UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

LOCATING GROUND-WATER SUPPLIES IN RANDOLPH COUNTY, WEST VIRGINIA

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ACKNOWLEDGMENTS

First and foremost thanks to Bert Thompson, retired driller, for the many hours spent touring the valley with the author pointing out high yielding and salty wells that he drilled. Mr. Thompson also provided well information from his records. His contributions made the author's work easier than it would have been otherwise. Thanks are due to Edsel Lucas for granting permission to drill on his land, and to MSHA, U.S. Dept. of Labor, Bruceton, Pa., for the use of their video-analog equipment in lineament analysis of aerial photographs and satellite imagery. Kirk McCabe and John Jansky of MSHA in particular provided technical assistance in operating the equipment and helpful discussions relating to lineaments and lineament analysis.

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1.0 CONCLUSIONS

GROUND WATER AVAILABLE FOR SMALL PUBLIC SUPPLIES

Ground water is available for small public supplies but encrustation may be a problem and the water may become salty if aquifer is continuously pumped at maximum capacity.

It was concluded from this study that (1) ground water is available from the alluvium and the underlying shale to supply 200 gal/min for public supplies; (2) good sites for production wells can be selected using lineaments mapped from satellite imagery and aerial photography; (3) surface electrical resistivity studies are valuable to map buried alluvial sand and gravel and lineaments in shale beneath the alluvium; (4) most of the water is stored in the alluvium; (5) low pH, and high concentrations of iron, manganese, and chloride may cause problems; (6) single-well aquifer tests indicate "high yielding" wells are located along lineaments; (7) multiple-well anisotropic aquifer tests indicate maximum permeability parallels lineaments in the shale; (8) because of the fractured nature of the shale beneath saturated alluvium it is difficult to predict long-term effects of drawdown; (9) drawdown may cause the upward migration of salty water, which lies at a depth of 100 to 300 feet, subsequently degrading water quality.

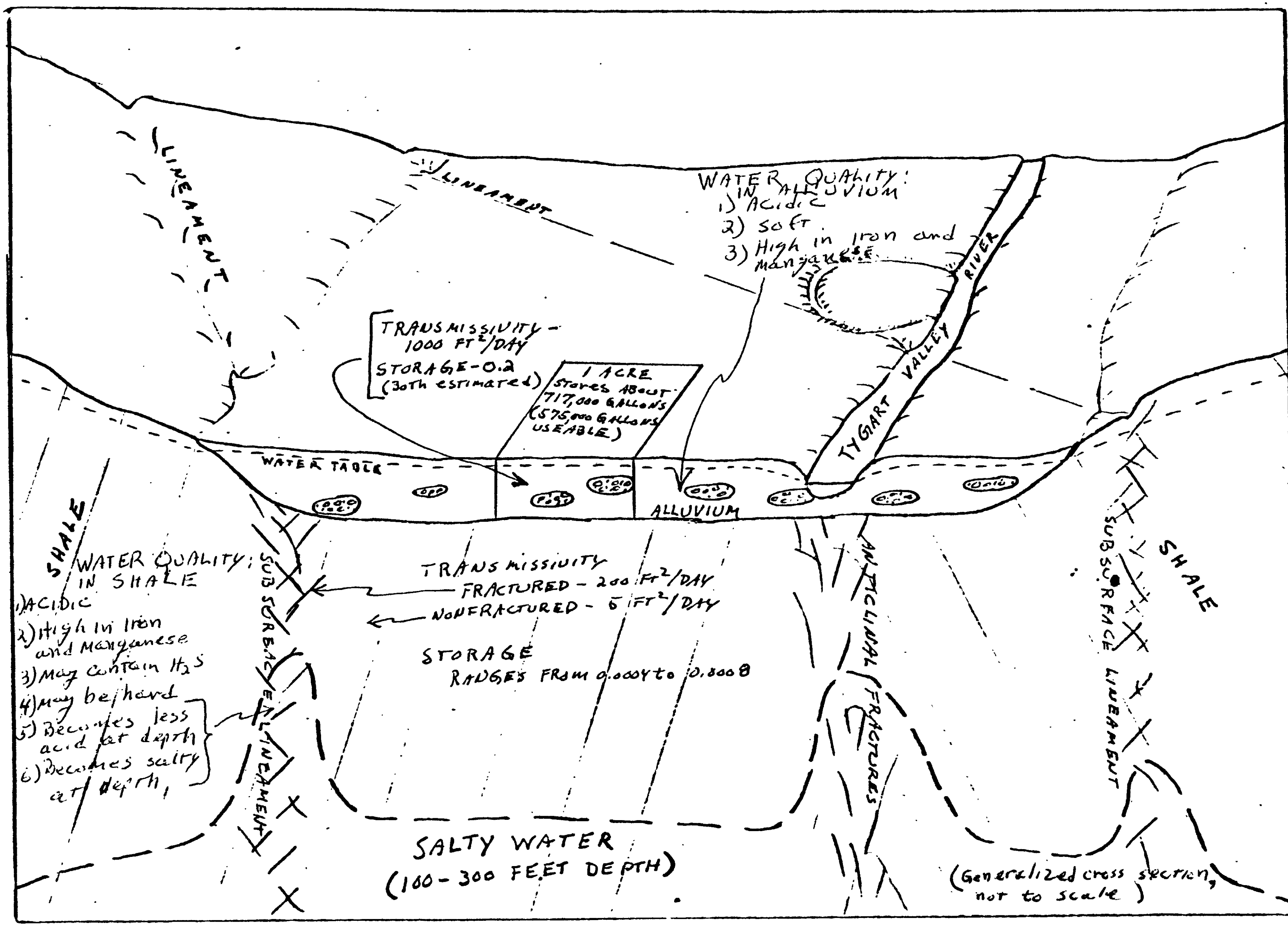


Figure 1.0-1.--Aquifer characteristics of alluvium and shale and ground-water quality in generalized section of Tygart Valley.

2.0 LOCATION AND HYDROLOGIC SETTING

TYGART VALLEY UNDERLAIN BY SHALE THAT STORES AND YIELDS LITTLE GROUND WATER

The Tygart Valley is underlain by shale rocks that do not release enough water to sustain the flow of Tygart Valley River during prolonged drought.

The Tygart Valley is an upland valley in central Randolph County on the western edge of the Appalachian Valley and Ridge Province. The Valley is developed on an eroded anticline formed by Devonian shales and sandstone. These rocks characteristically are poor water-bearing rocks and do not sustain the base flow of the Tygart Valley River during periods of prolonged drought. Records from the gaging station at Dailey show that the river had zero flow on two widely separated occasions: September 12 to November 30, 1930, and September 29 to November 5, 1953. The period of record for the gage at Elkins is not long, but it shows a flow of only 50 gal/min from September 20 to 29, 1959.

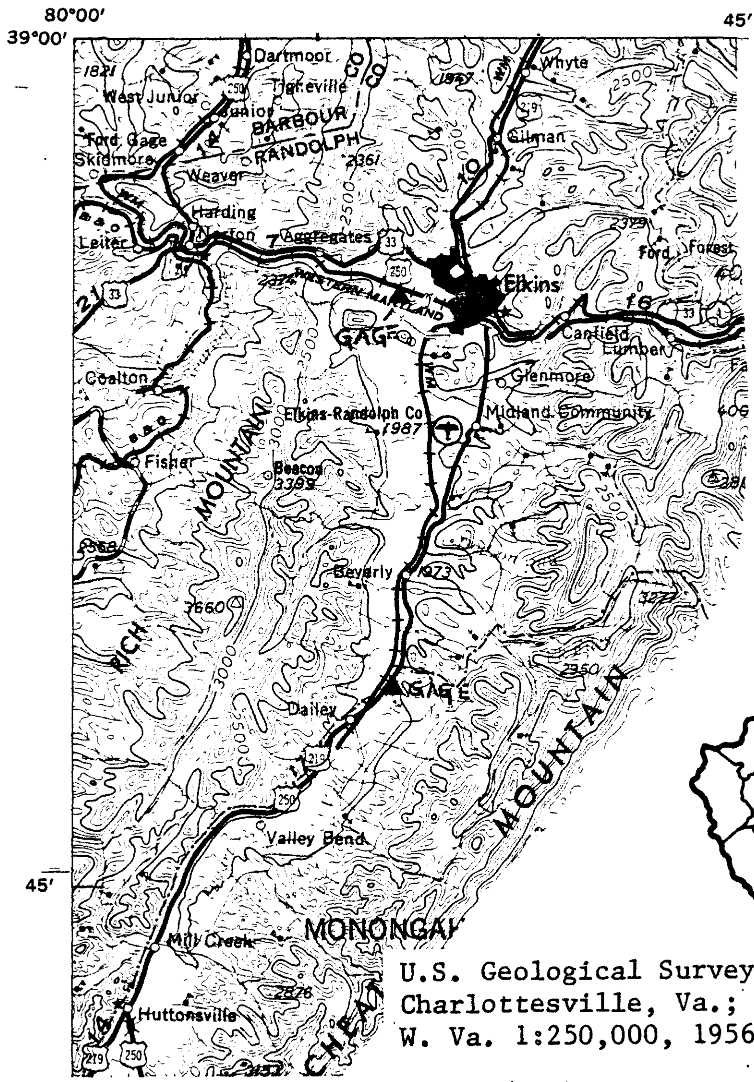
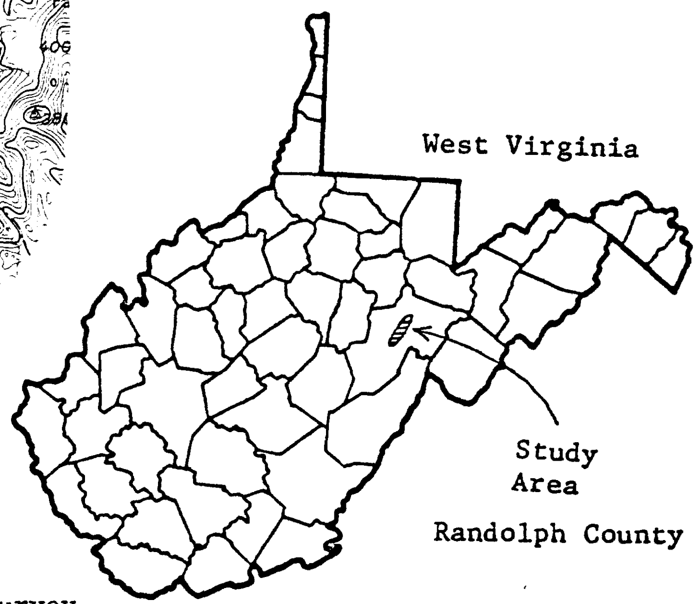


Figure 2.0-1--General topography and locations of towns, villages, and stream gages in Tygart Valley.



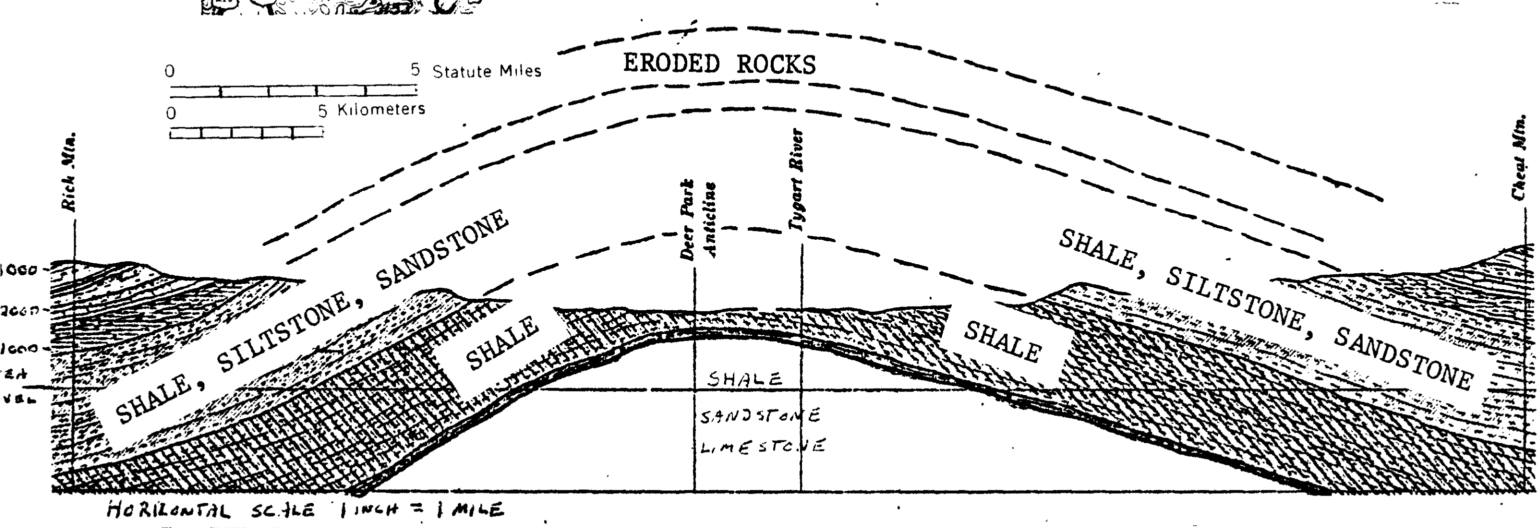


Figure 2.0-2.--Generalized west-east cross section from Rich Mountain to Cheat Mountain showing anticlinal structure and rock type beneath the valley. (Modified from Reger, 1931)

3.0 PURPOSE AND SCOPE

IS ENOUGH GROUND WATER AVAILABLE FOR PUBLIC SUPPLIES DURING DROUGHT?

Can water wells be drilled close to existing distribution pipes so that costs are reduced?

Population is increasing in the Tygart Valley. Most public water systems between Mill Creek and Elkins rely on surface water as a source of supply. County and regional planners are concerned that should a drought, such as the one in 1930, 1953, or 1959, come about, enough surface water would not be available to meet minimum demands. Thus, the main objective of this investigation was to delineate sites in the valley where water wells could be installed close to existing distribution systems and to determine if enough ground water of suitable quality could be obtained to supplement or supplant surface-water sources. If adequate supplies of good quality ground water could be obtained, then it may be used exclusively.

The table on the opposite page shows the current water demand of the towns served by public water systems and the projected demand in 2020. The required water in the table is the calculated continuous supply of ground water needed to supply approximately 100 gallons per day to each person served by the system. This figure could probably be reduced by half particularly during dry periods when the use of water could be restricted if necessary.

Figure 3.0-1.--

CURRENT AND PROJECTED POPULATIONS AND WATER REQUIREMENTS OF AREAS SERVED BY PUBLIC WATER SYSTEMS IN THE TYGART VALLEY. (POPULATION DATA FROM REGION VII PLANNING AND DEVELOPMENT COUNCIL.)

	PRESENT (1979)		40-YEAR PROJECTION (2020)	
AREA SERVED BY PUBLIC WATER	POPULATION SERVED BY SYSTEM	REQUIRED WATER (GAL/MIN)	POPULATION SERVED BY SYSTEM	REQUIRED WATER (GAL/MIN)
MONTROSE	300	20	400	30
KERENS	400	30	750	50
LEADSVILLE	2000		3500	
ELKINS	8600	875	9800	1200
MIDLAND	2000		4000	
BEVERLY	1100	75	2500	175
VALLEY BEND	1200	85	1500	105
MILL CREEK	1900	130	2400	165
VALLEY HEAD	350	25	450	30
MINGO	150	10	200	15

4.0 APPROACH

4.1 PREVIOUS REPORTS

PUBLISHED REPORTS CONTAINED USEFUL GEOLOGIC MAPS AND HYDROLOGIC DATA ON TYGART VALLEY

Published reports show that the Tygart Valley is underlain by shale and has the lowest average annual water runoff in the county.

The initial approach to this study was to examine reports on the geology and hydrology of the area. The geology was mapped at a scale of 1:62,500 and described by Reger (1931). His map provides the basis for the geologic units that were mapped by the author on the aerial photo. A hydrologic report by Friel and others (1967) and a hydrologic data report by Ward and Wilmoth (1968) provided useful information on approximately 50 wells in the valley. Information on most of these wells plus the recently inventoried wells is presented in the appendix 1. The Monongahela River basin interpretive report by Friel and others (1967) was particularly helpful in presenting a general over view of precipitation and runoff variations in the county. It can be seen in the illustrations (figs. 4.1-1, 2) that the Tygart Valley has lower amounts of precipitation and also a lower runoff per square mile than the surrounding mountainous area. This indicates that less water is available in the valley than in the adjacent mountainous area. The data report by Ward and Wilmoth (1968) indicated the salt water at depth, but the great extent of it was not realized until the present field work was done.

