

Hydrogeology of Crystalline Rocks: Case Studies of Two Areas in India

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Two-thirds of India is underlain by consolidated rocks and approximately one-half of this hard rock area is composed of Precambrian crystalline rocks. Many rural areas in India are dependent on ground water for drinking and irrigation water supply. Population growth and increasing demands for food and water have resulted in increased withdrawals of ground water in some areas and a decline in water levels. In contrast, the lack of technical expertise and seed money has inhibited the development of ground-water resources in other areas.

In this paper, the ground-water resources of two crystalline rock areas are described. The recent drilling of over 600 wells in these areas by the Evangelical Lutheran Church (E.L.C.) Water Development Project provided the data base. The geology, occurrence of ground water, and types of ground-water flow systems in these areas are discussed.

Well data such as yield, depth and thickness of overburden, aquifer depth, and well depth were analyzed statistically for both areas. The results helped to quantify the occurrence of ground water with depth and the distribution of well yields and expected well yields in different rock types and topographic settings.

Both step-drawdown and constant-rate pumping tests were conducted on 150 production wells. Aquifer transmissivity ranges from approximately 1 to 400 m²/day (meters squared per day) in both areas. Specific capacity results are also presented.

Introduction

The E.L.C. Water Development Project, headquartered in Betul, Madhya Pradesh, India, has been involved since 1971 in developing ground-water supplies in the Satpura Hills region of central India. From 1976 to 1978, the project assisted the Tamil Nadu State Water Supply and Drainage Board in the drilling of more than 300 wells in Coimbatore District in south India.

To date, more than 600 wells have been drilled in the crystalline rocks of these two areas, and over 150 of these wells have been pump tested to determine safe yields and aquifer hydraulic characteristics.

The main purposes of this study were to:

- 1) Describe the pertinent geologic and hydrogeologic features of the crystalline rocks in the two study areas;
- 2) discuss the status of ground water and agricultural development in the two study areas;
- 3) analyze well data such as yield, depth of overburden, aquifer depth and well depth to quantify the occurrence of ground water with depth and the distribution of well yields in different rock types and topographic settings; and
- 4) compare the results from both study areas.

Area Description

The E.L.C. Water Development Project is involved in the development of ground-water resources in two very interesting and quite diverse areas that are underlain by crystalline rocks. Project personnel have had the opportunity to collect hydrogeologic data and also experience first hand the role that the development of ground-water resources can play in economic development.

The crystalline rock areas of the Satpura Hills region are populated by Tribals who live in small villages and are primarily engaged in agriculture. Shallow, hand-dug, open wells are a common feature in the area and are used for both irrigation and drinking-water supply. There exists a potential for developing significantly larger quantities of ground water in the region as most of the ground water is naturally discharged via evapotranspiration and as base flow to streams.

Coimbatore District is a well-developed agricultural and industrial area in south India, and many parts of the district depend primarily on ground water for irrigation and industrial water supply. Ground-water pumpage is believed to be considerably greater than ground-water recharge in many areas, and there have been significant water-level declines in many parts of the district in the past decade. Also, waste effluents, primarily from textile industry lagoons, have at several locations infiltrated into underlying aquifers. This has resulted in the contamina-

tion of ground water in the vicinity of these lagoons and has affected nearby village water supplies. In this district there is a need for planned utilization of ground water to prevent further water-level declines and a depletion of the resource, and further ground-water contamination. The Swedish International Development Agency (SIDA) has been engaged in a very comprehensive study of both surface and ground-water hydrology in Coimbatore District and adjoining areas. When this study is concluded and findings published, it is expected that many of the above concerns will be addressed in more detail.

Satpura Hills Region

This study area is located in the south-central part of Madhya Pradesh state and covers the crystalline rock areas of Betul, Chhindwara, and Seoni Districts. These districts lie almost entirely on the Satpura Plateau and are traversed by the Satpura Hills.

The Satpura Plateau is an uplifted feature; landforms range from hilly, mountainous terrain to flat plateau country and gently rolling hills. The crystalline rock country is characterized by gently undulating topography with small drainage basins.

