 813256 | 550 | WS | 0 | 180 | -1 | 6 | 21 | -1.00 | | 1970 | Tom Lewis (deceased) DHEC old WS #636003 |
| ⊕ 37L-c002 | NEW-0158 | Bill White's MHP #2 | 341928 | 813256 | 530 | WS | 0 | 220 | -1 | 6 | 14 | -1.00 | | | Gowan DHEC old WS #636003 |
| ● 37L-c003 | NEW-0159 | Bill White's MHP #3 | 341933 | 813258 | 540 | WS | D | 610 | 84 | 6 | 12 | 36.00 | 12/29 | 1286 | Gowan DHEC new WS #3660014 |
| ● 37L-c004 | NEW-0160 | Bill White's MHP #4 | 341927 | 813257 | 530 | WS | D | 310 | 128 | 6 | 20 | -1.00 | | 1/87 | Gowan DHEC new WS #3660014 |
| ✳ 37L-c005 | NEW-0206 | Carol Ann Werts | 341928 | 813221 | 485 | DO | * | -1 | -1 | -1 | -1 | 999.99 | 22088 | >66 | * SPRING * WL at land surface |
| ○ 37L-c006 | NEW-0207 | Henry Lee Brooks | 341944 | 813206 | 535 | DO | 0 | 85 | -1 | 6 | -1 | -1.00 | | >71 | bought home in 71 well already there |
| 37L-c007 | NEW-0208 | James W. Brooks | 341945 | 813205 | 535 | DO | D | -1 | -1 | -1 | -1 | -1.00 | | | well behind house in concrete casing |
| ○ 37L-c008 | NEW-0209 | Willie Trapp | 341946 | 813203 | 535 | DO | D | 150 | -1 | 6 | -1 | -1.00 | | 1969 | driller fr. Columbia depth = yard length |
| 37L-c009 | NEW-0210 | Douglas Trapp | 341946 | 813204 | 535 | DO | 0 | -1 | -1 | 6 | -1 | -1.00 | | | driller fr. Columbia W. Trapp's neighbor |
| 37L-c010 | NEW-0211 | Johnnie L Hutcherson | 341947 | 813202 | 530 | DO | 0 | -1 | -1 | 6 | -1 | -1.00 | | | Lewis (deceased) |
| ○ 37L-c011 | NEW-0214 | Mrs. A. E. Sutphin | 341939 | 813228 | 520 | DO | D | 90 | -1 | 3 | -1 | -1.00 | | | |
| 37L-c012 | NEW-0222 | Kelsey Rowe | 341945 | 813245 | 530 | DO | D | -1 | -1 | -1 | -1 | -1.00 | | 1983 | |
| ⊕ 37L-c013 | NEW-0223 | Mark& Shirley Taylor | 341944 | 813240 | 535 | DO | D | 205 | -1 | 6 | 12 | -1.00 | | 1983 | |
| 37L-c014 | NEW-0224 | Russell Saverance | 341944 | 813242 | 535 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | 1982 | |
| 37L-c015 | NEW-0226 | Vernon Livingston | 341946 | 813238 | 530 | DO | D | -1 | -1 | -1 | -1 | -1.00 | | | |
| 37L-c016 | NEW-0227 | Jean B. Frient | 341948 | 813225 | 530 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | 1981 | occas. soapy taste |
| 37L-c017 | NEW-0228 | Charles Bowers | 341946 | 813224 | 535 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | | |
| 37L-c018 | NEW-0230 | Patrick L. Smith | 341948 | 813221 | 535 | DO | D | -1 | -1 | -1 | -1 | -1.00 | | | |
| 37L-c019 | NEW-0231 | Jimmie Mitchell | 341951 | 813230 | 500 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | | |
| 37L-c020 | NEW-0232 | Brenda Suber | 341949 | 813230 | 500 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | >85 | dr. > 3 yrs ago |
| △ 37L-c021 | NEW-0233 | Eugene Johnson | 341945 | 813222 | 540 | DO | B | 40 | 40 | 24 | -1 | -1.00 | | | Use rare- pumps dry |
| ● 37L-c022 | NEW-0234 | Joseph Bookman | 341922 | 813240 | 525 | DO | D | 120 | 40 | -1 | 40 | 30.00 | 1/79 | 1979 | Gowan |
| 37L-c023 | NEW-0235 | Ruby S. Renwick | 341945 | 813256 | 530 | DO | D | -1 | -1 | -1 | -1 | -1.00 | | 1975 | |
| 37L-c024 | NEW-0229 | Shannon Hepler | 341946 | 813222 | 545 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | >76 | dr. > 12 yrs ago |
| ○ 37L-c025 | NEW-0221 | James Massey | 341938 | 813245 | 550 | DO | D | 102 | -1 | -1 | -1 | -1.00 | | 1972 | spring near bridge |
| 37L-c026 | NEW-0263 | David Grey | 341946 | 813201 | 535 | DO | D | -1 | -1 | -1 | -1 | -1.00 | | | |
| ○ 37L-c027 | NEW-0266 | Narvis Gray | 341947 | 813202 | 530 | DO | D | 175 | -1 | 6 | -1 | -1.00 | | 1971 | quality problem 8 yr |
| 37L-c028 | NEW-0268 | Victoria Parks | 341945 | 813202 | 540 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | 1976 | |
| 37L-c029 | NEW-0269 | Willie Lee Gladney | 341944 | 813203 | 545 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | 1976 | |
| △ 37L-c030 | NEW-0282 | Calvin Counts | 341940 | 813248 | 550 | DO | B | 60 | 60 | 24 | -1 | -1.00 | | 1981 | |
| △ 37L-c031 | NEW-0283 | James Glasgow | 341926 | 813242 | 535 | DO | B | 50 | 50 | 24 | -1 | -1.00 | | 1947 | |
| ○ 37L-c032 | NEW-0284 | John W. Farmer | 341918 | 813239 | 520 | DO | D | 85 | -1 | 6 | -1 | -1.00 | | 1956 | well >32 yrs old |
| ⊕ 37L-c033 | NEW-0286 | James Glymph | 341948 | 813200 | 525 | DO | D | 105 | -1 | -1 | 5 | -1.00 | | 1965 | driller from Saluda |
| 37L-c034 | NEW-0287 | Sharon Nelson | 341949 | 813217 | 540 | DO | 0 | -1 | -1 | -1 | -1 | -1.00 | | | |
| 37L-c035 | NEW-0290 | Daisy Mae Chaplin | 341943 | 813204 | 540 | DO | D | -1 | -1 | 6 | -1 | -1.00 | | 1976 | |
| 37L-c036 | NEW-0291 | Joyce Mathis | 341941 | 813244 | 540 | DO | 0 | -1 | -1 | -1 | -1 | -1.00 | | 1972 | Gowan |
| 37L-c037 | NEW-0304 | Mai Faison | 341931 | 813240 | 545 | DO | 0 | -1 | -1 | 6 | -1 | -1.00 | | | old well filled in nearby |
| △ 37L-c038 | NEW-0309 | Edna Martin | 341945 | 813213 | 535 | DO | B | 60 | 60 | 30 | -1 | -1.00 | | 1968 | Gowan can be pumped dry |
| ○ 37L-c039 | NEW-0310 | Edna Martin | 341946 | 813214 | 545 | DO | D | 130 | -1 | 6 | -1 | -1.00 | | 1968 | Gowan |
| ○ 37L-c040 | NEW-0311 | Edna Martin | 341944 | 813216 | 540 | DO | D | 100 | -1 | 6 | -1 | -1.00 | | >68 | Gowan well > 20 yrs |