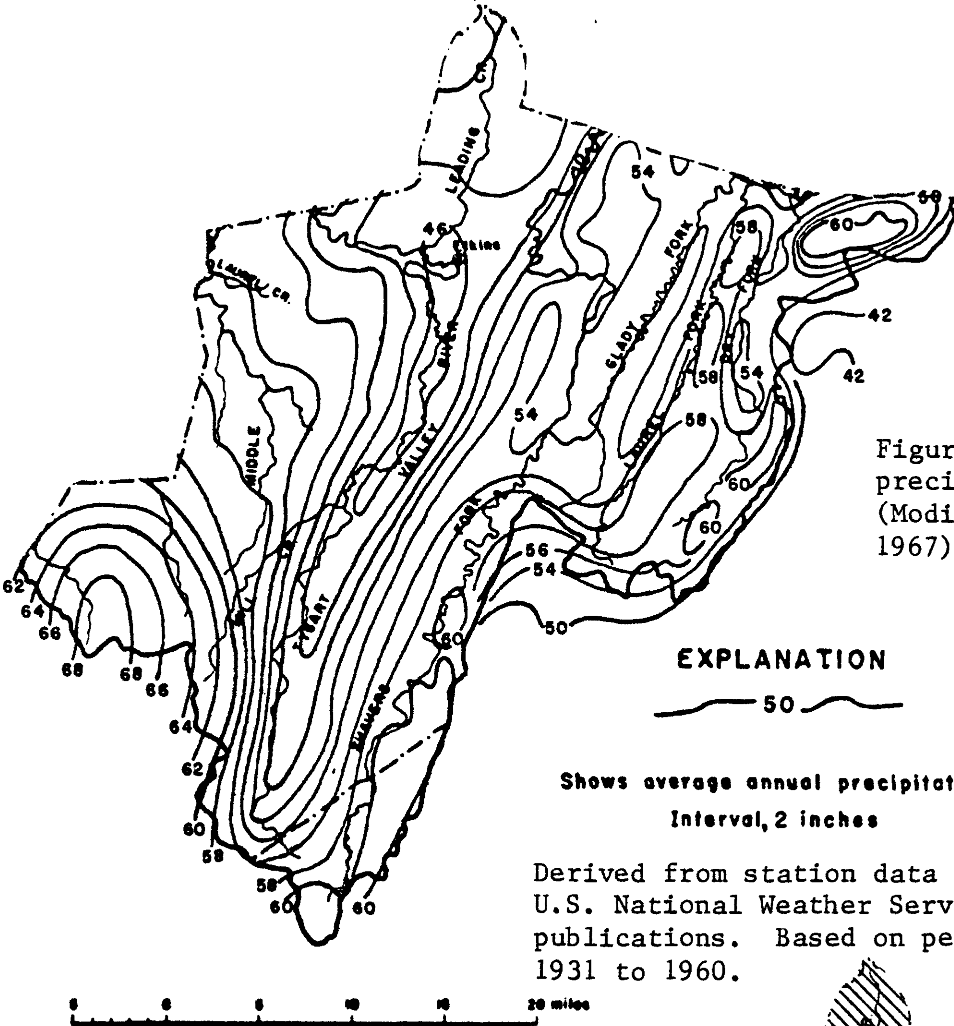
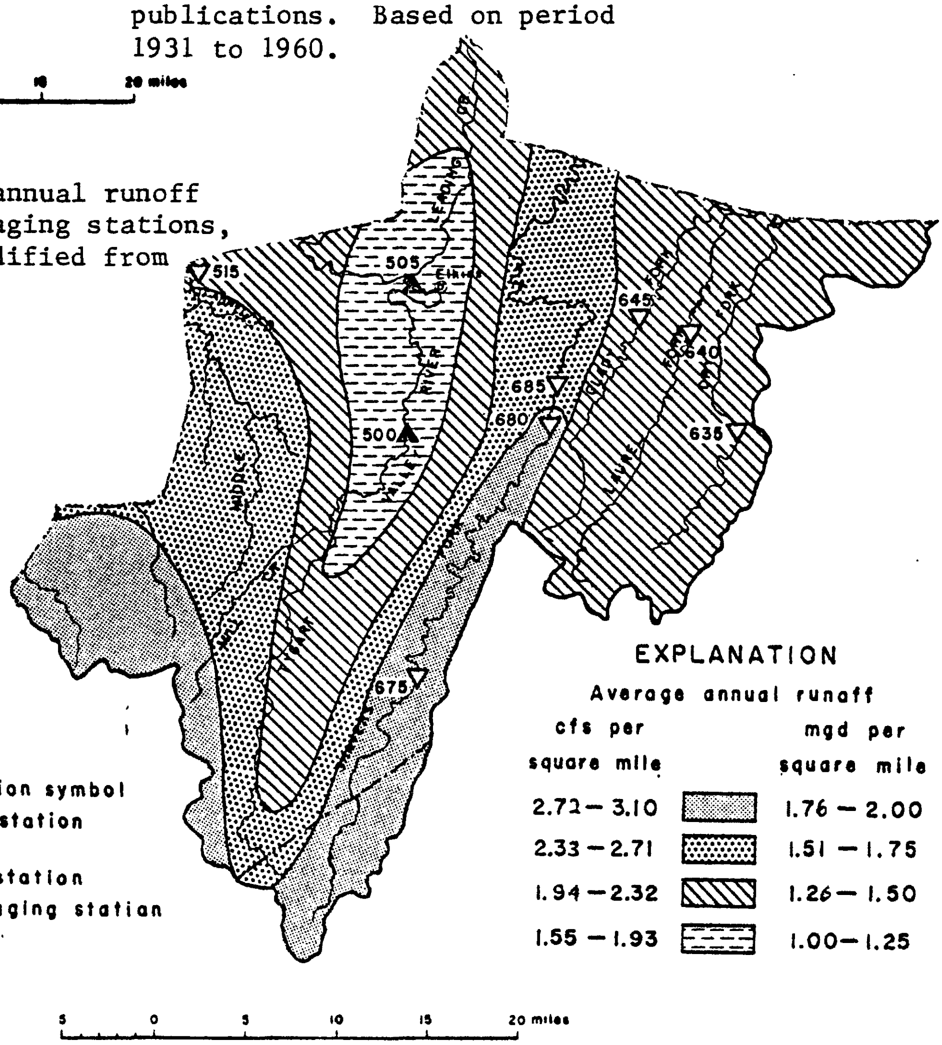


Figure 4.1-1 -- Average annual precipitation in Randolph County. (Modified from Friel and others, 1967)

Figure 4.1-2 -- Average annual runoff and location of stream-gaging stations, in Randolph County. (Modified from Friel and others, 1967)



NOTE: Number shown by station symbol is identification number of station

▲ Active stream-gaging station
▽ Discontinued stream-gaging station

4.2 REMOTE SENSING

4.2.1 GENERAL INFORMATION

FRACTURES AND FAULTS CAN BE MAPPED FROM AERIAL PHOTOGRAPHS AND SATELLITE IMAGERY

Fractures and faults can be mapped from aerial photographs and satellite imagery that have been electronically modified to enhance linear features.

Both satellite imagery and aircraft photography were used to map fracture traces or lineaments. Lineament mapping is based on the premise that faults and fractures are permeable zones of weakness in the rocks. Most of the water in the shale is contained in fractures. Fractures are distinguishable on the imagery and photography as tonal, vegetal, or topographic lineations. In mapping fracture traces or lineaments the imagery and photography were analyzed using a video analog (TV-type) display. This system permitted a view of the area much like that of a shaded relief map. Electronically the picture was enhanced and modified so that the "grain" or linear structure could best be seen. Figure 4.2-1 on the opposite page is a photograph of an enhanced TV display of a satellite image. Figure 4.2-2 is a similarly enhanced TV display of the high-altitude color infrared (CIR) photograph used in making the maps in sections 4.2.2 and 4.3. Notice the linear features that trend predominantly from NW to SE. This trend is best seen when viewed at a low angle from the southeast corner of the photographs. The lineament map in the next section was prepared using photographs such as this and satellite images.

Figure 4.2-1 -- Photograph of video-enhanced satellite image (NASA ERTS E-2726-15054-7 02, January 17, 1977) of the Elkins-Beverly area.

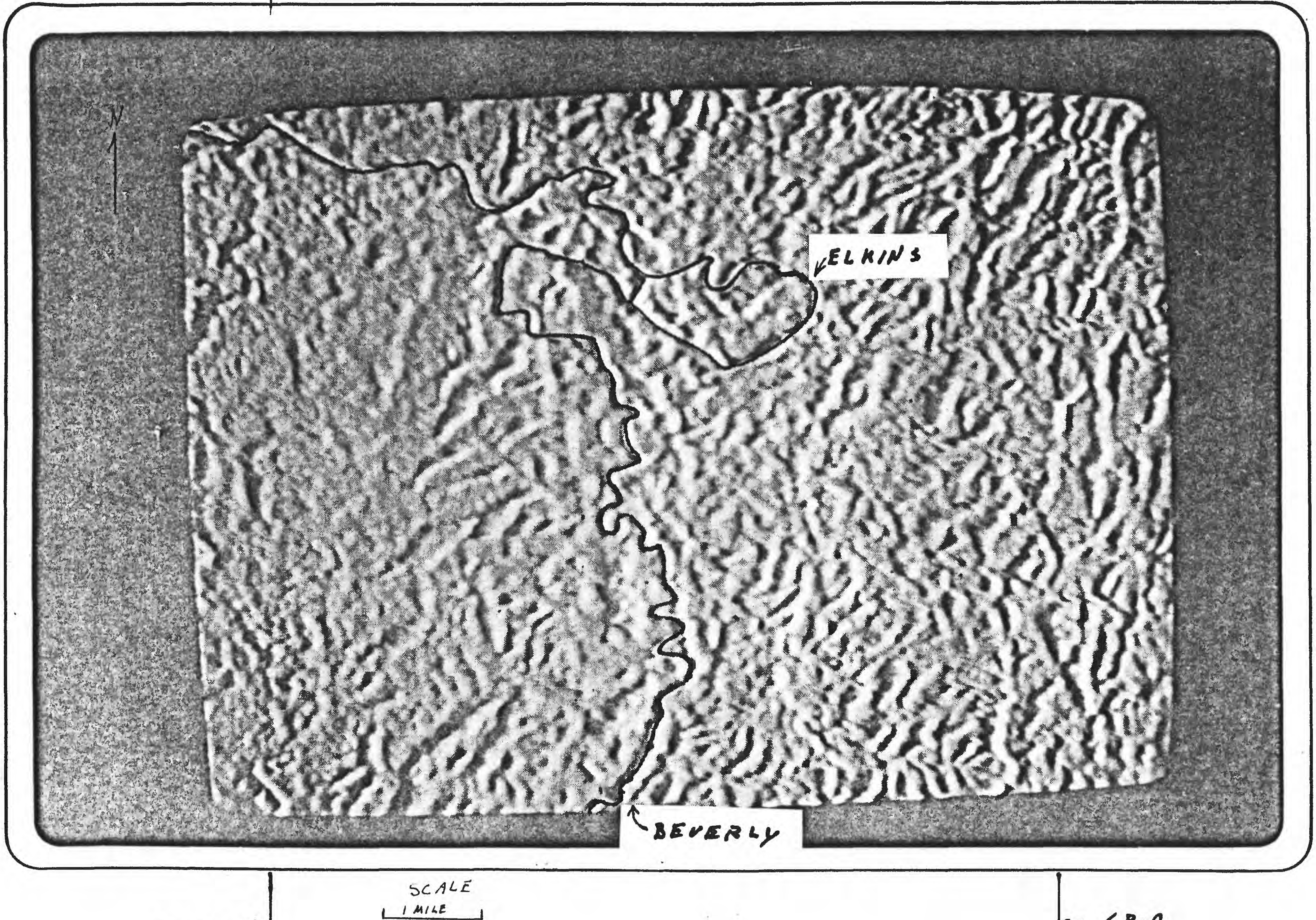
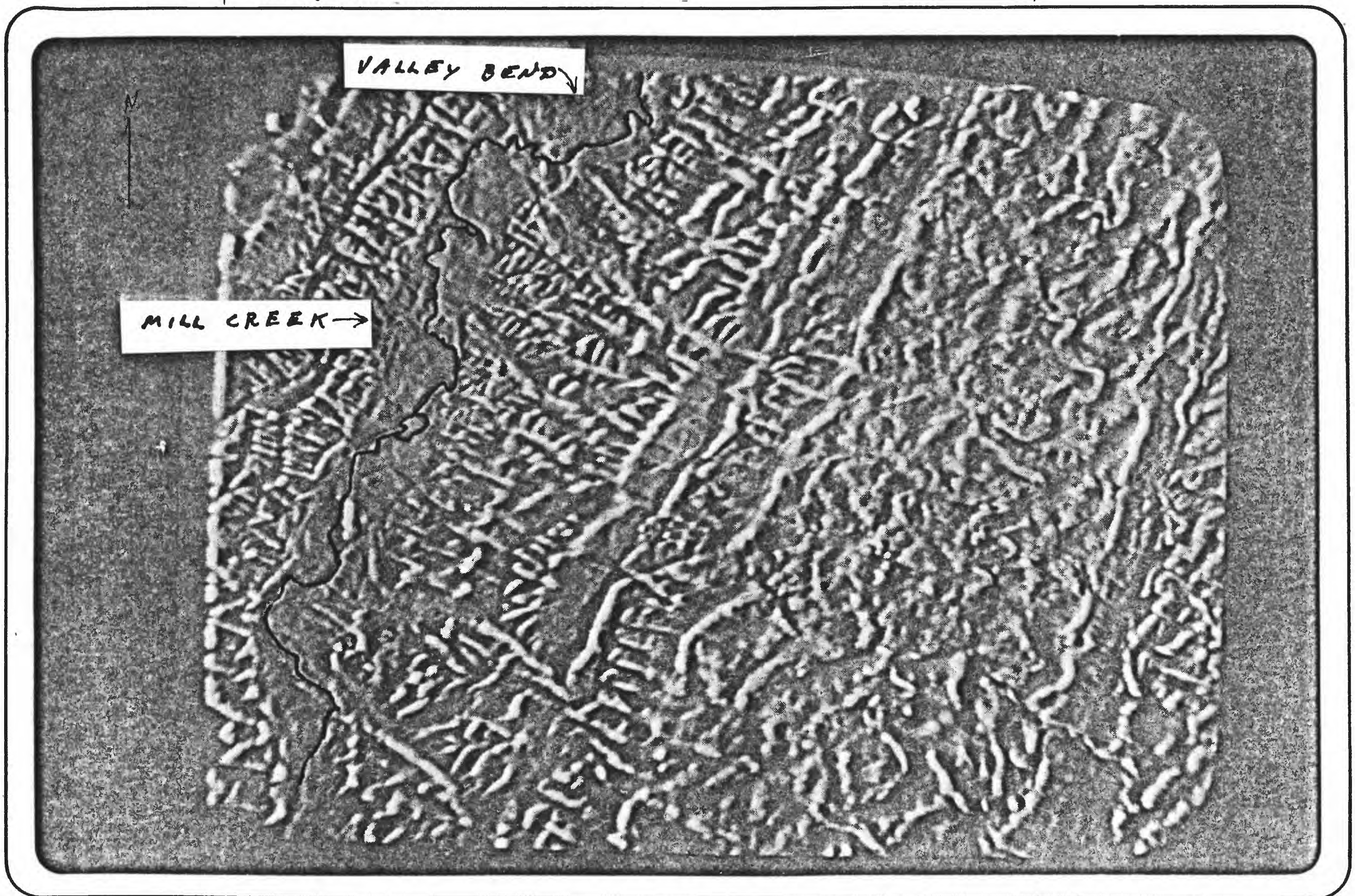


Figure 4.2-2 -- Photograph of video-enhanced color infrared NASA aerial photograph (frame 6969, Dec. 3, 1973) of the Mill Creek-Valley Bend area.



4.2 REMOTE SENSING

4.2.2 Lineament Analysis

VERY PERMEABLE ZONES FOUND IN ROCK ALONG LINEAMENTS

Lineaments generally indicate linear zones of fractured or faulted rock along which ground water may readily be stored and transmitted to water wells.

Lineaments are linear features that appear on photographs or images, but cannot generally be identified on the ground. Lineaments generally are caused by differences in plant types, soil tone or moisture content, alinement of disrupted rock outcrops, or alinement of topographic features such as straight segments of stream channels. Lineaments often represent fractures or faults which generally are zones of increased permeability and hence good places to drill water wells.

The photograph-map on the opposite page is a compilation of lineaments from satellite images and aerial photographs. It generally shows a predominant trend of lineaments to the northwest. In the northern half of the area there is another trend to north and northeast. Throughout the area there are a few lineaments that trend nearly east-west. Notice that most lineaments are not mapped across the alluvium because farming and erosion by the river have largely masked surface evidence of the lineaments. Some lineaments have been extended across the alluvium where evidence in the hills on both sides of the valley indicates that they cross. Many of the mapped lineaments could be projected into the valley. This study indicates that the fractured area along a lineament may be 50 feet or more wide. Thus, if lineaments are extended into the valley there is some latitude in regard to locating the well so that it taps the fractured zone at depth.

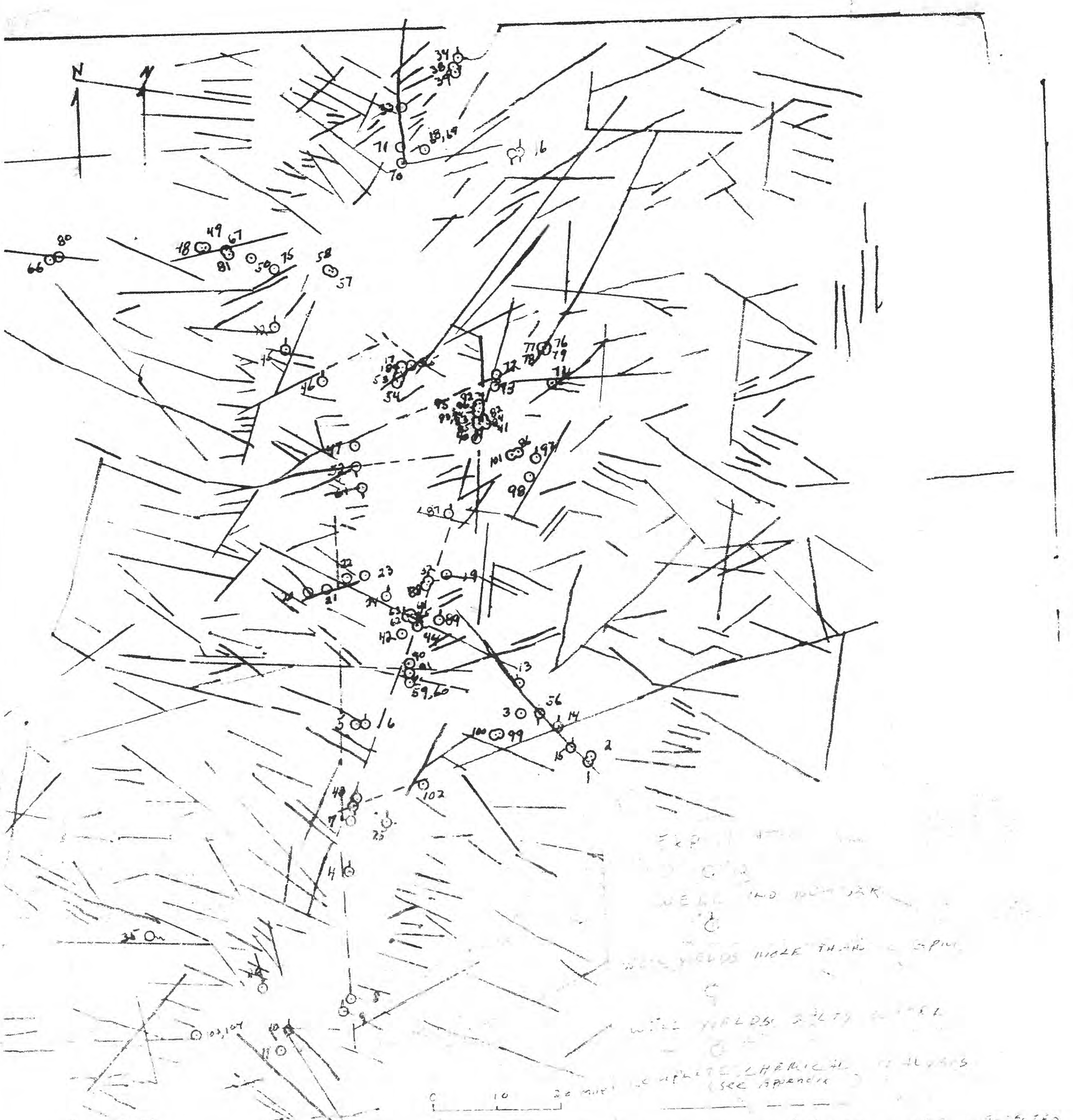


Figure 4.2.2-1.--Lineaments and well locations in [illegible] Valley

4.3 WELL INVENTORY AND SAMPLING

DATA COLLECTED ON MORE THAN 60 WELLS IN THE VALLEY

Data were collected on 60 wells, many of which were pointed out by the driller as being high yielding or salty.

Prior to this study data had been collected on approximately 50 wells (Ward and Wilmoth, 1968) throughout the valley. These data gave some insight as to water levels, well yields, and water quality. Then prior to collecting additional well data, the valley was toured with Mr. Bert Thompson, a retired local well driller, who drilled many of the wells in the valley. During this tour, map notes were made regarding high and low yielding wells and wells yielding salty water. Approximately 60 of these wells, especially the high yielding and salty ones, were visited and detailed data collected. These well locations are shown in figure 4.3-1 and the data are shown in Appendix 1. It is interesting to note that most high yielding and salty wells are located on lineaments.

Most wells were sampled and pH and specific conductance measured at the site. Some also were analyzed with a field test kit for iron or chloride. These data are also in the Appendix. Wells equipped with water-treatment equipment were not sampled unless water could be obtained.