The bulk of precipitation occurs during the southwest monsoon (June to September), and the average annual rainfall ranges from 95 to 120 cm. Fig. 1 is a plot of the mean monthly precipitation at Betul town.

This study area is inhabited by the Gond tribe. The Gonds work in the forests and on farms; most are marginal farmers who farm primarily for their own con-

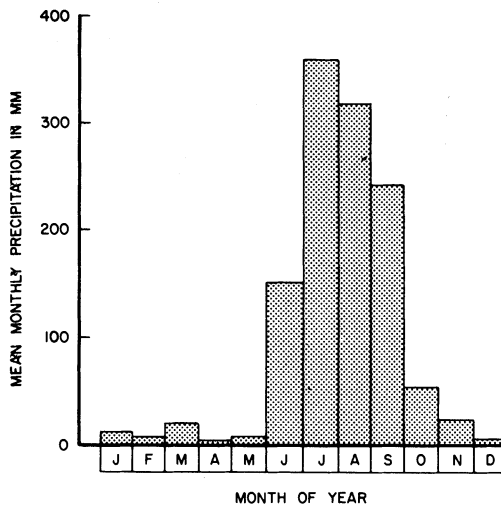


Fig. 1. Mean monthly precipitation at Betul town (1935-70).

sumption. Irrigation from both open wells and surface sources has helped to improve agriculture in certain areas.

Ground water is extracted via shallow open wells 9 to 15 m deep for irrigation and drinking-water supply. There are several hundred tube wells fitted with hand pumps and power pumps for drinking water supply and a few tube wells for irrigation purposes. In most of this study area, ground-water recharge is greater than ground-water pumpage, and the bulk of ground-water discharge is via evapotranspiration and as base flow to streams.

In summary, ground water is still a largely untapped resource and the potential exists for further ground-water development in this study area.

Coimbatore District

Coimbatore District is located in the northwest part of the Tamil Nadu State in south India. The district is bordered on the north, west, and south by mountains. Except for the mountainous areas, most of the study area is under cultivation, and the terrain is relatively flat with gentle slopes toward the major drainages.

The average annual rainfall in the district ranges from 60 to 85 cm; Fig. 2 is an isohyetal map of the district. The mean monthly distribution of precipitation in the district is plotted in Fig. 3.

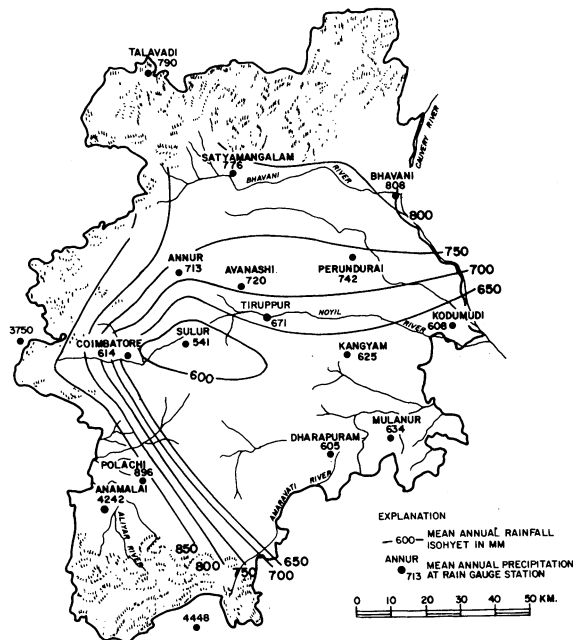


Fig. 2. Isohyetal map of mean annual precipitation for Coimbatore District (from Royal Institute of Technology, Stockholm, Sweden)

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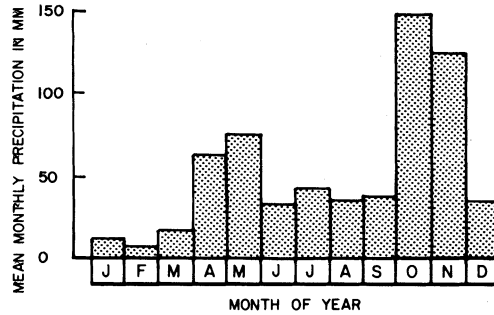