| SCWRC GRID# | COUNTY NUMBER | OWNER | LAT | LONG | ELEV | U | WT | TD | CD | DIA | GPM | SWL | SWL DATE | DATE COMP | DRILLER / REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37L-d001 | NEW-0201 | Dewey J. Icard, Jr. | 341907 | 813334 | 555 | DO | B | -1 | -1 | 24 | -1 | -1.00 | | 68? | owner says depth 40? bored ab. 20 yrs ago |
| ○ 37L-d002 | NEW-0202 | Mrs. Marian Kunkle | 341909 | 813330 | 560 | DO | D | 108 | -1 | 6 | -1 | -1.00 | | 1954 | Duffy (from Saluda) info from Frk.Boozer |
| △ 37L-d003 | NEW-0203 | Laurie A. Fenwood | 341910 | 813326 | 540 | UN | H | 60 | 60 | 36 | -1 | -1.00 | | | now on County water; info from Frk.Boozer |
| ● 37L-d004 | NEW-0204 | J. Frank Boozer, Jr. | 341912 | 813321 | 535 | DO | D | 207 | 180 | 6 | -1 | 18.00 | | 1977 | Gowan |
| ○ 37L-d005 | NEW-0205 | Williamson Folk | 341919 | 813310 | 545 | DO | D | 150 | -1 | 6 | -1 | 20.00 | | 1963 | Duffy; "well dug in drought 25 yrs ago" |
| 37L-d006 | NEW-0213 | James Bill Elkins | 341920 | 813316 | 550 | | D | -1 | -1 | -1 | -1 | -1.00 | | | next to windmill |
| 37L-d007 | NEW-0239 | Lyman E. Johnson | 341910 | 813340 | 565 | AB | D | -1 | -1 | 3 | -1 | -1.00 | | 1950 | maybe spring nearby |
| □ 37L-e001 | NEW-0212 | Pleasant Grove Ch. | 341902 | 813403 | 540 | AB | D | 19 | -1 | 4 | -1 | -1.00 | | | apparently abandoned |
| ○ 37L-e002 | NEW-0244 | Sease | 341944 | 813430 | 555 | DO | D | 85 | -1 | 6 | -1 | -1.00 | | | Jack Keinan |
| ⊕ 37L-e003 | NEW-0303 | Frank Hamm | 341926 | 813425 | 595 | DO | D | 300 | -1 | 6 | 2 | -1.00 | | 1978 | Coleman can be pumped dry |
| ○ 37L-e004 | NEW-0315 | Mt. Bethel Com. Ctr. | 341958 | 813416 | 515 | IS | D | 100 | -1 | 6 | -1 | -1.00 | | | about 100' deep |
| ✚ 37L-f001 | NEW-0082 | Water & Sewer Author | 341846 | 813418 | 530 | WS | D | 510 | 120 | 8 | 170 | 38.00 | | 6/80 | Gowan maintenance shop |
| 37L-f002 | NEW-0080 | White's Restaurant | 341838 | 813423 | 530 | WS | D | 187 | 107 | 7 | 75 | 50.00 | | 2/77 | Driller: Gowan lat/long estimated |
| 37L-f003 | NEW-0089 | White's Restaurant | 341838 | 813423 | 530 | WS | D | 267 | 115 | -1 | 150 | -1.00 | | | Driller: Gowan lat/long estimated |
| 37L-f004 | NEW-0091 | Newberry Inn | 341858 | 813429 | 535 | WS | D | 250 | -1 | 6 | 37 | -1.00 | | | DHEC WS #3670207 lat/long estimated |
| 37L-f005 | NEW-0092 | Newberry Inn | 341858 | 813429 | 535 | WS | D | 250 | -1 | 6 | 20 | -1.00 | | | DHEC WS #3670207 lat/long estimated |
| 37L-f006 | NEW-0093 | Newberry Inn | 341858 | 813429 | 535 | WS | D | 250 | -1 | 6 | 12 | -1.00 | | | DHEC WS #3670207 lat/long estimated |