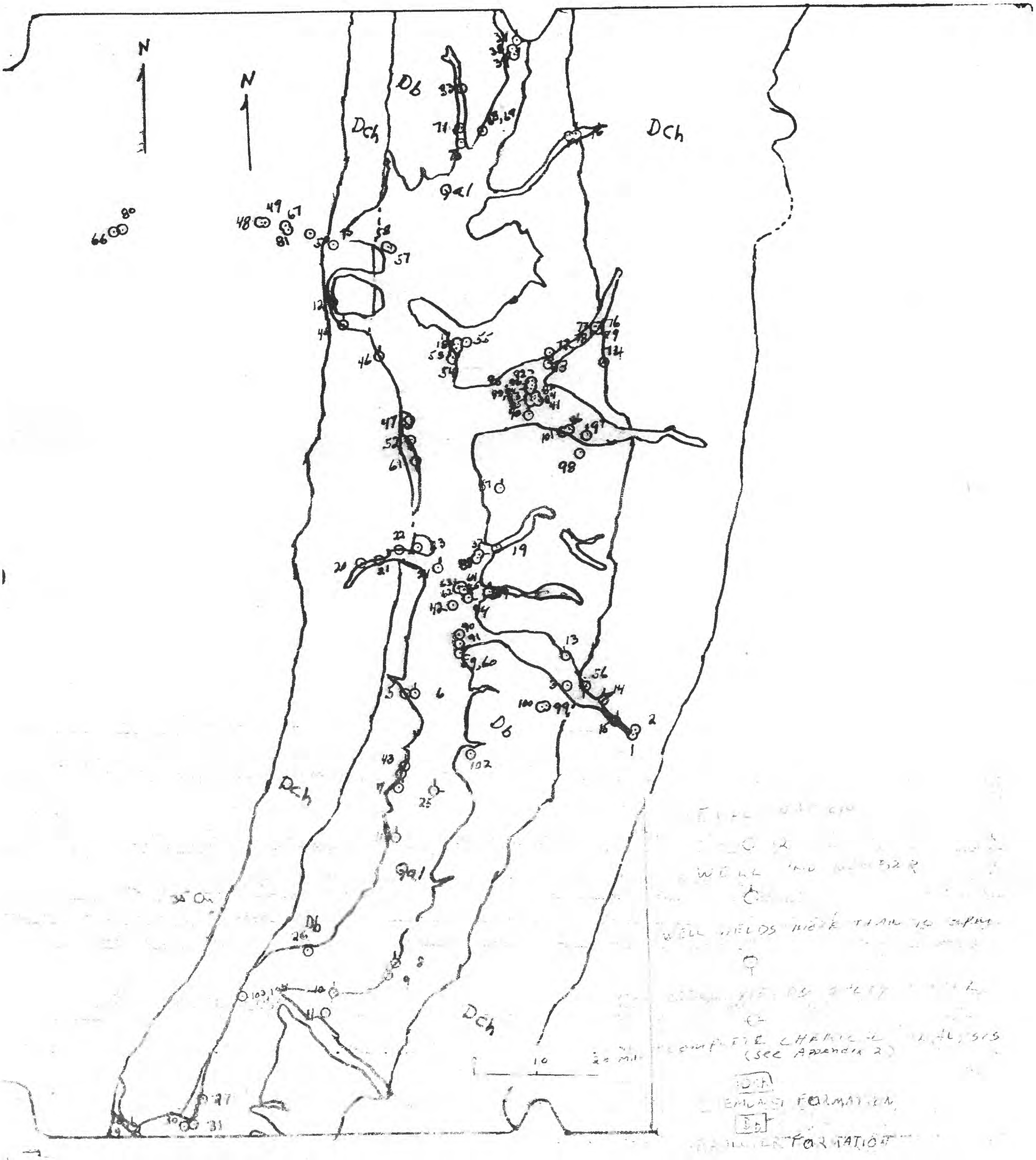


Figure 4.3-1.--Geology and well locations in Tygart Valley

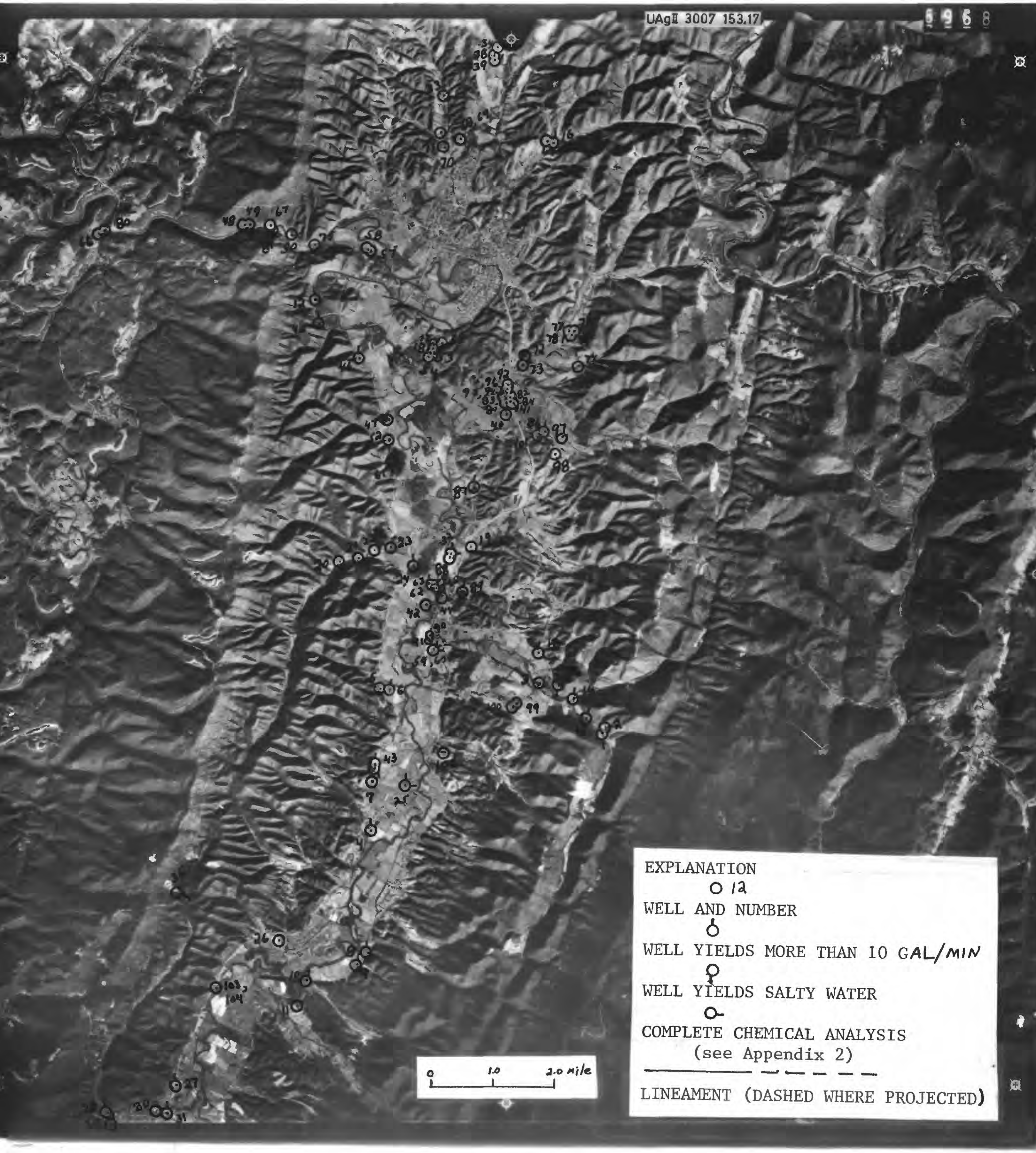


Figure 4.2.2-1 Lineaments and well locations in Tygart Valley

Use transparencies, Figure 4.2.2-1 and Figure 4.3-1 as overlays.

4.0 APPROACH

4.4 MEANING OF AQUIFER COEFFICIENTS

AQUIFER COEFFICIENTS MATHEMATICALLY DESCRIBE THE ABILITY OF ROCKS TO TRANSMIT AND STORE WATER

The coefficients of transmissivity and storage mathematically describe the ability of rocks (an aquifer) to transmit and store water and can be approximated by various well-testing techniques.

A rock must have porosity in order to store and transmit water. Porosity is simply the property of containing interstices or openings. Porosity may be classified as primary or secondary. Primary porosity is the original intergranular pore space contained when a soil or rock was formed. In a sand and gravel deposit the primary pores are the spaces contained between grains and pebbles. Secondary porosity is any space which developed along bedding planes, joints, faults, or solution cavities after the rocks were formed.

Permeability or hydraulic conductivity is a measure of the ability of primary and/or secondary openings to transmit water. In figure 4.4-1 (Ferris and others, 1962) hydraulic conductivity for a porous medium (K, also previously called "coefficient of permeability") is the flow of water through a section area "A" under a unit hydraulic gradient per unit time and at the prevailing water temperature. Transmissivity (T) is the flow of water through a section area "B" in figure 4.4-1 under a unit hydraulic gradient, at the prevailing water temperature. It is apparent from the figure that transmissivity is equivalent to hydraulic conductivity (K) times aquifer thickness (m).

Hydraulic conductivity is expressed in terms of ft^3 of water passing through 1 ft^2 of aquifer in one day (ft^3/ft^2 day), or ft/day. Transmissivity is equivalent to the thickness of aquifer in feet times K, thus, it is ft^2/day.

The storage coefficient (fig. 4.4-2) is the volume of water an aquifer releases from (or takes into) storage per unit surface area of the aquifer per unit drop (or rise) in water level normal to that surface. Ferris and others (1962, p. 76 and 78) describe the storage coefficients in the following way.

~~*Summary statement.*~~—For an artesian aquifer, regardless of its attitude, the water released from or taken into storage, in response to a change in head, is attributed solely to compressibility of the aquifer material and of the water. The volume of water (measured outside the aquifer) thus released or stored, divided by the product of the head change and the area of aquifer surface over which it is effective, correctly determines the storage coefficient of the aquifer. Although rigid limits cannot be established, the storage coefficients of artesian aquifers may range from about 0.00001 to 0.001.

~~*Summary statement.*~~—For a water-table aquifer, regardless of its attitude, the water released from or taken into storage, in response to a change in head, is attributed partly to gravity drainage or refilling of the zone through which the water table moves, and partly to compressibility of the water and aquifer material in the saturated zone. The volume of water thus released or stored, divided by the product of the area of aquifer surface over which the head change occurs and the component of head change normal to that surface, correctly determines the storage coefficient of the aquifer. Usually the volume of water attributable to compressibility is a negligible proportion of the total volume of water released or stored and can be ignored. The storage coefficient then is sensibly equal to the specific yield. The storage coefficients of water-table aquifers range from about 0.05 to 0.30.

Aquifer coefficients can be estimated by various methods. The conventional method is to pump a well at a constant rate and measure the drawdown in nearby observation wells. Transmissivity (but not storage) may be determined by measuring recovery in a pumped well when no observation wells are available. Transmissivity also may be determined using equations relating fluctuations of water levels in observation wells to that in surface streams (Ferris, 1951). This technique was tried unsuccessfully in this study. Aquifers coefficients were estimated during this study using single-well or multiple-well tests.

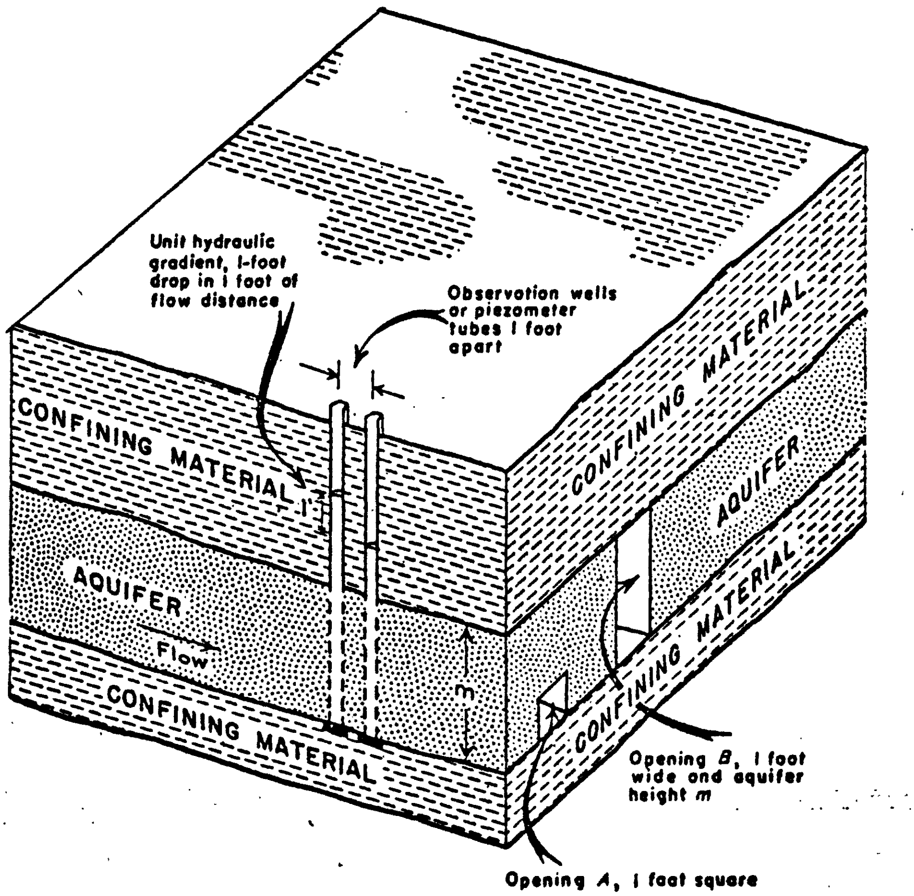


Figure 4.4-1.--Diagram for coefficients of permeability and transmissibility. (From Ferris and others, 1962)

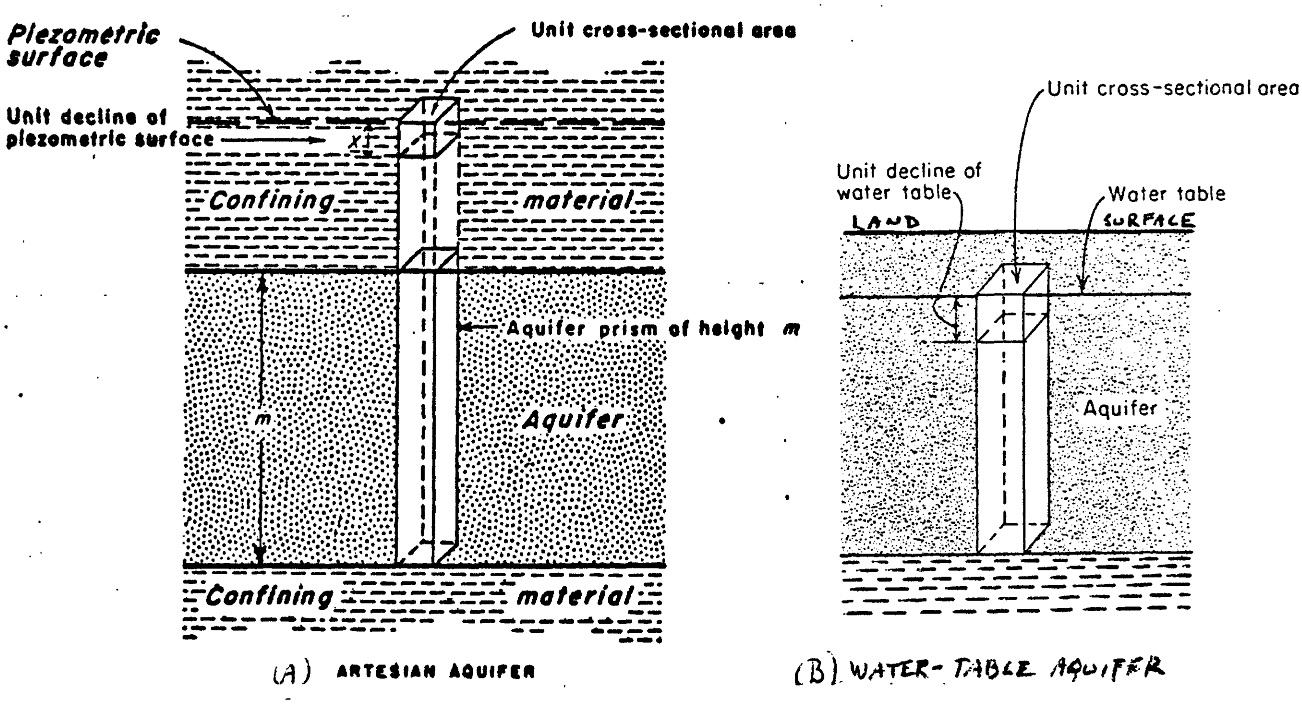


Figure 4.4-2.--Diagram for coefficient of storage. (Modified from Ferris and others, 1962)

4.0 APPROACH

4.5 SINGLE-WELL PUMP TESTS

SINGLE WELL RECOVERY TESTS INDICATE TRANSMISSIVITY RANGES FROM 1.5 TO 500 FT^2/DAY

Single-well recovery tests indicate that the transmissivity at one test well is greater than that at all the other tested wells.

Following the well inventory, short-term pumping tests were performed on 11 selected wells. By analyzing the drawdown and recovery in these wells (Theis, 1935) the permeability of the rocks could be evaluated and potential well yields estimated. Originally it was planned to pump the tested wells for 15 to 20 minutes, measure drawdown of the water level, then measure recovery of the water level for 60 to 90 minutes after pumping stopped. However some wells were pumped only a few minutes (see figure 4.5-1) when their water level fell below the pump intake. Thus, pumping stopped and recovery measurements were begun. By plotting the result as in the accompanying graphs (figs. 4.5-2, 4.5-3) the permeability (or transmissivity) of the rock can be approximated and compared from one well to another. Additionally, information on recharge and discharge boundaries is apparent from the graphs.

The recovery rate of the water level in the well reflects the transmissivity of only the rocks within which the openings control the rate of water movement toward the well. In other words (all other hydrologic factors being equal) if the saturated rocks near the well contain few joints and fractures transmissivity will be lower than if the rocks contain many joints and fractures. In addition to the degree of jointing and fracturing these openings are generally planar in nature, and they create variation in permeability according to their direction: permeability may be high parallel to the openings but low in most other directions. Thus the transmissivity value determined by a single well test generally represents some value in between maximum and minimum transmissivity at that site. The directional permeability at the test site is discussed in detail in section 5.3.

The graphical analysis shown is for well 44, which is located about 400 feet south of the major east-west lineament near the north end of Beverly. This well was pumped for 24 hours at an average rate of 10.7 gallons per minute to determine if chloride content would increase with pumpage. The chloride content did not change with pumpage and drawdown and recovery data were collected at the well. The semilog plot (fig. 4.5-2) of drawdown in the well versus time since pumping started shows the water level declines at one rate for the first 200 minutes of pumping, then at a faster rate from 200 minutes to 900 minutes, then at a slower rate after 900 minutes. The first change in slope after 200 minutes indicates that a ground-water barrier is affecting the well and thus causing a greater rate of drawdown in the pumped well. The second change in slope at 900 minutes indicates a recharge boundary is affecting the water level in the well and thus causing a lesser rate of drawdown in the pumped well. In order to estimate transmissivity of the rocks near this well it is necessary to plot residual drawdown (measured depth to water referred to static water-level datum, or projected drawdown minus recovery water level) against t/t' (time since pumping started/time since pumping stopped) on semilog graph paper (fig. 4.5-3). The slope of the line per log cycle drawn through the points near the origin (or for points with largest values of t and t') is used in the given equation to compute T for the aquifer.