Fig. 3. Mean monthly precipitation for Coimbatore District (1931-1960)
(from Royal Institute of Technology, Stockholm, Sweden)

The district is well developed both industrially and agriculturally. Agriculture development has been based mostly on irrigation from both open wells and tube wells. The area has well-developed market facilities as well as good roads and transport facilities. The farmers are progressive, adapt new agricultural techniques quite rapidly, and grow a variety of food and cash crops.

Ground water is extracted via large-diameter open wells, 30 to 60 m deep, for irrigation, industrial, and drinking-water supply. Several thousand tube wells ranging in depth from 30 to 150 m have been drilled in the district and are used for irrigation, industrial, and drinking-water supply. In most of this study area, ground-water pumpage is greater than ground-water recharge and water levels are in a general state of decline.

Hydrogeology

Satpura Hills Region

Crystalline metamorphic and igneous rocks of Precambrian age crop out in approximately 20 per cent of the Satpura Hills region. The metamorphic rocks are Precambrian in age, and common rock types include gneiss, schist, and quartzite. The igneous rocks include coarse-grained, porphyritic, intrusive granite and pegmatite veins. These rocks exhibit an intrusive relationship with the Precambrian metamorphic bedrock, and thus are younger in age.

The metamorphic rocks strike in a general east-northeast to west-southwest direction, dip 70° to 90° , and are folded in places. Quartz-pegmatite veins are a common feature and occur as broad dikes and thin strings. These veins are generally porphyritic and occur along the prominent joint system of the metamorphic rocks. Fig. 4 is a surface geologic map of Betul, Chhindwara, and Seoni Districts.

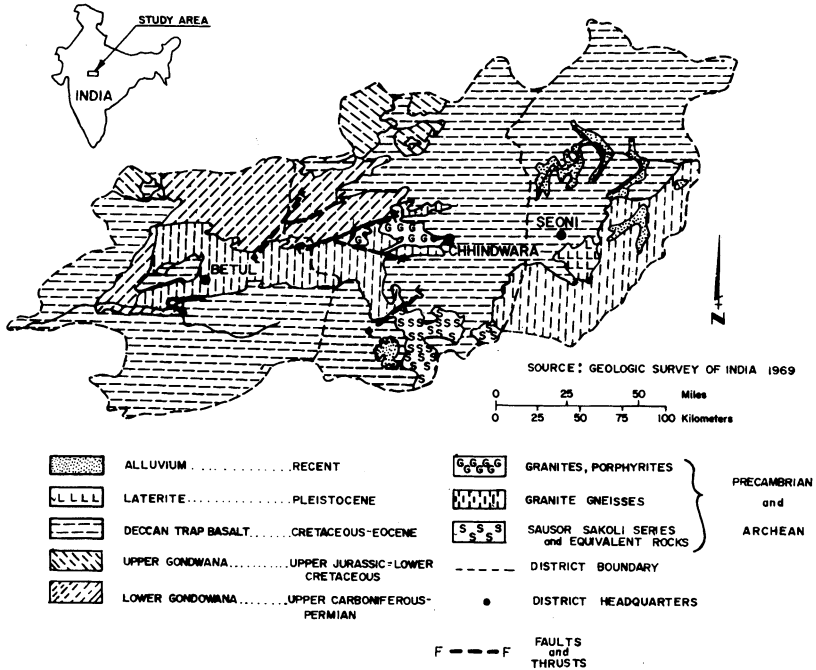


Fig. 4. Surface geologic map of Betul, Chhindwara, and Seoni Districts (from Geologic Survey of India, 1969).

The crystalline-rock country is gently undulating; ground-water basins are conterminous with surface drainage sub-basins, which are a few square miles in area, and drainage patterns are dendritic. The ground-water flow systems are of a local type, where each local system has its recharge area at a topographic high and its discharge area at a topographic low which are adjacent to each other (Fig. 5). Intermediate and regional ground-water flow systems do not exist because of negligible hydraulic conductivity with depth.