Heading Abbreviations: **SCWRC GRID#** S.C. Water Resources Commission well-grid number; **COUNTY NUMBER** sequentially assigned well identification number for this county; **OWNER** owner or tenant of well; **LAT** latitude; **LONG** longitude; **ELEV** elevation in feet above mean sea level; **U** well use (**AB** abandoned; **DO** domestic; **IR** irrigation; **IS** institutional; **LS** livestock; **UN** unused; **WS** public water supply); **WT** well type (**O** open: usually subdivided into following types: **B** bored; **D** drilled; **H** hand-dug); ***** denotes a spring; **TD** total depth in feet; **CD** casing depth in feet; **DIA** casing diameter in inches; **GPM** well yield in gallons per minute; **SWL** static water level in feet below land surface; **SWL DATE** date of static water level measurement; **DATE COMP** drilling completion date; **DRILLER / REMARKS** driller if known, and other remarks.

Symbols denote wells shown on location map. For meaning of symbols, see legend on map.

# APPENDIX 5

## Summary of Work by U.S. Geological Survey

## PROJECT STATUS REVIEW SHEET, QUARTERLY REPORT

Project Number: 88-074
Date of Review: ~~April~~ July 1988

Project Name: "Evaluation of Techniques to Assess Ground-Water Resources in the Piedmont of South Carolina"

Project Chief: Barry Smith
Section Chief: Glenn Patterson

Report Period: ~~January - March~~ April- June 1988
Cooperator: SCWRC

Project Completion Date: October 1990

PROJECT OBJECTIVES:

1. Evaluate the utility of a variety of techniques for assessing the ground-water resources of a selected basin in the Piedmont.

2. Assess the availability of ground water in the basin using selected techniques and, where possible, verify the availability with well production data.

PROGRESS DURING PREVIOUS QUARTER:

1. Well inventory was completed and well locations were digitized
2. GWSI search for data was completed.
3. Satellite imagery (SPOT) was purchased and delivered.
4. Wadi, very-low frequency sensor was checked out and delivered to cooperator.
5. EM-16 R very-low frequency, EM-34, conductivity, and DC resistivity sensors were borrowed from the surface-geophysics specialist and tested in the field.
6. Literature search and gathering continued.
7. Weather station was designed, instruments were gathered and calibrated.
9. Streamflow records of Hellers Creek near Pomaria were checked.

Project Number: 88-074

Report Period: Jan.-Mar. 1988

SIGNIFICANT FINDINGS:

PLANS FOR NEXT QUARTER:

1. Digitize maps and data when they become available
2. Construct a preliminary model of ground-water flow in a cross section to test hypotheses.
3. Construct and install the weather station
4. Check low-flow conditions of Hellers Creek.

Status of Reports:

A report on the availability of ground water in Upper Hellers Creek basin is planned.

Project Number: 88-074

Report Period: Jan.-Mar. 1988

SIGNIFICANT FINDINGS:

PLANS FOR NEXT QUARTER:

1. Gather, calibrate, and install equipment to measure evapotranspiration.
2. Complete initial evaluations of EM-16R and Wadi.
3. Continue evaluation of other geophysical sensors.
4. Digitize base map, contours, well locations, geologic maps, and other data as it becomes available.
5. Continue well inventory.

STATUS OF REPORTS:

A report on the availability of ground water in the basin is planned.

## PROJECT STATUS REVIEW SHEET, QUARTERLY REPORT

Project Number: 88-074 Date of Review: April 1988

Project Name: "Evaluation of Techniques to Assess Ground-Water Resources in the Piedmont of South Carolina"

Project Chief: Barry Smith Section Chief: Glenn Patterson

Report Period: January - March 1988 Cooperator: SCWRC

Project Completion Date: October 1990

PROJECT OBJECTIVES:

1. Evaluate the utility of a variety of techniques for assessing the ground-water resources of a selected basin in the Piedmont.
2. Assess the availability of ground water in the basin using selected techniques and, where possible, verify the availability with well production data.

PROGRESS DURING PREVIOUS QUARTER:

1. The upper part of Hellers Creek basin was chosen for evaluation.
2. The Survey's surface-geophysics specialist, Pete Haeni gave a two-day synopsis of the use of geophysics in water resources.
3. High altitude photographs, radar imagery, and aerial photoghraphs were collected.
4. Student aids were hired and, with project personnel, a door-to-door, well-inventory was begun.
5. Radiometer, cyclometers, and data loggers were gathered for installation of an evapotranspiration station.
6. GWSI-data base was searched for pertinent data.
7. Wadi, very low-frequency sensor was purchased and initial field checks begun.
8. EM-16 R, very low-frequency sensor was recieved and is being evaluated.
9. Geologic maps of study area were collected.
10. Literature on use of surface geophysics was collected.
11. Satellite imagery was ordered.