The data for each of the tested wells was analyzed and the results summarized in the accompanying table. The transmissivities for 2 wells in the Pocono and Mauch Chunk Formations were 1.5 and 6.3 ft^2/day which indicates a low permeability. Transmissivities for wells in the Brallier Formation ranged from about 5 to 535 ft^2/day. The lowest of these transmissivity values was at a USGS test well 64 drilled off the lineament near Beverly and the highest was at USGS test well 65. The transmissivity computed by the recovery method at this well is 1740 ft^2/day. By comparison, well 32 is reported by the driller to be the "one of the best wells he ever drilled" in this area, and transmissivity computed by the same recovery method is 510 ft^2/day or about 1/3 of the transmissivity at test well 65. Although the recovery method is not always the best method of aquifer analysis, it does provide a simple means by which the transmissivity of the rocks at the various wells can be compared. This comparison indicates that test well 65 is tapping a fracture zone as good or better than fractures or fracture zones tapped by the other tested wells.

Figure 4.5-1.--Single-well pump test data

WELL NO.	DEPTH (FT)	DEPTH CASED (FT)	WATER LEVEL (FT)	PUMP RATE (GPM)	PUMPING TIME (MIN)	DRAW DOWN (FT)	SPECIFIC CAPACITY (GPM/FT)	SPECIFIC CAPACITY ADJUSTED TO 30 MIN (GPM/FT)	TRANS-MISSIVITY ~~(GPM/FT)~~ (FT^2/DAY)	ROCK FORMATION	REMARKS
32	133	60	3.05	11.5	20	4.95	2.32	2.25	508	Brallier	
4	71.35	17.65	7.33	37.5	16.25	10.05	3.73	3.15	106	Brallier	
18-4-5	140	e40	5.95	3.17	31	2.16	1.47	1.47	160	Brallier	
14	24	15	3.25	7.14	15	3.92	1.80	1.46	47	Chemung	
49	60.1	27.65	3.96	21.4	3.5	30	.71	0.4	6	Mauch Chunk	
34	33.5	17.15	5.00	25.0	14	19.52	1.28	1.13	80	Brallier	
50	42.15	8.65	11.30	5.1	7.5	29.40	.17	.07	2	Pocono	
44	80.3	20.4	12.70	25	3	23	.92	.58	19	Brallier	
25	85	21	5.87	6.5	15	11.56	.56	.51	40	Brallier	
18-2-4	55	50	20	25	720	21	1.19			Greenbrier	Reported
57	84	13	12.07	10.3	20	51.93	.20	.14	8	Brallier	
58	80	15	10.84	10.3	20	46.71	.22	.18	16	Brallier	
* 62	96	13	3.84	10.7	270	33.94	.32	.51	78	Brallier	
* 63	98	14.5	4.01	11.1	105	18.06	.61	.82	267	Brallier	
* 64	97	14.0	3.43	33	1.5	26.89			5	Brallier	
* 65	86	13.5	3.78	33	118	16.39	2.01	2.02	1738	Brallier	

* USGS Test Well

Figure 4.5-2.--Time-drawdown graph for pumped well 44 showing the effect of discharge and recharge boundaries.

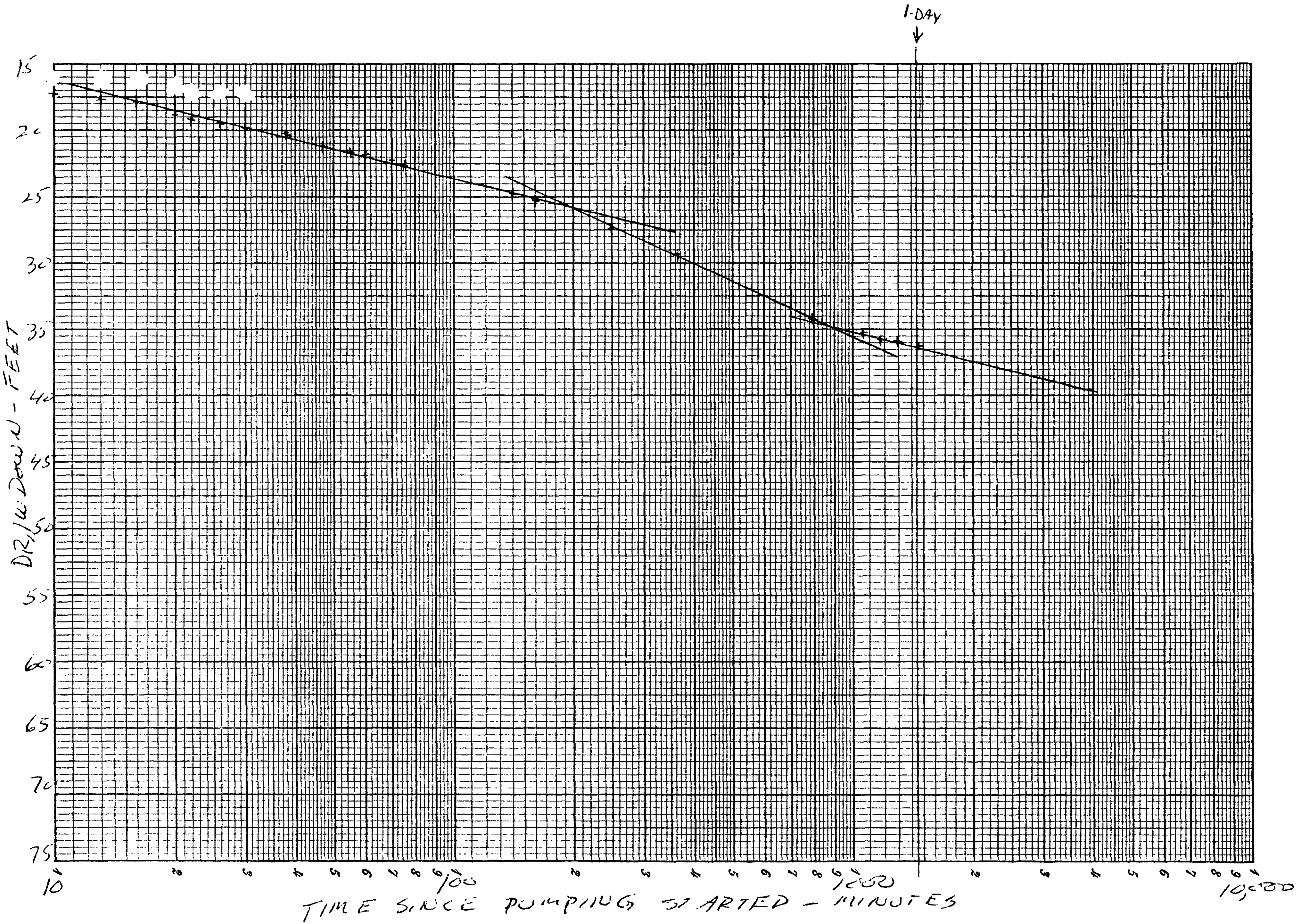
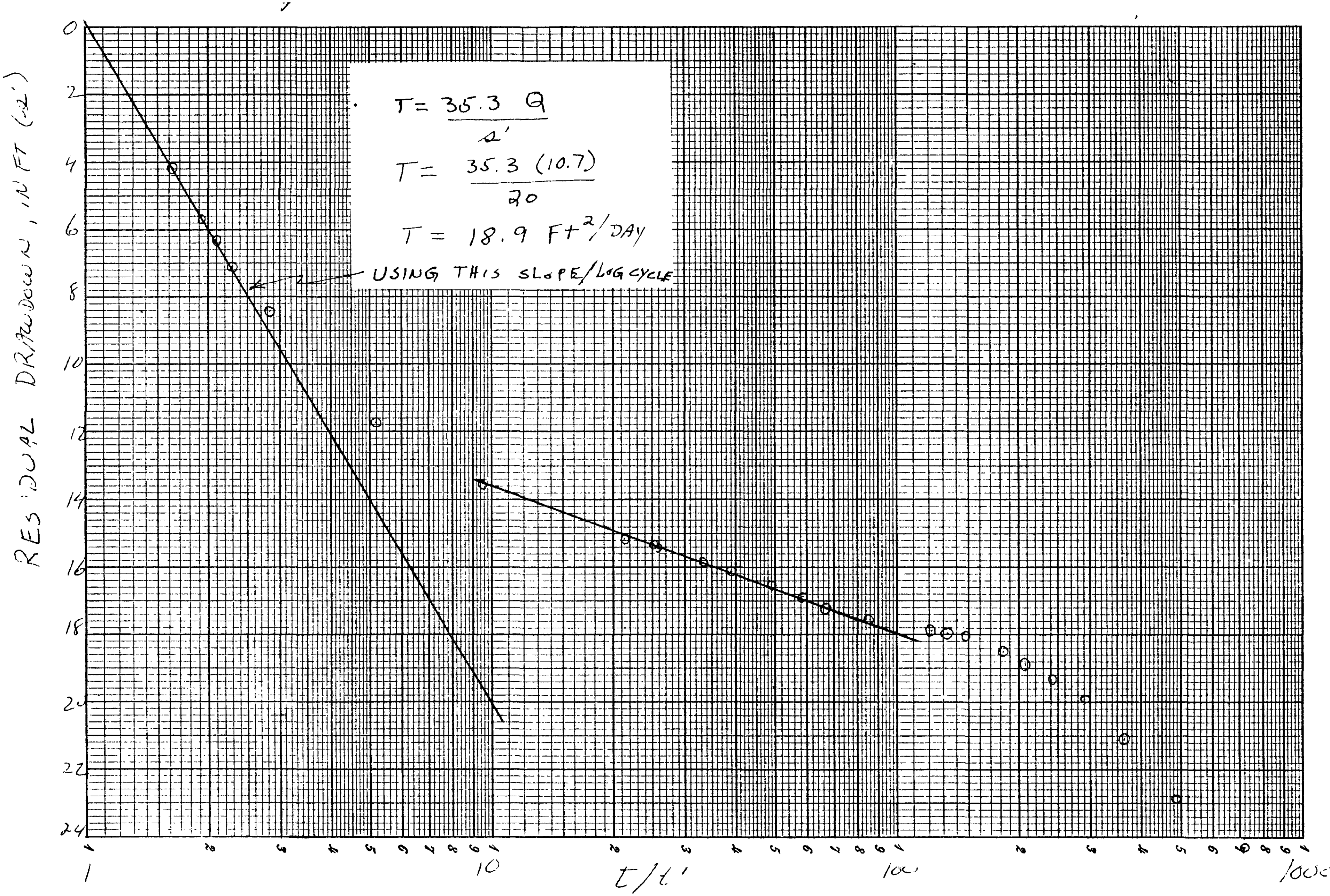


Figure 4.5-3.--Residual drawdown versus t/t' for pumped well 44 showing calculation of transmissivity using late recovery data.



4.0 APPROACH

4.6 TEST DRILLING SITE SELECTION

TEST DRILLING SITE SELECTION BASED ON SIX FACTORS

Primary factors considered in selecting the test drilling site were nearness to existing distribution system, available recharge, topography, degree of rock fracturing, depth to the water table, and depth to salty water.

A primary objective of this study was to determine if ground water of adequate quantity and quality could be obtained from wells near public water-distribution systems for use during prolonged drought. The largest distribution system in the Tygart Valley is in the Elkins area. Therefore, the county's three priorities for test sites were: (1) near South Elkins, (2) North Beverly, and (3) Dailey-Valley Bend area. The area near South Elkins was eliminated from consideration because it seemed unlikely, based on the well data that had been collected, that a supply of 1,200 gal/min could be developed near the distribution system there.

Therefore, the test drilling site was selected based on the following:

1) Proximity to the existing Beverly water system.

   The number 2 site was chosen (fig. 4.6-1) because it seemed likely that within the financial and time limitations of this study that an area could be located that would supply 175-200 gallons per minute.

2) Recharge water available to the well field.

The water level in the valley area is only 2-3 feet below land surface. Approximately 14 feet of alluvium overlies the bedrock; 11 to 12 feet of the alluvium saturated and the water is available to wells. The site is also near the Tygart Valley River which could supply water. Just upstream from this site the river receives water from Files Creek which derives water from the mountains east of the main valley.

3) Valley location.

The site is in the valley and previous studies indicate that valley wells generally yield more water than hillside or hilltop wells. Some of the factors that may cause valley wells to yield more water are (1) valleys tend to develop along fractures, (2) erosion in valleys causes stress-relief phenomena to create still more fracturing, (3) ground-water levels generally are high in valleys thus the near surface rock which is generally more fractured and permeable than deeper rock, is saturated with water.

4) Fracture or fault intersections.

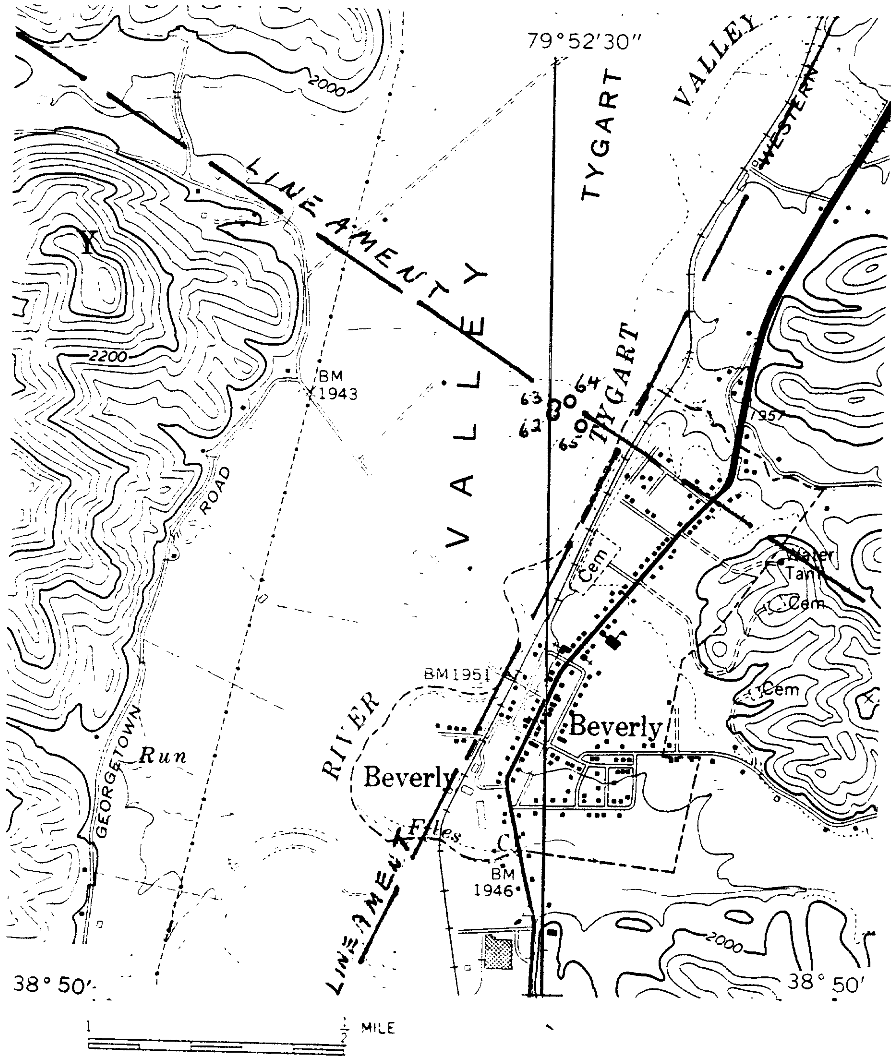
Fractures or faults are broken zones which are usually more permeable than the surrounding rocks. Where two or more faults or fractures intersect permeability may be increased even more.

5) Anticlines crests.

Statistical well data for parts of West Virginia indicate that wells located on anticlines yield more water than wells located on synclines or on flat-lying beds. This is because of tensional fractures that develop when anticlines are formed. A northeast-trending anticlinal crest lies somewhere in the vicinity of the river at the test site.

6) Depth to salty water.

Pump tests and chemical analyses of high-yielding wells tapping lineaments in the Beverly area indicated low chloride content, at least to a depth of 140-feet.



Base from U.S. Geological Survey
Beverly East 1:24,000, 1969 and
Beverly West 1:24,000, 1968

Figure 4.6-1 Location of lineaments and test wells near Beverly .

4.7 RESISTIVITY STUDY

ELECTRICAL-RESISTIVITY DATA INDICATE FRACTURE ZONE HAS LOW RESISTIVITY

Electrical-resistivity data show a resistivity low about 60 feet west of the surface location of a lineament.

The map (fig. 4.7-1) on the opposite page shows the plan view of the test site area showing the line of the resistivity profile run using the Wenner configuration and the stations where depth soundings were taken.

The profile (fig. 4.7-2) shown was prepared from data collected at 10-foot intervals along the N. 25° E. line which is approximately parallel to the strike. The 4-electrode array was spaced at 100-foot intervals along a line normal to that of the profile. A voltage of 90 volts was applied to the outer power electrodes and the resistance in ohms was measured across the two inner electrodes. After each reading the electrodes were advanced 10 feet and another reading taken. Theoretically the depth of earth affecting each reading is roughly equal to the spacing of the electrodes (in this case 100 feet). However, the upper 50 feet of earth has the greatest affect on the resistivity readings. Thus, the resistivity profile suggests the nature of the materials that lie at depth but cannot determine the exact depth. For example, one might get a high resistivity response from a water-saturated sand and gravel or a dry impervious layer of shale. One might get a low resistivity response from a water-saturated fracture containing clay or mineralized water. It should be noted that significant amounts of saturated sand and gravel were found above the shale at wells 62 and 63. Only silty sand was found above the shale at well 65. Note on the cross section that a higher resistance is indicated at wells 62 and 63 than at well 65. All of these wells are presumed to be on the fracture in the shale. However, the overall effect of the near-surface sand and gravel at wells 62 and 63 is to mask the effects of the underlying fracture on resistivity reading.

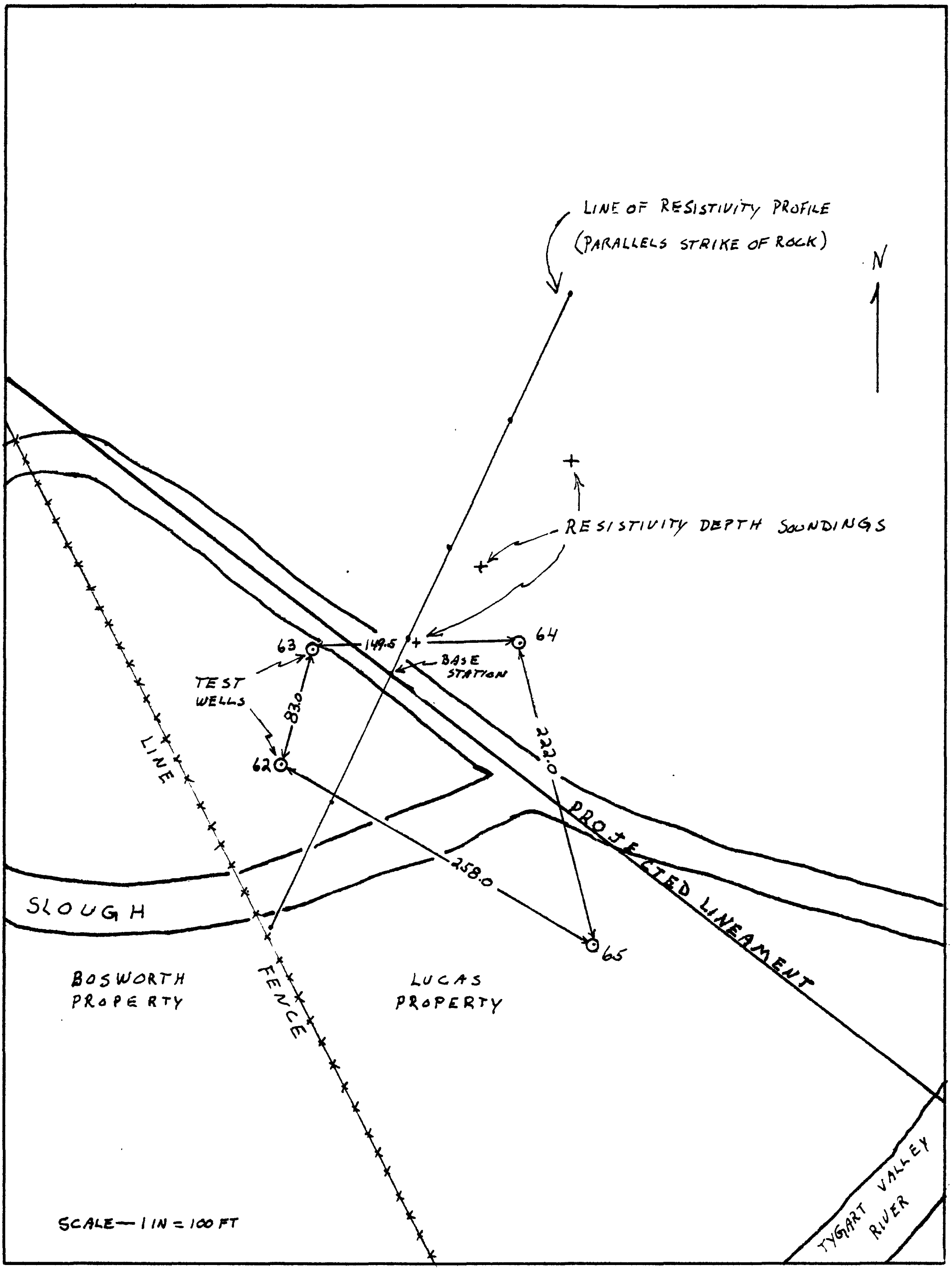


Figure 4.7-1.--Locations of resistivity profile, depth soundings, and test wells at site near Beverly.