Crystalline rocks generally do not possess original or primary openings, and fresh crystalline rocks have less than one-percent porosity and negligible hydraulic conductivity. The ability of crystalline rocks to store and transmit water is dependent on the development of secondary openings, which were formed by fracturing and weathering.

The weathered part (saprolite) of these crystalline rocks is of particular importance both as a storage zone for ground water and as an aquifer for open wells and shallow tube wells. The thickness of saprolite in the study area ranges from less than 1 m to 35 m and averages about 12.8 m in depth. Significant differences exist in the permeability of saprolite zones. These differences, although not measured quantitatively, were noted in the field during drilling operations. In general,

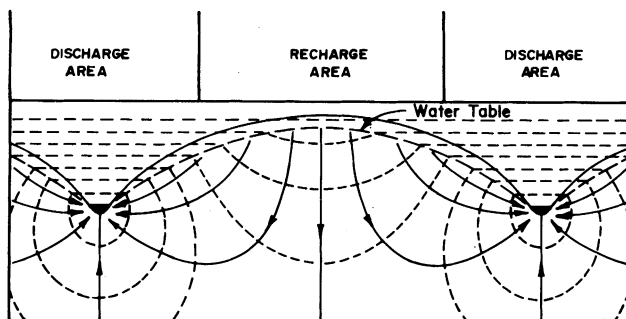


Fig. 5. Flow pattern in a uniformly permeable material between the sources distributed over the air-water interface and valley sinks (from Hubbert, 1940).

shallow tube wells that derive water primarily from saprolite have low well yields ranging from 0 to 35 lpm (liters per minute).

In addition to the permeable saprolite layer, aquifers occur where bedrock and the quartz-pegmatite intrusive veins are jointed and fractured. The yield of an open well or shallow tube well is dependent largely on the thickness and permeability of the saprolite, and for the deeper rock wells, upon the intensity of spacing, areal extent and interconnection of joints, fractures, and fractured quartz-pegmatite veins. Fractures tend to close shut with depth, and this accounts for the shallow ground-water circulation in these crystalline rocks.

The more productive wells in these crystalline rocks were generally completed in fractured bedrock and, in a few of the highly productive wells, fracture zones are 9 to 12 m thick. In less productive wells, saprolite is generally followed by massive or slightly jointed bedrock. Significant variations in well yield occur in some places at close distances, but, in general, ground-water discharge areas (mean well yield 170 lpm) are more productive locations for wells than ground-water recharge areas (mean well yield 71 lpm). Depths to water range from less than 1 m to 15 m, and annual water-level fluctuations are more pronounced in ground-water recharge areas (6 to 15 m) than in ground-water discharge areas (0 to 3 m).

Coimbatore District

Crystalline metamorphic and igneous rocks crop out in most of Coimbatore District except in river valleys which are generally covered by alluvial deposits that comprise the valley fill. The metamorphic rocks are Precambrian in age, and the general rock types are mixed or composite quartz and biotite gneiss and hornblende gneiss. The common igneous rocks that outcrop in the area are granite and charnockite. Charnockite rocks are generally composed of bluish colored quartz,