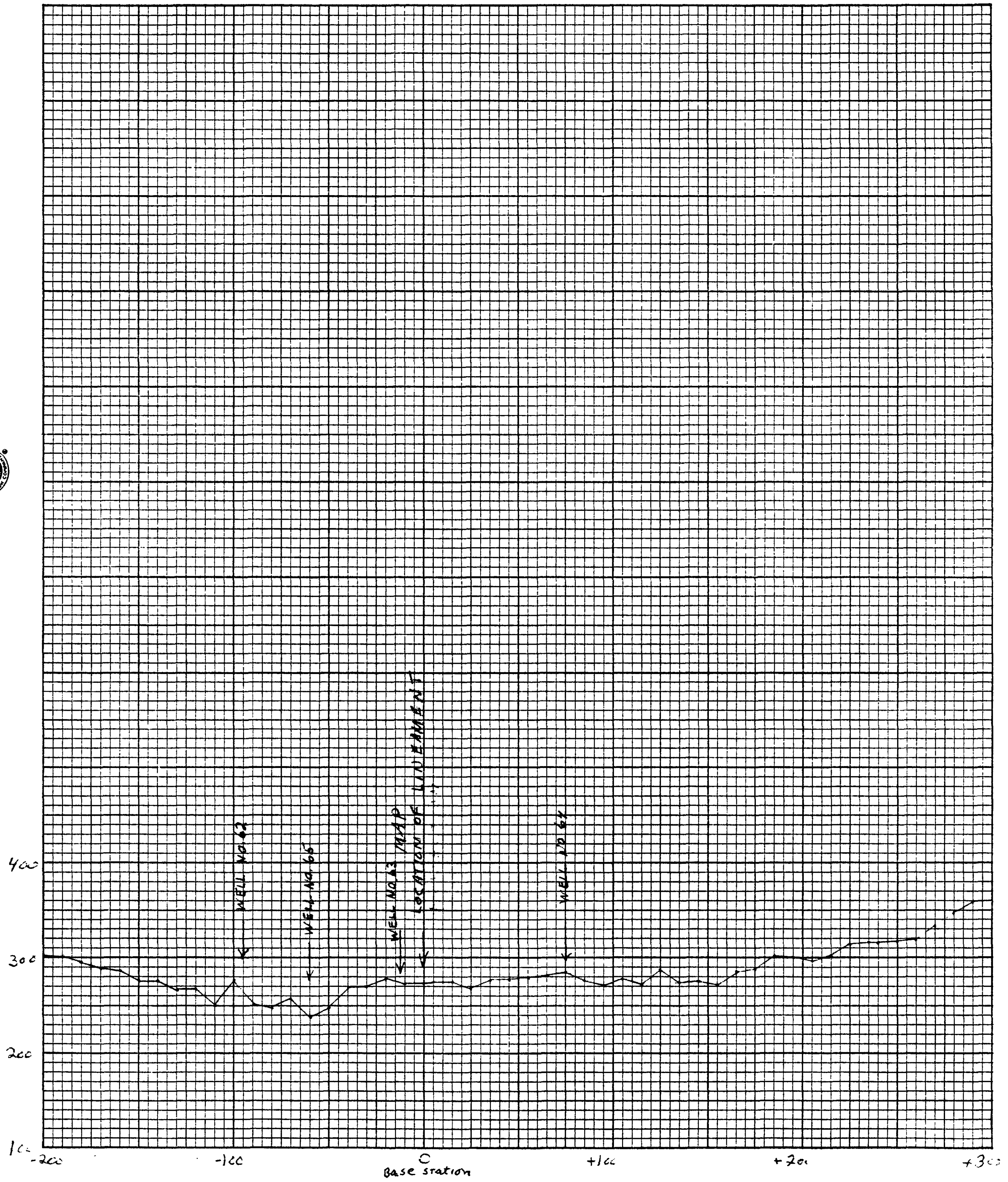


Figure 4.7-2.--Resistivity profile using 100-ft electrode spacing (Wenner configuration) and showing approximate well and lineament locations.

5.0 RESULTS AT TEST SITE

5.1 TEST DRILLING

FOUR TEST WELLS 86 TO 98 FEET DEEP YIELD 2 TO 100 GALLONS PER MINUTE

The best producing test well was drilled just south of the projected lineament and in the area of a resistivity low which was thought to represent the lineament at depth.

The sites for the four test wells were selected on the basis of the lineament map and the resistivity survey. Well 63 was drilled on the projected surface expression of the lineament, well 62 was drilled toward the southern limits of the lineament, well 64 was drilled north of the lineament on a resistivity high, and well 65 was drilled just south of the projected lineament at a point where resistivity was lowest and suggested the presence of the lineament at depth. The graphic logs for the test wells are given in figure 5.1-1. It is apparent that the thickness of alluvium at each site is about 14 feet but wells 62 and 63 had 7 to 8 feet of saturated sand and gravel. Wells 64 and 65 had about 14 feet of silt and sand over the shale. Beneath the alluvium the wells all penetrated mostly soft, nonlimy, blue and black shale with some hard layers of blue shale. The black beds of shale apparently contain sulfide minerals as a hydrogen sulfide odor was generally detectable as these beds were being drilled. When well 62 was 44 feet deep a sample of water was collected and analyzed. It's conductance was about 7 times higher than that water from test well 63 when it was drilled into the same formation. Another sample collected when well 62 was 90 feet deep indicated an increase in sodium of about 20 mg/L. This suggests a corresponding increase in chloride content.

Wells 64 and 65 were drilled in the areas of highest and lowest resistivity, respectively. The alluvium overlying the bedrock at both sites is about the same in composition and thickness. A detailed record of the shale bedrock is not available for well 64, but its low yield indicates a low degree of fracturing. Well 65 on the other hand has a high yield which indicates a high yield which indicates a high degree of fracturing in the shale. Drill cuttings from well 65 contained some calcite veins which would indicate fractures and soft clayey shale which suggests that the shale is fractured and weathered.

Using the accompanying table (Lohman, 1972, p. 53) hydraulic conductivities of the alluvium penetrated at each well was estimated based on thickness and type of material. The average transmissivity in the alluvium (hydraulic conductivity X saturated thickness) was determined to be 1100 ft^2/day. Since these wells do not represent a statistical sampling of the alluvium character and thickness, the actual transmissivity may be less than 1100 ft^2/day, perhaps 800-1000 ft^2/day.

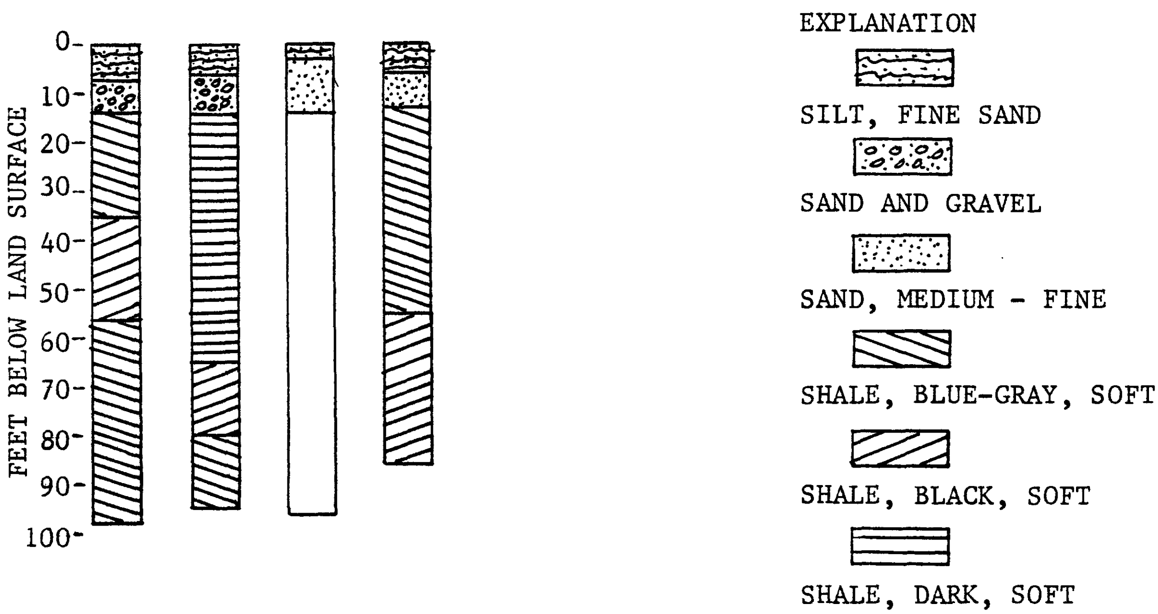


Figure 5.1-1 -- Logs for test wells drilled near Beverly.

Figure 5.1-2.—Average values of hydraulic conductivity of alluvial materials in the Arkansas River valley, Colorado

[Courtesy of R. T. Hurr]

Material	Hydraulic conductivity[1] (ft day^{-1})
Gravel:	
Coarse	1,000
Medium	950
Fine	900
Sand:	
Gravel to very coarse	800
Very coarse	700
Very coarse to coarse	500
Coarse	250
Coarse to medium	100
Medium	50
Medium to fine	30
Fine	15
Fine to very fine	5
Very fine	3
Clay	1

[1] Values were converted from gallons per day per square foot and were rounded.

5.0 RESULTS AT TEST SITE

5.2 AQUIFER TESTS

AQUIFER TESTS INDICATE COEFFICIENT OF TRANSMISSIVITY RANGES FROM ABOUT 80 TO 265 FT^2/DAY AND COEFFICIENT OF STORAGE IS ABOUT 0.0005

The aquifer tests indicate that water is confined in the shale by the alluvium and that the river recharges the aquifer when it is pumped.

In testing the aquifer, wells 63 and 65 were pumped while performing two separate aquifer tests. As each well was pumped the water levels were measured in the other three wells. Well 63 was pumped at 11.1 gal/min for 106 minutes with a 3/4 HP submersible pump and well 65 was pumped at 33 gal/min for 118 minutes with a gasoline centrifugal pump. One semilog plot (fig. 5.2-1) shows the drawdowns in each of the two pumped wells with time, and the other plot (fig. 5.2-2) shows drawdowns in wells 62, 64, and 65 for 106 minutes as well 63 was pumped.

It is apparent after about 45 minutes of pumping, the drawdown in well 65 remained constant (fig. 5.2-1). This indicates that recharge to the well is equal to the discharge. As long as the recharge is available the water level will remain stable at this pumping rate. If the discharge is doubled to 66 gal/min (and artesian conditions prevail) then the drawdown will be doubled to 32.75 feet. Allowing drawdown to be 57 feet or about two-thirds of the static column of water in the well, then maximum yield of the well would be about 115 gal/min.

The proportional relationship between yield and drawdown does not necessarily remain constant since a recharge boundary is supplying water to the well. If recharge continues with a higher pumping rate the well may yield more than 115 gal/min. If the recharge is lost or decreases with a higher pumping rate the well may yield less than 115 gal/min. A step drawdown test (a test whereby the well is pumped at subsequently higher rates held constant for a period of time) would be helpful in evaluating maximum yield and well efficiency. A long-term pumping test at a high yield during a dry period would be helpful in evaluating the recharge boundary.

Well 63 was pumped at a lesser rate (11.1 gal/min) and its water level dropped below 18 feet before it appeared to start stabilizing. Assuming two-thirds drawdown of the static column of water in this well and artesian conditions, the maximum yield would be about 40 gal/min. Here again, the maximum yield of the well depends upon recharge and discharge boundary effects and whether artesian or water-table conditions prevail as pumping continues or is increased. The "hump" in the drawdown data between 40 and 90 minutes is of unknown origin. However, it may be due to a decrease in pumping rate (no pumping rate measurements were made between these times).

Distance-drawdown graph (fig. 5.2-2) is prepared from drawdown data obtained when pumping well 63. The slope of the line drawn through the points representing drawdown in wells 62 and 64 (at 83 feet and 150 feet from the pumped well) after 106 minutes is used in the equation to compute transmissivity (T) for the rocks (there was no measurable effect of pumping in well 65). The intercept (r_o) of this line where drawdown equals 0 is used in the equation to compute storage coefficient. Transmissivity computed from the distance-drawdown graph is about 185 ft^2/day.

The accompanying table shows values of transmissivity and storage calculated from various graphical analytical techniques. The table shows transmissivity ranges from 80 to 265 ft^2/day. The value of 1735 ft^2/day for recovery data at well 65 is erroneously high because recharge affects the water level in the well within three minutes after pumping begins. Average transmissivity probably lies somewhere between 185 and 250 ft^2/day.

		TRANSMISSIVITY, FT^2/DAY AND ANALYTICAL TECHNIQUE			
PUMPED WELL	OBSERVED WELL(S)	TIME DRAWDOWN GRAPH	TIME RECOVERY GRAPH	DISTANCE DRAWDOWN GRAPH	STORAGE COEFFICIENT
63	62	195	230		.0003, .0004
63	62, 64			185	.0008
65	62, 65			250	.0006
65	64, 65			245	.0007
*62	62		80		
*63	63		265		
*65	65		**1735		

*Single well recovery test
** This value too high because of recharge effects

Figure 5.2-1.--Drawdown in pumping wells 63 and 65 versus time.

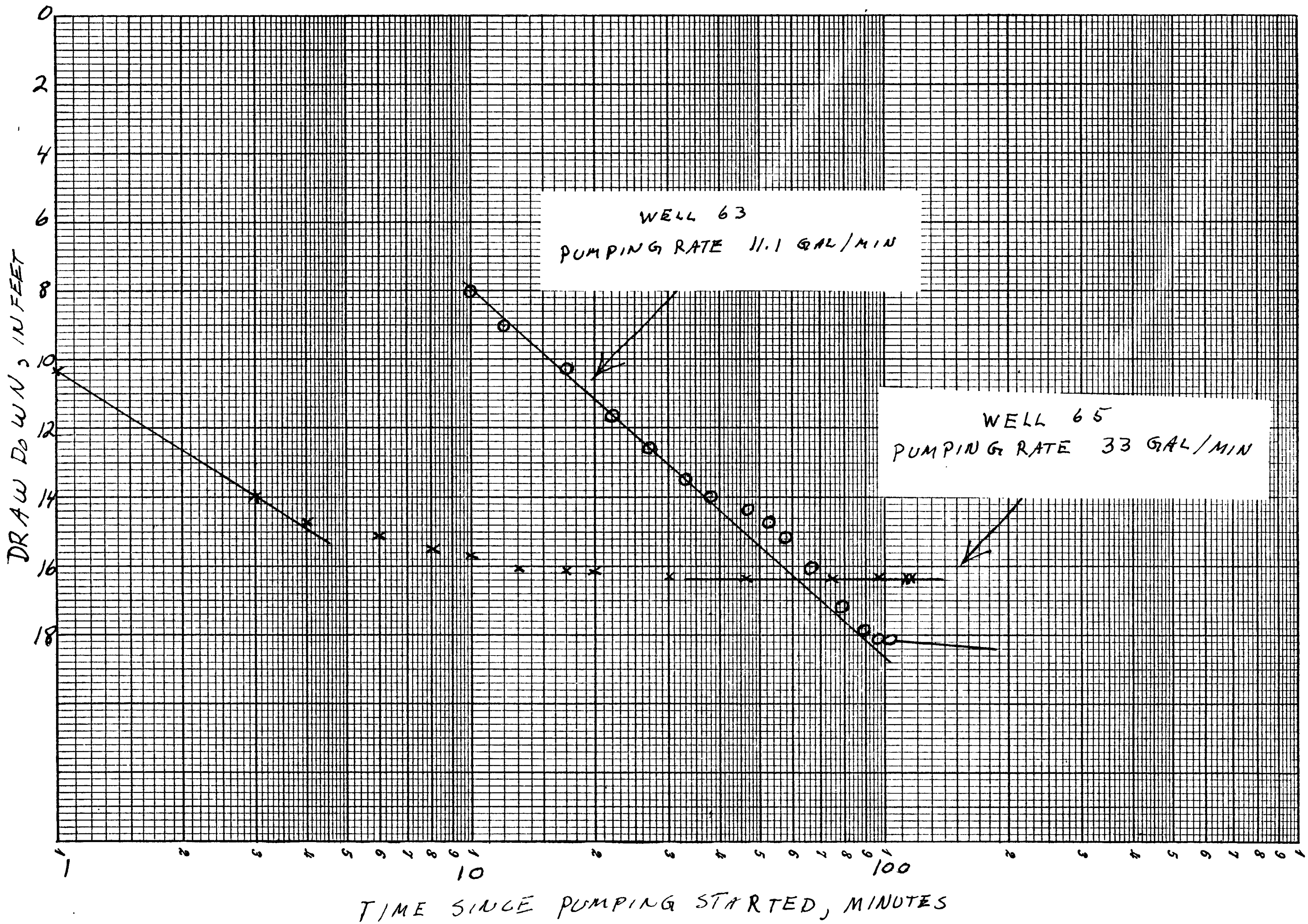
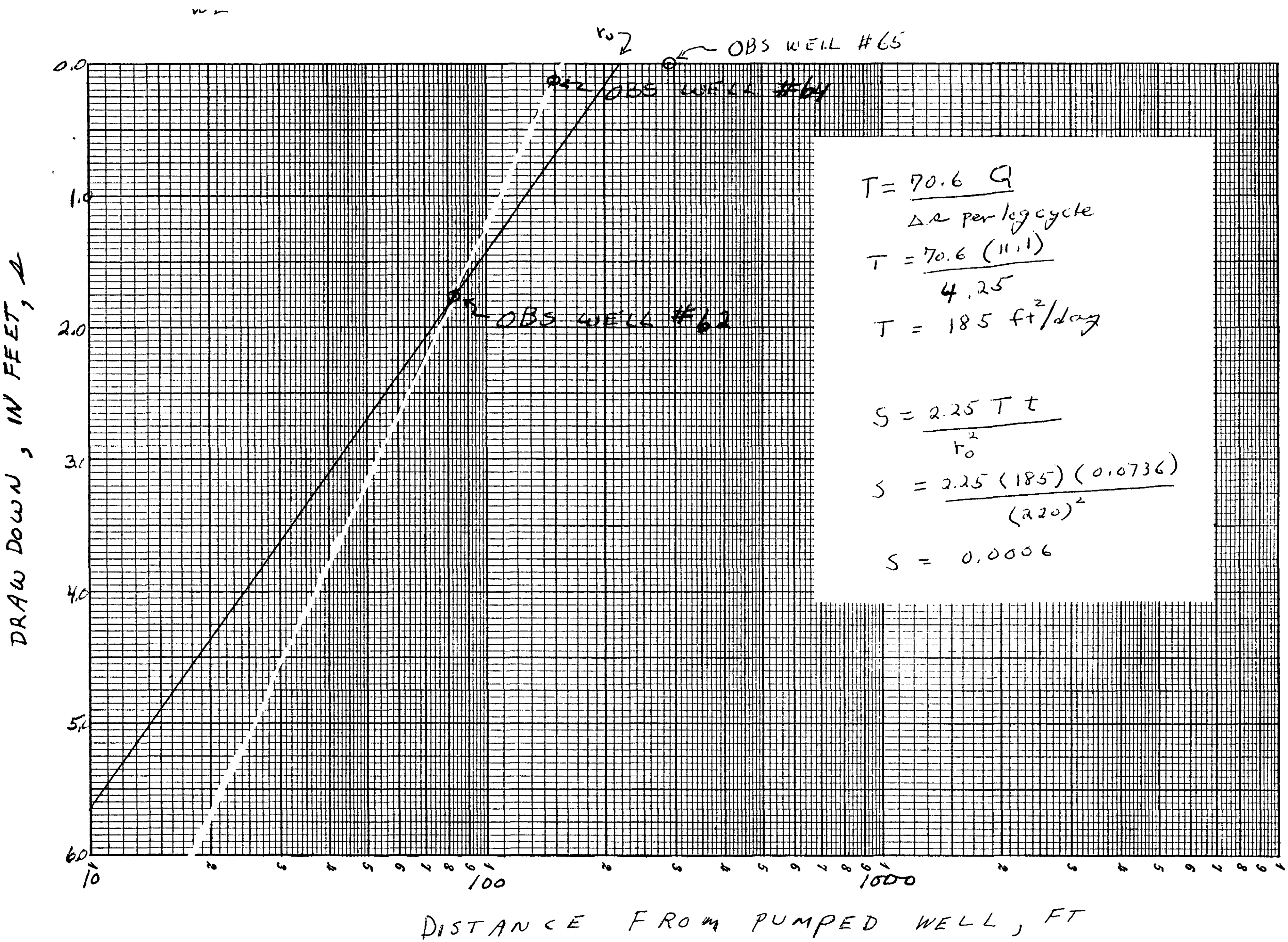


Figure 5.2-2.--Drawdown in observation wells 62 and 64 after pumping well 63 for 106 minutes (or 0.0736 day).



5.0 RESULTS AT TEST SITE

5.3 AQUIFER TESTS SHOW DIRECTIONAL PERMEABILITY

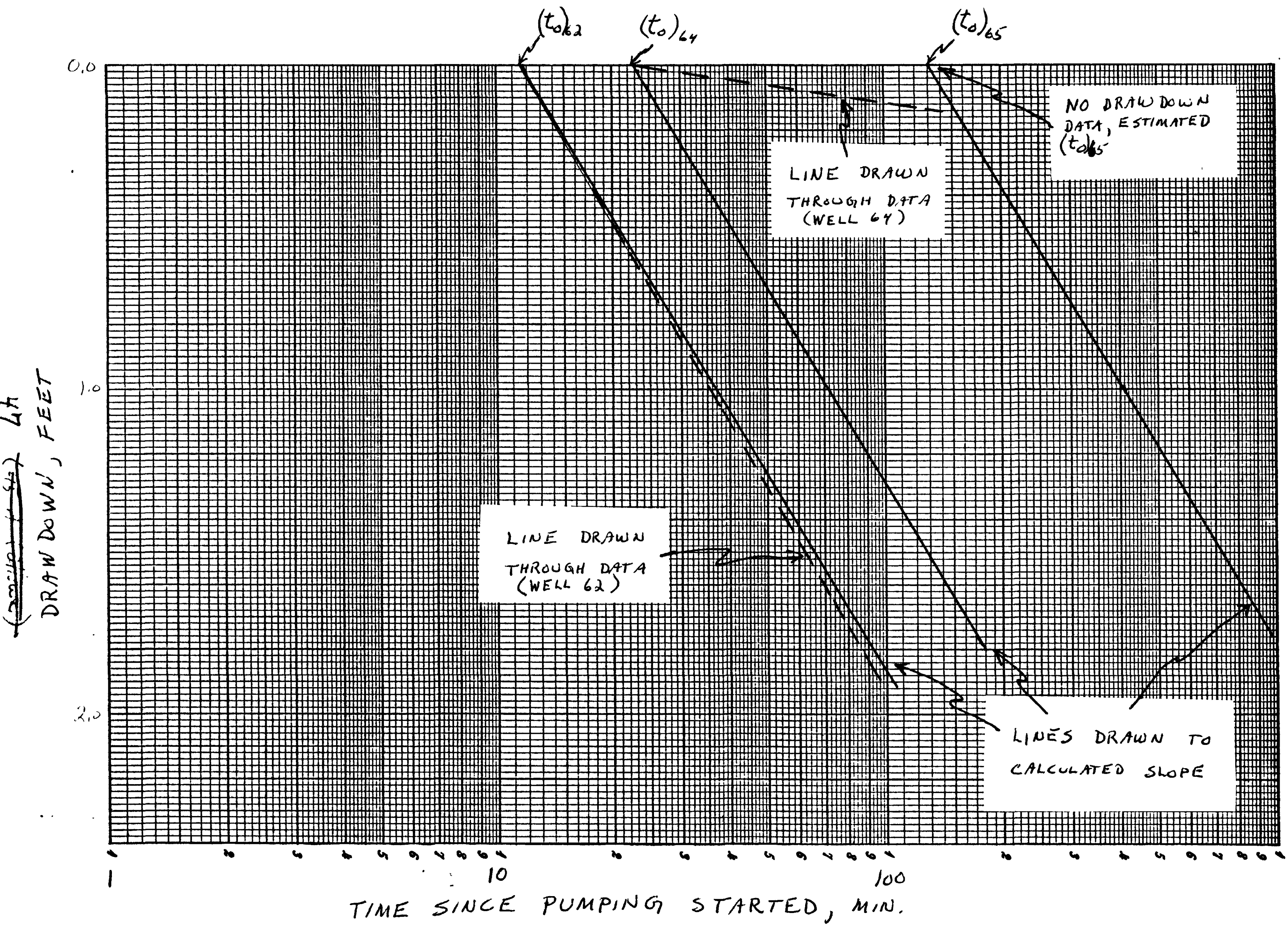
ANISOTROPIC ANALYSIS OF AQUIFER TEST DATA INDICATES MAXIMUM PERMEABILITY PARALLELS LINEAMENT

The aquifer test data indicate the direction of maximum permeability parallels the lineament and minimum permeability parallels the strike of the rocks.

Papadopulos (1965) used a method of analyzing drawdown data from three observation wells in the vicinity of a well pumping from a homogenous anisotropic aquifer to determine directions of maximum and minimum permeability in a cartesian coordinate system. This technique was used on the aquifer test data acquired while pumping well 63 then again on the data acquired while pumping well 65. In order to perform the anisotropic analysis it is necessary to have three observation wells. However, because of the small water level response at observation well 65 during the first test and at observation well 63 during the second test, some time estimates were made for the analysis. One method of applying the anisotropic technique is to plot drawdown data for each observation well against time on semilogarithmic graph paper (fig. 5.3-1). A line is then drawn through that part of the data forming a straight line after a sufficiently long period of pumping. This line is then extended to the point of zero drawdown and time (t_o) is determined. The slope of the line through the data for each well was different. When this occurs, in order to use the anisotropic analysis, the same average slope is assigned to the line for each well. Thus, all of the lines are parallel. However, the slope used here was a computed slope based on the transmissivity value calculated from distance-drawdown graphical plot of the test data (section 5.2). The distance-drawdown plot yields reliable values of transmissivity (Johnson, 1966, p. 132) regardless of the effects of recharge or impermeable boundaries on these aquifer tests. Thus, lines with the calculated slope were drawn on the graphs through the "t_o" values determined earlier from the actual data plots. As mentioned above "t_o" was estimated for the wells where there was little water level response to pumping. For example, there was little response at well 63 while pumping well 65. However, when pumping stopped the water level in well 63 began to rise slightly after 19 minutes. The water level in nearby well 62 began to rise after 26 minutes. A "t_o" value was calculated for well 63 by assuming the same proportional relationship that exists between "t_o" and response time (26 min.) for well 62 also holds true for well 63.

The anisotropic analysis is lengthy and somewhat complicated. Therefore, only one time-drawdown graph and a map (fig. 5.3-2) showing the orientation and magnitude of transmissivity (permeability) axes as determined by the anisotropic analysis are shown. Note that the axis of maximum permeability, as determined by pumping well 65, essentially parallels the mapped lineament. The axis of maximum permeability as determined by pumping well 63 forms about a 20 degree angle with that of the mapped lineament. Both tests indicate maximum permeability parallel to the lineament and minimum permeability at right angles to the lineament. Since the shale bedrock strikes to the northeast and dips steeply to the west, the axis of minimum permeability nearly parallels the strike of the rock. This suggests poor permeability along bedding plane openings in the shale.

Figure 5.3-1.--Time-drawdown graph showing slopes of curves and (t_o) values used in anisotropic analysis when well 63 was pumped.



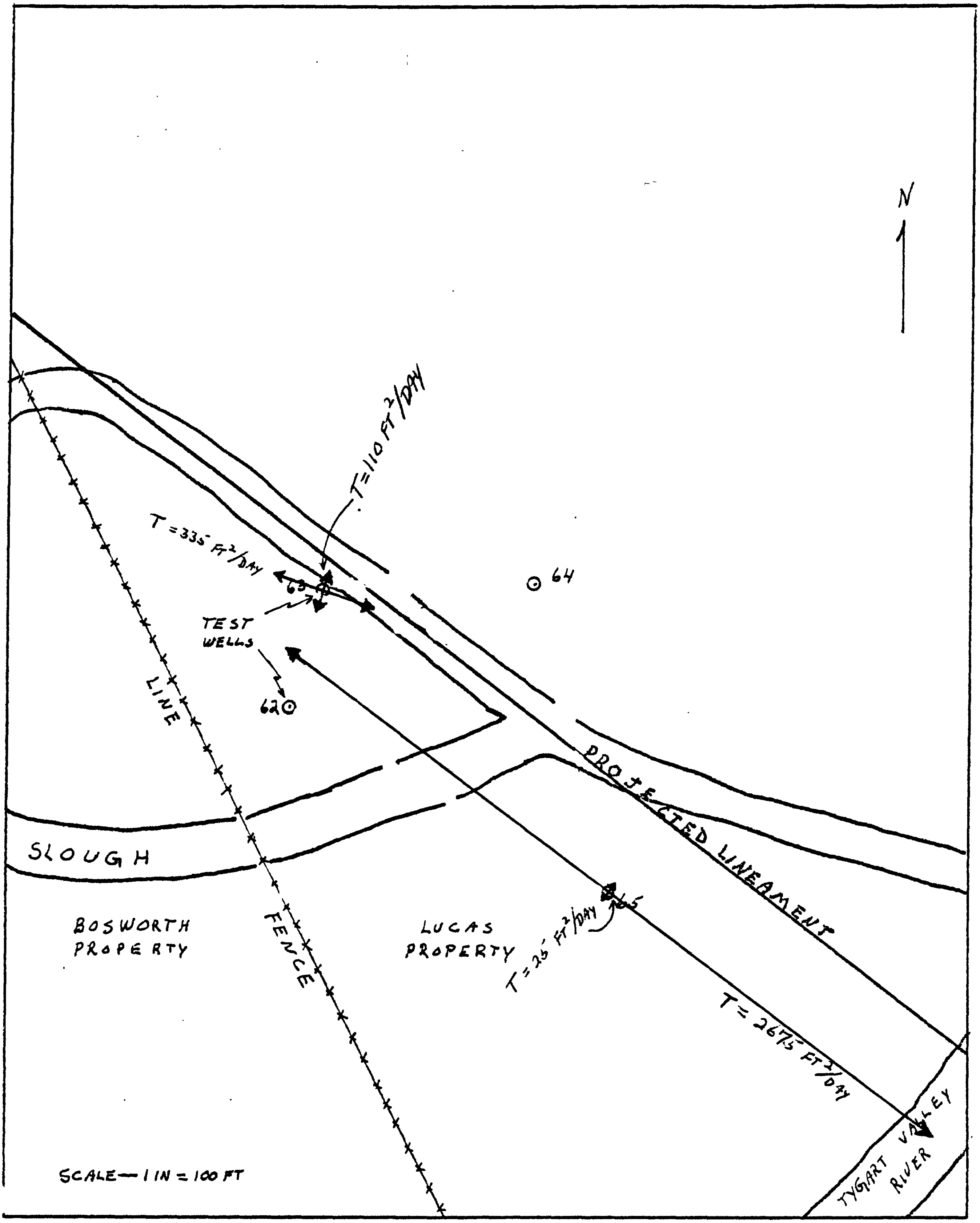


Figure 5.3-2.--Direction and magnitude of transmissivity as determined by anisotropic analysis of aquifer test data. (Length of arrows proportional to magnitude of transmissivity, T).

6.0 WATER QUALITY

SOME GROUND WATER HAS HIGH IRON CONCENTRATION, SOME WATER IS SALTY

Shallow ground water generally contains large amounts of iron and salty water occurs as shallow as 80 feet below land surface.

The valley area is underlain by steeply dipping beds of blue and black shale which, in turn, is generally overlain by alluvium of variable thickness. The water from the alluvium contains less dissolved minerals than water from the shale. However, the dissolved problem constituents found in both are generally the same with the exception of chloride. The ranges of concentrations of problem constituents are given in the accompanying table--additional water quality data are given in Appendix 1 and 2.

Specific Conductance (micromhos at 25°C)	pH (pH units)	Iron (mg/L)	Manganeese (mg/L)	Chloride (mg/L)
45-1050	4.9-8.5	0.1-80.0	0.18-1.3	3.5-593

The chloride problem apparently occurs when wells are drilled too deep, or when a relatively shallow well is drilled into a vertical fracture carrying salty water upward. The highest chloride content was found in water from well 61 which is 140 feet deep. This well is on or near a fracture or lineament. Well 34 is only 33.5 feet deep yet has a chloride content of 94 mg/L. This is unusually high for a shallow well. However, the chloride content of the water here may be affected by salt spreading on the nearby highway or gasoline storage area, or by natural upward discharge of salty water.

During this study two high-yielding wells (well 59 and well 44) located on or near fractures were pumped for approximately 24 hours to determine if chloride content would increase with pumpage. These wells are 140 and 80 feet deep and were pumped at 7.5 and 10.7 gallons per minute, respectively, and sampled periodically.

Figure 6.0-1 shows the chloride content of the water from both wells was essentially the same after 24 hours* of pumping. Drawdown measurements in these wells suggest recharge to the aquifer after a short period of pumping. A hydraulic connection to a surface source would explain the consistently low chloride content of the samples.

It is expected that the four test wells are located in a similar hydraulic situation. Two of these wells were pumped for 106 and 118 minutes and then sampled for complete analyses. Both of these analyses indicated a chloride content of less than 3 mg/L. However, analyses of water during construction of test well 62 at depths of 44 feet and 90 feet show sodium increases from 44 mg/L to 60 mg/L. Because sodium is closely associated with chloride this suggests a corresponding increase in chloride.

Figure 6.0-2 shows the general water-quality characteristics of ground water in the alluvium and the shale.

* Well 59 was pumped for 21.3 hours out of 30 hours because trouble developed with the gasoline pump; it was shut down several times for periods of about 30 minutes and at one time was off for 7 hours.

Figure 6.0-1.--
CHANGES OF CHLORIDE, pH, SPECIFIC CONDUCTANCE AND TEMPERATURE WITH TIME OF PUMPING FROM WELLS 44 AND 59

WELL NO.	DATE	TIME	CHLORIDE MG/L	pH (pH UNITS)	SPECIFIC CONDUCTANCE (MICROMHOS AT 25° C)	TEMP °C	REMARKS
59	9-26-78	1340	3.75	6.2	170	15.0	
		1620	4.00	6.3	170	14.8	
		2000	4.00	6.3	170	14.4	
		2300	4.00	6.3	170	14.4	
		1150	4.00	6.2	175	14.8	
		1515	4.25	6.2	175	15.0	
		1800	4.00	6.3	175	14.7	
44	9-25-78	1700	4.25	6.0	140	12.4	H_2S odor
	9-26-78	1025	3.50	6.2	145	12.3	
		1430	3.50	6.2	145		
		1650	3.50	6.2	140	12.4	

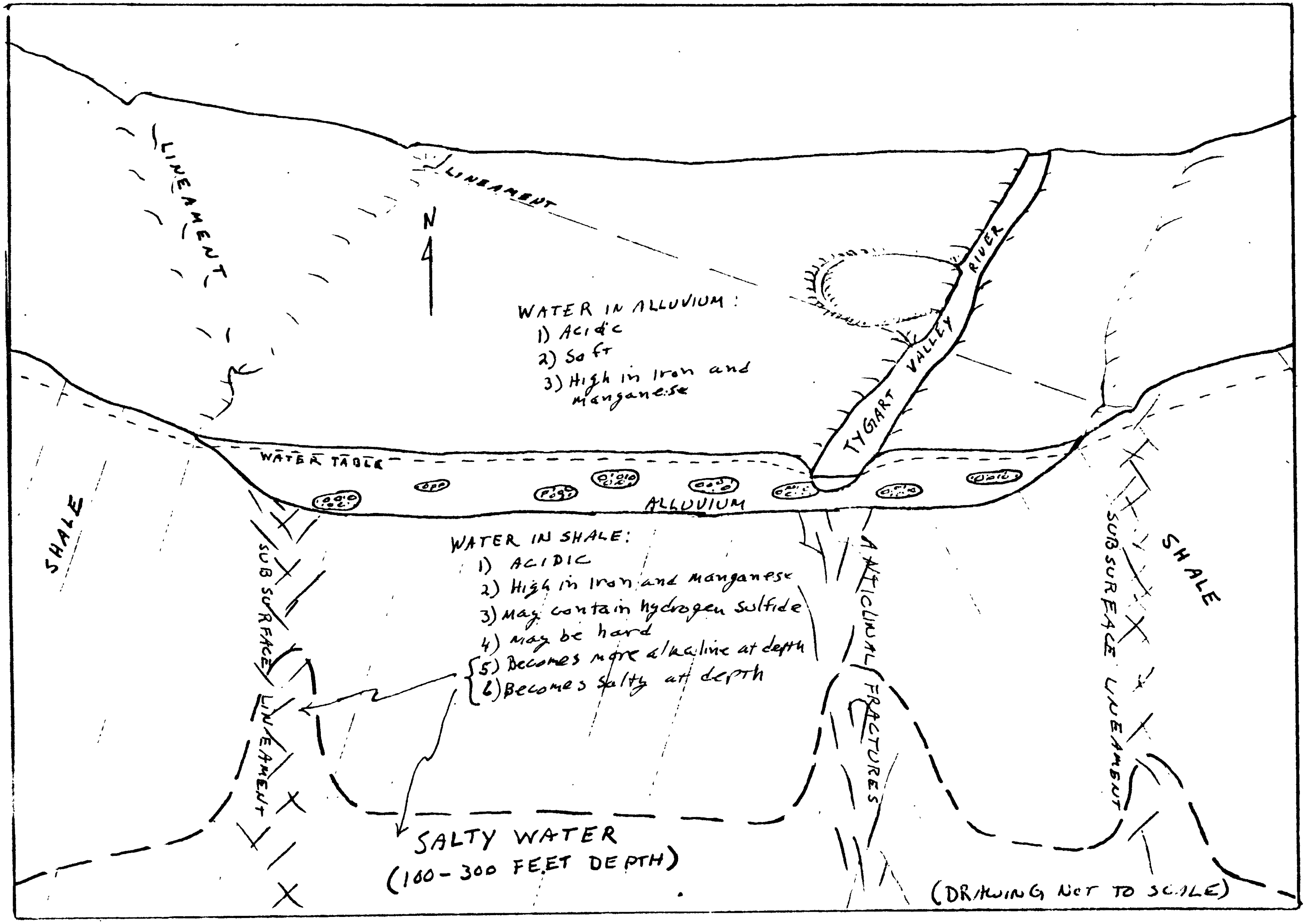


Figure 6.0-2.--Generalized ground-water quality in Tygart Valley

7.0 METHODS OF DEVELOPING 200 GAL/MIN OF GROUND WATER

AQUIFER TESTS INDICATE THAT AS FEW AS TWO OR THREE WELLS COULD SUPPLY 200 GAL/MIN

Developing 200 gal/min from deep wells in fractured shale at depths of less than 150 feet appears to be more advantageous than developing the water from shallow wells in the alluvium.