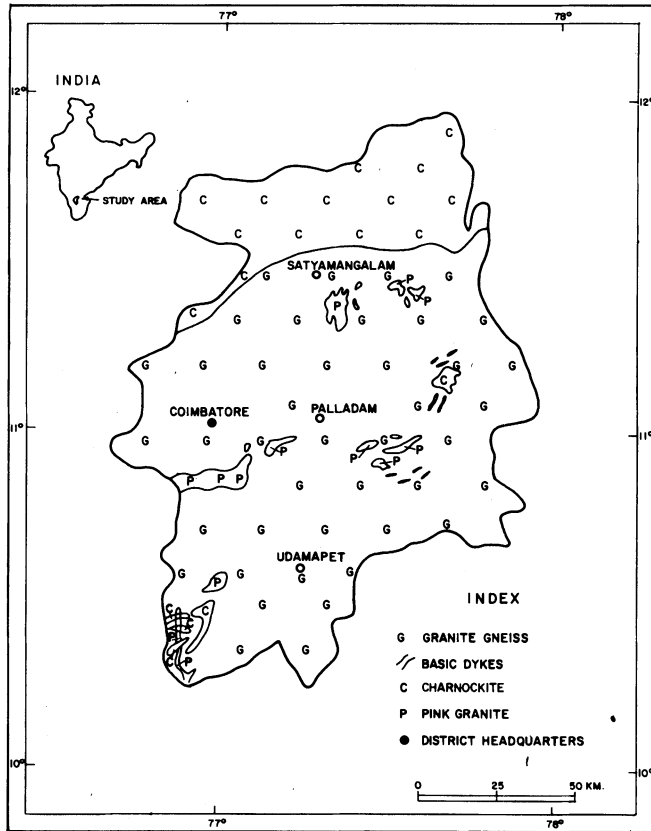


Fig. 6. Surface geologic map of Coimbatore District.

feldspar-hypersthene and iron ore.

The strike of the metamorphic rocks varies throughout the district; the rocks dip 70° to 90° and are folded at places. Quartz-pegmatite veins are a common feature and these veins generally occur along the prominent joint system of the metamorphic rocks. The width of the veins ranges from a few cm to 1 m. The veins dip 40° to 60° on the surface and dips up to 90° have been observed within 30 m of ground surface. Fig. 6 is a surface geologic map of the study area.

The topography of the district is quite flat with gentle slopes towards the major drainage basins. Ground-water flow systems have not been investigated in detail but preliminary indications are that both local and intermediate flow systems occur in the area. Fig. 7 is a water-level contour map for the Noyil River Basin which was prepared by the AFPRO (Action for Food Production) ground-water investigation team in 1971 (AFPRO 1973). This map indicates that an intermediate flow system exists in the Noyil River Basin. An intermediate system is charac-

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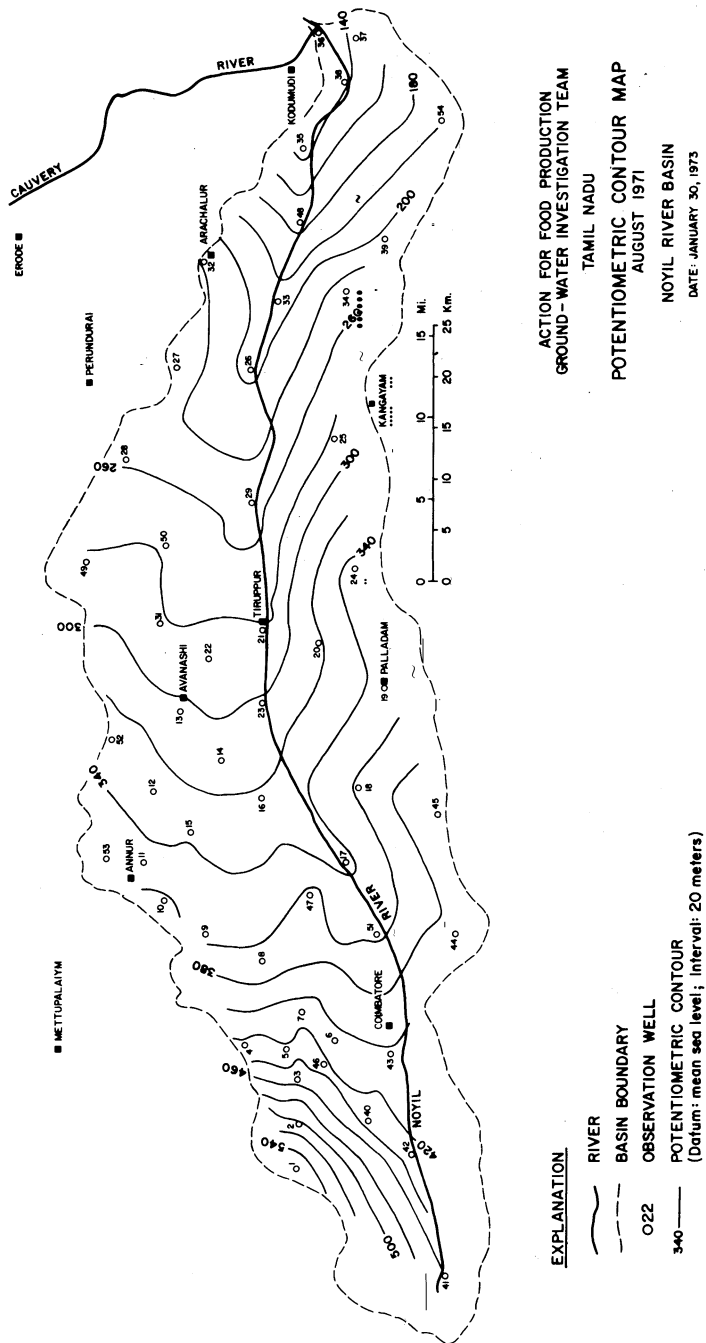


Fig. 7. Water-level contour map for the Noyil River basin (from AFPRO, 1973).

terized by one or more topographic highs and lows between its recharge and discharge areas.

In Coimbatore District the thickness of overburden is quite variable. For example, at locations within a few miles of the mountain front in the western part of the district, it is not uncommon to drill through 60 to 90 m of valley fill before encountering bedrock. In areas to the east of the mountain front where valley fill is not present, the weathered zone (saprolite) ranges from a few meters to more than 30 m in thickness. The average thickness of the weathered zone and overburden as taken from the records of 182 wells is 27 m, and in about 90 per cent of the wells drilled, the water table is below the saprolite.

A detailed study of joint systems was not undertaken for this study; however, it was observed in several outcrops that the gneiss in the area shows prominent, well-developed joints along the strike direction. The joints tend to close shut with depth. The quartz-pegmatite veins were generally intruded along these joint systems and are fractured at places.

These two features (quartz-pegmatite veins and joints) exert the major control on the occurrence and movement of ground water in the crystalline metamorphic rocks in the area, and approximately 90 per cent of the aquifers were penetrated while drilling through either quartz-pegmatite veins or joints. Charnockite generally does not show any well-developed joint systems. Incidentally, the name »charnockite« derives from the founder of Calcutta, Job Charnock, whose tombstone is made of this rock.

The yield of an individual well is largely dependent on the intensity of spacing, areal extent, interconnection of joints, and other openings in the rock which, without the openings, would be essentially impermeable. These openings tend to close shut with depth and this accounts for the shallow ground-water circulation in these crystalline rocks. The deepest seated aquifer penetrated in the area was found at a depth of 106 m, although many wells have been drilled to depths of 120 to 150 m.

Static water levels range from 2.5 meters to 49 meters below ground surface in the area and average about 25 meters below ground surface.

Analysis of Well Data

Records of 341 wells drilled by the E.L.C. Water Development Project were used in this analysis of well data; 159 in the Satpura Hills region and 182 in Coimbatore District. All wells were drilled by air-hammer drilling rigs, and the diameter of these wells range from 11.4 to 16.5 cm. No cores were taken during the drilling of these wells.

Well sites were located by the following methods: 1) surface electrical resistivity

surveys, 2) surface geological observations including delineation of fracture patterns, faults, drainage patterns, and topographic inferences, 3) sites selected randomly in proximity to the user, and 4) sites selected considering proximity to the user but with some judgment regarding topography. All site selections were governed by one major consideration; namely, wells were located within proximity of the villages, institutions, or farmers who were to use the wells.