There are several ways by which 200 gal/min could be developed from a well field in this area:

1) One way would be to drill wells into fracture zones in the shale bedrock (fig. 7.0-1). The wells should be drilled less than 150 feet deep and spaced laterally along fractures such that most of the water stored in 100 acres of alluvium can be removed by pumping. Possibly four wells could supply this quantity of water assuming transmissivity coefficient ranges from 5 to 200 ft^2/day, storage coefficient ranges from 0.0004 to 0.0007, and most of the water is derived from 11 feet of overlying saturated alluvium.
2) Another way would be to drill shallow wells less than 20 feet deep on a 750-foot grid pattern in the alluvium (fig. 7.0-2). Seven to nine wells may be sufficient if they will yield 25-30 gal/min, assuming transmissivity coefficient is 1000 ft^2/day, storage coefficient is 0.20, saturated thickness is 11 feet, each acre stores 575,000 gallons of obtainable water (80 percent of that stored), and water-table conditions prevail.

3) A third method may be a combination of two or three deep wells and two or three shallow wells. Ideally, the deep wells would be spaced along fractured zones in the shale such that much of the water stored in the alluvium could be removed by pumping. The shallow wells would be located in sand and gravel areas of the well field in places where water levels are little affected by pumping from the deep wells.

Each of these methods requires that assumptions be made regarding the aquifer and each method has advantages and disadvantages. For example, wells drilled into fractured shale beneath the alluvium will not require well screens to keep sand out. Shallow wells in the alluvium will require screening and well screens often develop encrustation problems. Bacterial contamination should be less likely for shale wells than for the alluvium wells simply because of the lengths of casing used in their construction. However, chemical contamination (especially by chloride) would be more likely for wells in shale than for wells in alluvium, because the wells in shale would be deeper and closer to the source of salty water. The water within a given area may be efficiently removed by conjunctive use of wells in both the shale and the alluvium, but mixing the water from the two sources may cause undesirable variations in chemical quality.

The data indicate that approximately 100 acres of valley bottom will supply 200 gal/min of water to wells for 200 days with no recharge. However, the yield of wells and the size of the recharge area required depends on the degree of fracturing in the shale and the degree of hydraulic connection to surface water sources and to saturated gravel stringers buried in the alluvium--a good connection would permit stringers to act as drainage laterals and conduct water from the finer grained alluvium to the fractures and then into the well. Under ideal conditions fewer than 100 acres and fewer than 3 wells would supply 200 gal/min. Under adverse conditions of prolonged drought or poor hydraulic connection between shale fractures and gravel stringers perhaps more than 100 acres and more than 3 wells would be necessary to supply 200 gal/min. Factors such as the amount of recharge derived from a nearly dry or dry river cannot be predicted.

It may be worthwhile to develop a well field for a small community, such as Beverly, Dailey-Valley Bend or Mill Creek, to determine the feasibility of long-term pumping and the solution to water-quality problems that develop. Based on the results of the small-scale well field a better decision could be made in regard to developing a large-scale ground-water supply for Elkins.

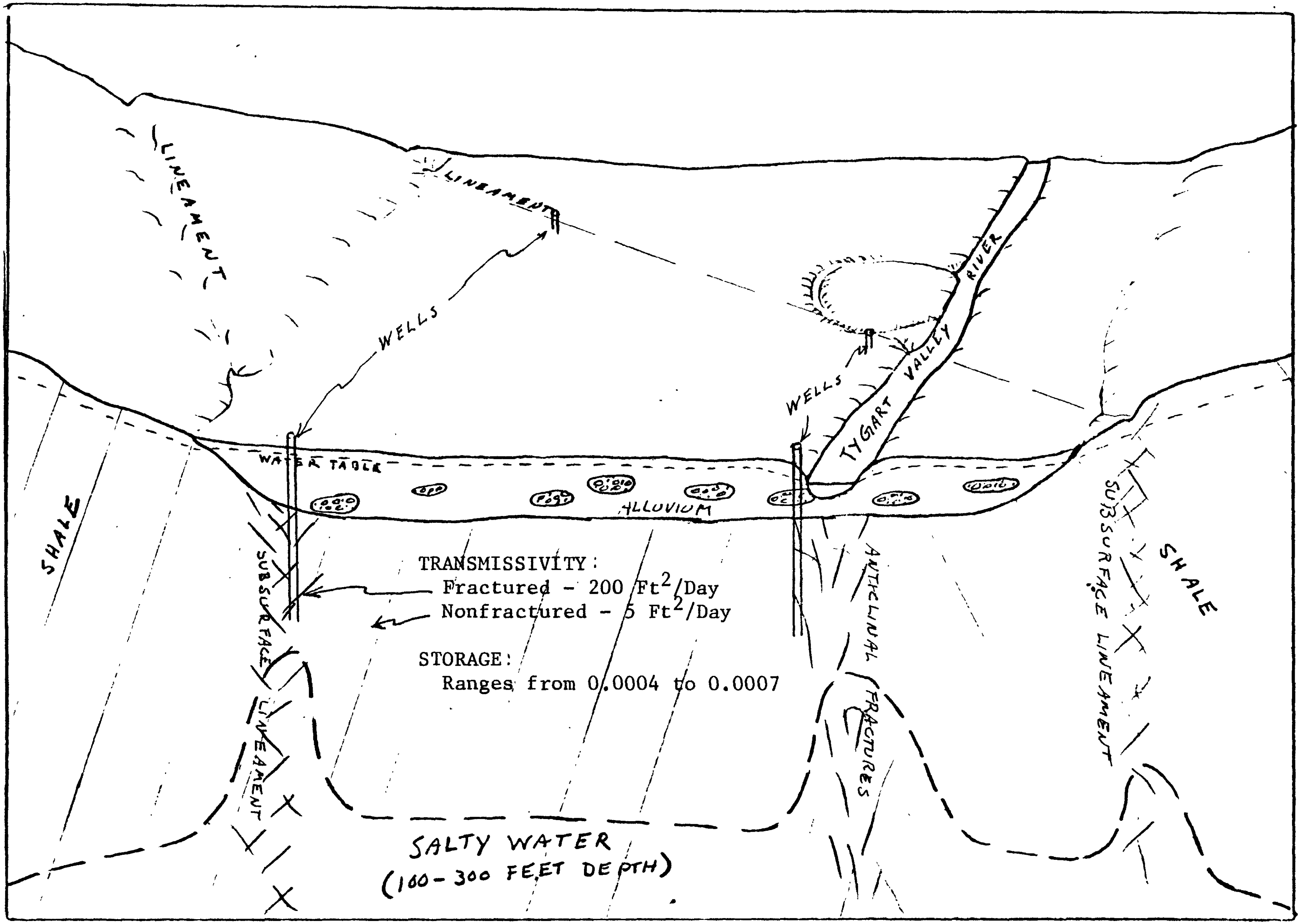


Figure 7.0-1 Generalized sketch showing possible well layout for developing 200 gal/min from about 100 acres of alluvium overlying fractured zones in shale.

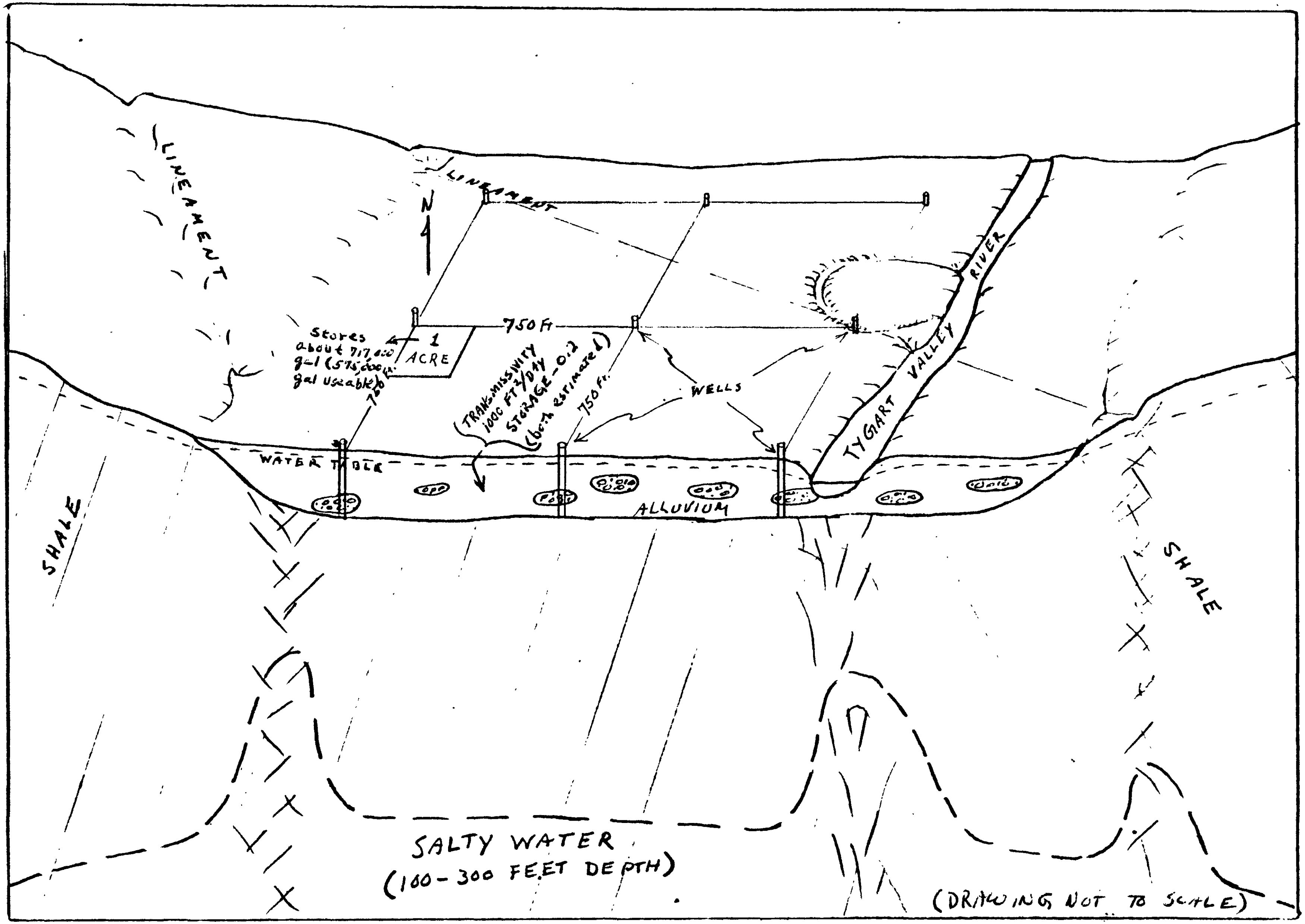


Figure 7.0-2 Generalized sketch showing possible well layout for developing 200 gal/min from about 100 acres of alluvium having a saturated thickness of 11 to 12 feet, Either drilled wells or screened well points could be used.

8.0 REFERENCES

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APPENDIX 1--TABLE OF WELL DATA

EXPLANATION

REPORT NO.: A sequential number assigned to the wells appling only to this report.

OWNER OR NAME: The reported owner or user on the date indicated.

WELL DEPTH: Depth, in feet below land-surface datum, as reported by owner, driller, or others, or as measured by the Geological Survey.

DIAMETER: Inside diameter of the well in inches.

DEPTH CASED: Length of casing, in feet below land-surface datum.

WELL FINISH:

- H Horizontal collector
- O Open end
- P Perforated or slotted casing
- S Well screen
- W Walled or shored
- X Open hole in aquifer

WATER USE

- A Air conditioning
- C Commercial
- D Dewatering
- H Domestic
- N Industrial, includes mining
- P Public Supply
- R Recreation
- S Stock
- T Institutional
- U Unused
- Z Other

ALTITUDE OF LSD: Altitude of land-surface datum, in feet, above mean sea level. Land-surface datum is an arbitrary plane closely approximating land surface at the time of the first measurement and used as the plane of reference for all subsequent measurements.

WATER LEVEL: Depth to water, in feet, above (+) or below land-surface datum. F indicates well was flowing, D indicates well was dry.

DATE MEASURED: Month and year of the water-level measurement; other data given generally apply for this date.

YIELD OF WELL: Yield in gallons per minute.

METHOD CONSTRUCTED:

- A Air rotary drill
- C Cable tool drill
- D Dug

DRAWDOWN: Decline in water level, in feet, during pumping.

TOPOGRAPHIC SETTING: The topographic setting in which the well is situated:

- C Stream channel
- F Flat surface
- H Hilltop
- S Hillside (slope)
- T Alluvial terrace
- V Valley flat

LITHOLOGY:

- 1 Very fine grained
- 2 Fine grained
- 3 Medium grained
- 4 Coarse grained
- 5 Very coarse grained
- 6 Clayey
- 7 Silty
- 8 Sandy
- 9 Gravelly
- 10 Cavernous
- A Argillaceous
- B Bouldery
- C Calcareous
- G Granular
- I Interbedded
- J Jointed or fractured
- M Massive
- Ø Organic
- Q Cherty or siliceous
- R Redbed
- U Unconsolidated
- V Semiconsolidated
- Y Shaly or slaty
- 8 Weathered

- A Alluvium
- B Sedimentary rock, unclassified
- C Conglomerate
- F Shale
- G Gravel
- H Igneous, granular (granite, gabbro
- L Limestone
- M Marl or shell marl
- P Clay
- Q Silt or loess
- R Sand and gravel
- S Sand
- U Unconsolidated sediments
- V Sandstone
- W Siltstone
- 8 Other

LIFT:

- B Bucket
- C Centrifugal pump
- J Jet pump
- P Piston pump
- S Submergible pump

ORIGIN OF MAJOR WATER-BEARING ZONE: Refers to the principal geological processes that created the water-bearing deposits.

- 0 Glacial outwash
- 2 Fluvial
- 5 Lacustrine
- 6 Marine
- 7 Igneous
- 8 Metamorphic

NUMBER OF WATER-LEVEL MEASUREMENTS: I Intermittantly or Irregular

- # Original (inventory) measurement only

CHEMICAL ANALYSES:

- C Complete
- K Specific conductance
- L Chloride
- M Multiple--complete and one or more partial
- P Partial

BACTERIA

- A Fecal coliforms
- B Fecal streptococci
- C Both fecal coliforms and streptococci

LOG DATA:

- D Driller's log
- E Electric log
- G Geologist log or sample log

PRINCIPAL AQUIFER:

- 324ex 327 PSVL - Pottsville Formation
- 331 MCCK - Mauch Chunk Formation
- 331 GRBR - Greenbrier Limestone
- 337 POCN - Pocono Formation
- 341 DVNUM - Upper-middle Devonian Series
- 341 BRLR - Brallier Formation
- 321 CNMG - Conemaugh Formation

APPENDIX 1--TABLE OF WELL DATA

REPORT NUMBER	SITE-ID	OWNER	USE OF WATER	METHOD CONST-RUCTED	TYPE OF LIFT	CASING DIAM-ETER (INCHES)	ALTITUDE OF LAND SURFACE (FEET)	DEPTH OF WELL (FEET)	DEPTH CASED
01	384843079494201	THOMAS, HELEN	H	C	J	6	2130	80	20
02	384847079494101	THOMAS, HELEN	H	C	J	--	2160	85	--
03	384928079504301	WAYBRIGHT, KENNETH	H	C	J	6	2025	40	15
04	384740079540301	COAST LUMBER CO	U	C	C	6	1970	71	17
05	384937079533701	BARD, ROLLIN	H	A	S	6	1960	80	10
06	384937079532801	THORN, HOWARD	H	C	J	6	1960	92	20
07	384822079534501	CURRENCE, HUGH	U	C	J	6	2005	62	20
08	384557079541701	WEBER, WILLIAM M	H	C	J	6	1990	56	40
09	384547079542701	ARBOGAST, ALLEN	H	C	S	6	1990	78	29
10	384537079552601	WAMSLEY, THOMAS A	H	C	S	6	1985	108	60
11	384522079553601	WAMSLEY, THOMAS A	H	C	S	6	2130	168	30
12	385502079540701	DOIG, ANDREW T	H	C	S	--	1925	33	--
13	384953079504201	PINGLEY, RUSSELL	H	C	C	6	2045	37	17
14	384917079501101	ATLANTIC SEABOARD	N	C	J	6	2060	25	11
15	384857079495801	CAMPBELL, CHARLIE	H	C	S	6	2090	195	63
16	385658079493401	CONRAD, WILSON	H	--	J	8	1995	64	21
17	385418079520301	HOWELL, CLYDE	H	C	J	6	1960	90	75
18	385417079520601	HOWELL, EDWARD	H	C	J	6	1955	72	--
19	385128079514301	SUMMERFIELD, ROGER	H	C	S	6	1940	78	20
20	385128079541201	WYATT, RAYMOND	H	C	J	6	2040	38	15
21	385128079534801	WEBB, KENNETH	H	C	J	6	1995	56	20
22	385136079532801	CUNNINGHAM, JOHN	H	C	J	6	1980	60	20
23	385136079531301	CUNNINGHAM, JAMES	H	A	--	6	2020	375	20
24	385117079524901	LUCAS, EDSEL	H	C	J	6	1945	--	20
25	384826079532201	JACK, DEAN	H,N	--	J	6	1955	85	21
26	384615079554801	PHARES, STELLA	U	C	--	6	2020	100	--
27	384421079575601	SCOTT, HAYES	U	C	--	6	2060	23	--
28	384407079591301	SCOTT, HAYES	H	C	J	6	2070	40	--
29	384357079590801	CHIDESTER, VIRGIL	H	C	J	--	2090	46	--
30	384400079581801	LIGHT, OLAN	U	C	P	6	2035	69	--
31	384402079580901	BRADY, P F	U	C	--	6	2020	62	21
32	385127079520301	MYLES LUMBER CO	N	C	J	6	1950	133	60
33	385743079512901	MALLOW, ELMER	H	--	C	--	1925	54	--
34	385817079502701	MCCAULEY, ROBERT	H	C	C	6	1925	33	17
35	384712079573201	UNKNOWN	U	--	--	--	2580	--	--
*36	385859079505501	KALAR, ILEE	H	C	J	--	1930	--	--
*37	385917079504301	WILLIAMS, ARCHIE	H	C	--	--	1950	--	--
38	385809079503201	MYERS, LEO	--	--	--	6	1930	10	16
39	385807079502901	PETERS, PAUL W	H	C	J	6	1940	90	--
40	385313079505501	NESTOR, RONALD	C	C	S	6	1985	120	60

* Well not plotted on map--located just north of map area.

APPENDIX 1--TABLE OF WELL DATA--Continued

REPORT NUMBER	WATER LEVEL (FEET)		DATE WATER LEVEL MEASURED	DISCHARGE (GALLONS PER MINUTE)	DRAW-DOWN (FEET)	DATE COMPLETED	TEMPERATURE (DEGREES C)	SPECIFIC CONDUCTANCE (UMHOS/CM AT 25 C)	DATE QUALITY PARAMETERS MEASURED	PRINCIPAL AQUIFER
01	29.36	R	08/14/1978	--	--	1963	16.4	140	08/14/1978	341DVNUM
02	48.98		08/14/1978	--	--	1963	18.6	180	08/14/1978	341DVNUM
03	4.00		1978	--	--	1969	18.0	600	08/14/1978	341DVNUM
04	6.80		08/17/1978	38	10	--	18.8	270	09/08/1978	341DVNUM
05	48.00	R	08/17/1978	2	--	1973	23.0	180	08/17/1978	341DVNUM
06	16.00		--	12	--	1962	20.0	140	08/17/1978	341DVNUM
07	11.00		08/18/1978	--	--	1958	13.2	160	08/18/1978	341DVNUM
08	--		--	8	--	03/26/1956	17.8	210	08/18/1978	341DVNUM
09	9.00		08/18/1978	12	--	08/18/1970	--	--	--	341DVNUM
10	9.00		08/ /1978	6	8	11/ /1973	16.2	215	08/18/1978	341DVNUM
11	56.00		08/18/1978	10	--	06/06/1975	--	--	--	341DVNUM
12	--		--	12	--	1960	15.2	145	08/18/1978	341DVNUM
13	1.00		08/21/1978	35	--	1968	16.7	245	08/21/1978	341DVNUM
14	6.39		08/21/1978	7	4	1950	20.0	235	08/21/1978	341DVNUM
15	60.00		--	--	--	1966	19.5	280	08/21/1978	341DVNUM
16	--		--	--	--	1968	15.2	205	08/22/1978	341DVNUM
17	21.67	R	08/22/1978	2	--	06/ /1977	19.2	130	08/22/1978	341DVNUM
18	4.00		--	3	--	--	--	--	--	341DVNUM
19	11.10		08/22/1978	6	--	--	17.0	390	08/22/1978	341DVNUM
20	10.00		--	2	--	1958	17.6	70	08/22/1978	341DVNUM
21	15.00		--	5	--	1966	17.5	385	08/22/1978	341DVNUM
22	--		--	3	--	1972	18.5	180	08/22/1978	341DVNUM
23	40.62		08/22/1978	0.6	--	07/ /1978	--	--	--	341DVNUM
24	3.93	P	08/22/1978	12	--	--	--	--	--	341DVNUM
25	4.36	R	08/23/1978	7	12	1975	15.2	205	08/23/1978	341DVNUM
26	12.75		08/23/1978	2	--	1975	--	--	--	341DVNUM
27	21.00		08/23/1978	12	--	1970	--	--	--	341DVNUM
28	2.98		08/23/1978	12	--	1970	17.6	215	08/23/1978	341DVNUM
29	16.13	R	08/23/1978	12	--	1960	17.4	180	08/23/1978	341DVNUM
30	1.63		08/23/1978	--	--	--	--	--	--	341DVNUM
31	6.00		--	12	--	1963	--	--	--	341DVNUM
32	1.55		08/23/1978	12	5	12/11/1974	16.2	315	08/23/1978	341DVNUM
33	4.12		08/24/1978	--	--	--	--	--	--	341DVNUM
34	4.33		08/24/1978	21	13	--	--	--	--	341DVNUM
35	--		--	60 F	--	--	10.7	190	08/23/1978	~~334~~GRBR 331
*36	--		--	12	--	1961	16.5	205	08/24/1978	341DVNUM
*37	--		--	12	--	1976	--	--	--	341DVNUM
38	3.67	S	08/24/1978	0.5	--	1959	--	--	--	341DVNUM
39	11.85		08/24/1978	12	--	1966	17.8	270	08/24/1978	341DVNUM
40	5.76		08/24/1978	12	--	1964	16.5	305	08/24/1978	341DVNUM

* Well not plotted on map--located just north of map area.

APPENDIX 1--TABLE OF WELL DATA--Continued

REPORT NUMBER	SITE-ID	OWNER	USE OF WATER	METHOD CONST-RUCTED	TYPE OF LIFT	CASING DIAM-ETER (INCHES)	ALTITUDE OF LAND SURFACE (FEET)	DEPTH OF WELL (FEET)	DEPTH CASED
41	385324079504501	VET CLINIC	U	C	--	--	1975	--	--
42	385043079523801	JENKINS, JAMES	H	A	J	6	1940	90	23
43	384836079534301	HULVER, DAVID	H	A	J	6	2020	100	20
44	385051079522001	THOMPSON, BERT	U	C	--	6	1990	80	20
45	385443079535801	WAGSTAFF, ANNA	H	C	J	--	1940	--	--
46	385416079532601	PINGLEY, KENNETH	H	C	J	--	1935	--	--
47	385323079530101	TYRE, KEITH	H	C	J	6	1990	557	36
48	385612079551001	GORDON, ROBERT	H	D	C	36	1960	8	8
49	385612079550701	GORDON, ROBERT	U	C	--	6	1930	60	27
50	385602079542401	MARSH, RICHARD	H	--	P	6	1930	42	8
*51	385911079492301	CORLEY, JAY	U	C	--	--	1980	--	--
52	385303079530301	CAPLINGER, WILSON JR	H	C	S	6	1940	105	65
53	385413079520701	HOHMAN, CHARLES	H	C	J	--	1950	53	--
54	385408079521101	SPONAUGLE, WILLARD M	H	C	S	6	1940	78	16
55	385419079515501	ROBERTS, MARGRET	H	C	B	6	1950	34	--
56	384928079502601	MCGARY	H	A	S	6	2100	--	--
57	385537079530301	DAVIS, THOMAS	H	A	--	6	1920	84	13
58	385538079530701	HANCOCK, JAMES	H	A	S	6	1910	80	15
59	385007079523901	LABCRAFT	U	C	C	8	1940	140	--
60	385007079523902	LABCRAFT	U	C	S	6	1940	88	44
61	385252079525801	HAMMACK, FLOYD	H	C	J	6	1950	149	60
62	385059079522901	LUCAS, EDSEL	U	A	S	6	1940	96	14
63	385100079522901	LUCAS, EDSEL	U	A	S	6	1940	98	14
64	385101079522701	LUCAS, EDSEL	U	A	C	6	1938	97	14
65	385058079522601	LUCAS, EDSEL	U	A	C	6	1937	86	13
66	385618079574501	NORTON P S DIST	P	A	S	10.75	1900	500	20

* Well not plotted on map--located just north of map area.

APPENDIX 1--TABLE OF WELL DATA--Continued

REPORT NUMBER	WATER LEVEL (FEET)		DATE WATER LEVEL MEASURED	DISCHARGE (GALLONS PER MINUTE)	DRAW-DOWN (FEET)	DATE COMPLETED	TEMPERATURE (DEGREES C)	SPECIFIC CONDUCTANCE (UMHOS/CM AT 25 C)	DATE QUALITY PARAMETERS MEASURED	PRINCIPAL AQUIFER
41	--		--	10	--	--	--	--	--	341DVNUM
42	9.50	R	08/24/1978	--	--	1978	15.0	130	08/24/1978	341DVNUM
43	4.00		--	40	--	09/15/1977	15.0	140	08/24/1978	341DVNUM
44	11.35		08/24/1978	12	23	1958	--	--	--	341DVNUM
45	3.00		1978	12	--	--	18.2	140	08/25/1978	341DVNUM
46	--		--	12	--	1975	14.8	160	08/25/1978	341DVNUM
47	20.00	R	06/ /1978	5	--	1974	22.2	160	08/25/1978	341DVNUM
48	3.70		08/25/1978	--	--	--	15.0	45	08/25/1978	331MCCK
49	3.45		08/25/1978	21	23	1950	10.9	150	09/07/1978	331MCCK
50	10.80		09/14/1978	5	29	--	11.4	155	08/25/1978	337POCN
*51	--		--	--	--	1950	--	--	--	341DVNUM
52	18.00		--	2	--	1965	14.0	1050	09/06/1978	341DVNUM
53	--		--	9	--	--	--	--	--	341DVNUM
54	--		--	10	--	1958	20.7	210	09/19/1978	341DVNUM
55	7.80		09/19/1978	2	--	1945	--	--	--	341DVNUM
56	--		--	--	--	1974	--	--	--	341DVNUM
57	12.07		09/28/1978	10	52	09/25/1978	11.7	155	09/28/1978	341DVNUM
58	10.84		09/28/1978	10	47	09/26/1978	11.8	165	09/28/1978	341DVNUM
59	5.95		09/07/1978	8	4	1957	14.7	175	09/26/1978	341DVNUM
60	3.39		08/17/1978	--	--	1957	--	--	--	341DVNUM
61	--		--	12	--	1970	--	2865	12/19/1978	341DVNUM
62	1.40		12/15/1978	11	30	11/14/1978	--	530	11/14/1978	341DVNUM
63	1.00		12/15/1978	11	15	11/16/1978	11.0	200	12/15/1978	341DVNUM
64	0.93		12/16/1978	33	27	11/15/1978	11.0	108	12/16/1978	341DVNUM
65	1.28		12/16/1978	33	16	11/13/1978	11.8	130	12/16/1978	341DVNUM
66	28.42		08/14/1978	220	119	06/27/1978	13.3	--	07/19/1978	327PSVL

* Well not plotted on map--located just north of map area.

APPENDIX 1--TABLE OF WELL DATA--Continued

REPORT NUMBER	LOCAL NUMBER	SITE-ID	OWNER	USE OF WATER	METHOD CONST-RUCTED	TYPE OF LIFT	CASING DIAM-ETER (INCHES)	ALTITUDE OF LAND SURFACE (FEET)	DEPTH OF WELL (FEET)	DEPTH CASED
67	1802004	385608079544401	ELKINS LS & ASH	N	C	J	6	1900	55	--
68	1802013	385707079511101	H B TRIPLETT	C	D	J	24	1940	12	--
69	1802014	385707079511102	H B TRIPLETT	D	C	P	6	1940	125	--
70	1802015	385701079513601	GLEN DAYTON	H	C	P	6	1910	50	--
71	1802016	385710079513601	T P SHAW	H	D	J	24	1930	14	--
72	1802017	385402079502601	R H UTZ	H	C	P	6	2100	209	--
73	1802018	385352079502801	NESTOR WILLIAMS	H	C	J	6	1960	85	--
74	1802019	385348079494001	CHAS THORNHILL	H	C	J	6	2050	38	--
75	1802026	385549079540001	R BATESON	H	C	J	4	1920	90	--
76	1802027	385421079493201	A C PHILLIPS	H	C	J	6	2000	76	--
77	1802028	385420079493901	E SCHOONOVER	H	C	J	6	2000	60	--
78	1802029	385420079493902	E SCHOONOVER	U	C	--	6	2025	300	--
79	1802030	385418079493501	G SCHOONOVER	--	C	J	6	2025	138	--
80	1802031	385618079573501	TOWN OF NORTON	P	C	C	6	1860	1000	--
81	1803002	385600079544301	ELKINS LS & ASP	N	C	P	6	2050	90	--
82	1804007	385330079054901	A D MCLAUGHLIN	H	C	J	6	1975	28	--
83	1804008	385329079055101	J C FERGUSON	C	C	J	6	1950	87	--
84	1804009	385328079054901	J C FERGUSON	H	C	J	6	1950	104	--
85	1804010	385327079505101	J C FERGUSON	C	C	J	6	1950	95	--
86	1804011	385300079502101	JOHN DANIELS	H	C	S	--	1950	62	--
87	1804012	385213079513501	CHAS ARBOGAST	H	D	--	36	2000	22	--
88	1804013	385128079520001	MILES LUMBER CO	N	C	J	6	1930	54	--
89	1804014	385055079520001	F STALNAKER	C	C	J	4	1950	53	--
90	1804015	385017079524101	TYGART MOLDING	N	C	J	6	1940	65	--
91	1804016	385011079523901	W P GADD	H	C	J	6	1940	55	--
92	1804017	385341079505001	WAYNE STALNAKER	P	C	S	6	1950	219	--
93	1804018	385335079505401	D H BRYANT	H	C	J	6	1950	76	--
94	1804019	385337079505601	ATLANTIC CO	N	C	J	6	1950	100	--
95	1804020	385338079505101	ELKINS BAKING	N	C	J	6	1950	160	--
96	1804021	385338079505102	ELKINS BAKING	N	C	J	6	1950	180	--
97	1804022	385252079500001	L WINFIELD	H	C	S	6	2050	62	--
98	1804023	385240079501001	S CHENOWETH	H	C	J	6	2200	90	--
99	1804024	384915079511001	4H CLUB	P	C	J	--	2050	52	--
100	1804025	384913079511901	4H CLUB	P	C	S	--	2050	76	--
101	1804026	385300079502901	T H COX	H	C	J	6	2050	190	--
102	1804028	384843079523401	H C SCOTT	--	C	J	6	2050	180	--
103	1807001	384540079570001	GERALD DEAN	U	C	--	6	1990	330	--
104	1807002	384540079570002	GERALD DEAN	U	C	--	6	1980	90	--

APPENDIX 1--TABLE OF WELL DATA--Continued

PORT MBER	WATER LEVEL (FEET)	DATE WATER LEVEL MEASURED	DISCHARGE (GALLONS PER MINUTE)	DRAW-DOWN (FEET)	DATE COMPLETED	TEMPERATURE (DEGREES C)	SPECIFIC CONDUCTANCE (UMHOS/CM AT 25 C)	DATE QUALITY PARAMETERS MEASURED	PRINCIPAL AQUIFER
67	20.00	--	100	2	1955	--	--	--	--
68	3.00	--	--	--	1956	--	--	--	341BRLR
69	30.00	--	--	--	1939	--	--	--	341BRLR
70	--	--	--	--	--	--	--	--	341BRLR
71	8.00	--	--	--	1954	--	--	--	--
72	40.00	--	--	--	1930	--	--	--	341BRLR
73	18.00	--	1	--	--	--	--	--	341BRLR
74	3.00	--	20	--	1946	--	--	--	341BRLR
75	80.00	--	--	--	1959	--	--	--	321 341TCMNG
76	20.00	--	1	--	1930	--	--	--	341BRLR
77	--	--	--	--	1960	--	--	--	341BRLR
78	21.00	--	--	--	--	--	--	--	341BRLR
79	10.00	--	--	--	--	--	--	--	341BRLR
80	--	--	100	--	1900	--	--	--	--
81	50.00	--	100	--	1962	--	--	--	--
82	15.00	--	--	--	1948	--	--	--	341BRLR
83	30.00	--	--	--	1941	--	--	--	341BRLR
84	--	--	--	--	1960	--	--	--	341BRLR
85	--	--	--	--	1945	--	--	--	341BRLR
86	--	--	--	--	1960	--	--	--	341BRLR
87	12.00	--	--	--	--	--	--	--	341BRLR
88	30.00	--	20	--	1961	--	--	--	341BRLR
89	10.00	--	--	--	1955	--	--	--	341BRLR
90	8.00	--	20	--	1948	--	--	--	341BRLR
91	8.00	--	--	--	1961	--	--	--	341BRLR
92	--	--	--	--	1948	--	--	--	341BRLR
93	--	--	--	--	1959	--	--	--	341BRLR
94	--	--	--	--	1952	--	--	--	341BRLR
95	--	--	--	--	--	--	--	--	341BRLR
96	--	--	2	--	1962	--	--	--	341BRLR
97	20.00	--	1	--	1959	--	--	--	341BRLR
98	30.00	--	3	--	1937	--	--	--	341BRLR
99	--	--	16	--	1953	--	--	--	341BRLR
100	--	--	16	--	1953	--	--	--	341BRLR
101	15.00	--	--	--	1953	--	--	--	341BRLR
.02	25.00	--	--	--	--	--	--	--	341BRLR
03	19.00	--	--	--	1957	--	--	--	341BRLR
04	5.00	10/ /1962	--	--	1957	--	--	--	341BRLR

APPENDIX 2--TABLE OF WATER QUALITY ANALYSES

REPORT NUMBER	DATE OF SAMPLE	PUMPING RATE (GAL/MIN)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	TEMPERATURE (DEG C)	HARDNESS (MG/L AS CACO3)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	ALKALINITY (MG/L AS CACO3)
25	78-09-13	6.5	305	5.8	14.6	82	19	8.3	17	1.0	44
59	78-09-27	7.1	175	6.3	14.7	45	10	4.8	6.8	1.0	50
44	78-09-26	10	140	6.2	12.4	37	8.8	3.6	15	.9	59
65	78-12-16	--	--	--	--	26	7.5	1.8	9.3	.8	41
63	78-12-15	--	--	--	--	74	20	5.8	10	1.2	90
64	78-12-16	--	--	--	--	15	3.9	1.2	21	1.4	60
32	78-09-14	11	260	7.0	12.8	110	29	9.3	24	1.0	130
34	78-09-08	25	480	6.3	12.8	110	22	14	13	2.1	25
[1]61	78-12-19		2865	7.9	--	--	71	9.6	593	--	--
[1]62	[2]78-11-14		372	7.2	--	--	35	10.5	44	--	--
[1]62	[3]78-11-14		480	7.2	--	--	35	9.0	60	--	--

REPORT NUMBER	DATE OF SAMPLE	SULFATE DISSOLVED (MG/L AS SO4)	CHLORIDE, DISSOLVED (MG/L AS CL)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)	NITROGEN, NO2+NO3 DISSOLVED (MG/L AS N)	ALUMINUM, DISSOLVED (UG/L AS AL)	IRON, DISSOLVED (UG/L AS FE)	MANGANESE, DISSOLVED (UG/L AS MN)
25	78-09-13	.9	57	.1	26	184	.03	10	18000	640
59	78-09-27	8.9	4.6	.0	21	80	.00	10	21000	680
44	78-09-26	3.6	3.5	.1	30	91	.01	30	4000	180
65	78-12-16	.7	1.6	.0	19	74	.01	0	17000	440
63	78-12-15	5.4	2.9	.1	23	131	.00	--	--	--
64	78-12-16	.2	1.1	.1	22	94	.00	--	--	--
32	78-09-14	13	18	.1	21	193	.47	30	1500	230
34	78-09-08	20	94	.0	16	246	.01	0	80000	1300
[1]61	78-12-19	6.2	795	--	--	--	--	--	--	--
[1]62	[2]78-11-14	28	[4]	--	--	--	--	--	--	--
[1]62	[3]78-11-14	15	[4]	--	--	--	--	--	--	--

[1] Analysis by G. Nicholson, WV Geol. Survey
[2] Well 44 ft deep when sample collected
[3] Well 90 ft deep when sample collected
[4] Iron interferred with chloride analysis