In the Satpura Hills region, approximately 45 wells were located using either a geophysical or hydrogeologic survey and 114 wells were located by randomly selecting a site in proximity to the ultimate user or selecting the site in proximity to the user with some judgment regarding topography. In Coimbatore District, all of the wells were drilled at sites selected on the basis of either a geophysical or hydrogeologic survey. However, it is worth noting that if the results of either a geophysical or hydrogeologic survey at a specific village were not encouraging and if that same village lacked a potable water-supply source, a test well was drilled irrespective of the survey results.

Well Yields

Well yields were measured by use of a V-notch weir during drilling; additionally, a number of more productive wells in both areas were pump tested. The wells in the Satpura Hills region have been grouped according to topographic location, and in Coimbatore District the wells have been grouped according to rock type; gneiss or charnockite. In general, well yields in the crystalline rocks of the Satpura Hills region and in gneiss in Coimbatore District are comparable, and well yields in charnockite are significantly lower than in gneiss in Coimbatore District. Table 1 contains a summary of well yields. Figs. 8, 9, and 10 are well yield histograms for all of the wells in crystalline rocks of the Satpura Hills region and for wells in gneiss and charnockite in Coimbatore District.

Table 1 - Summary of well yields in liters per minute for wells drilled in crystalline rocks in the Satpura Hills region and Coimbatore District

	No. of Wells	Min.	Max.	Mean	Mode	Median	No. of dry wells
<i>Satpura Hills Region</i>							
Total wells	159	0	757	90	6.4	43	12
Valleys	31	6.4	757	170	87	125	0
Flat uplands	125	0	742	71	0	23	12
<i>Coimbatore District</i>							
Gneiss	147	0	567	102	0	50	20
Charnockite	35	0	283	34	0	6.3	12

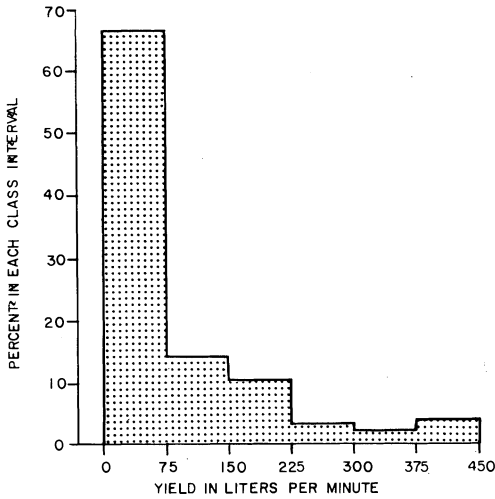


Fig. 8. Well yield histogram for crystalline rocks in Satpura Hills region.

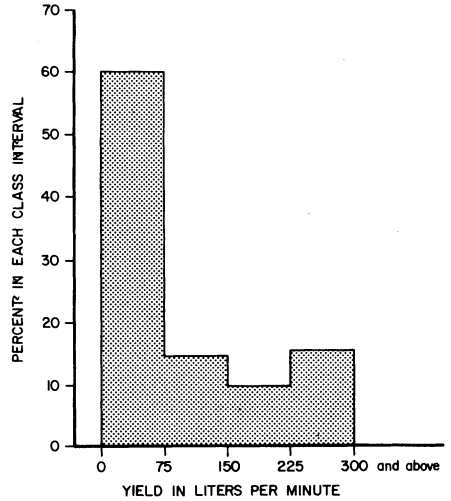


Fig. 9. Well yield histogram for gneiss in Coimbatore District.

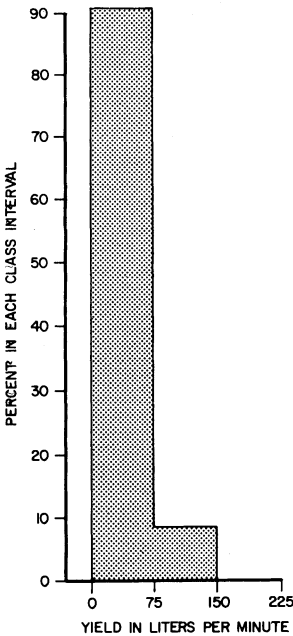


Fig. 10. Well yield histogram for charnockite in Coimbatore District.

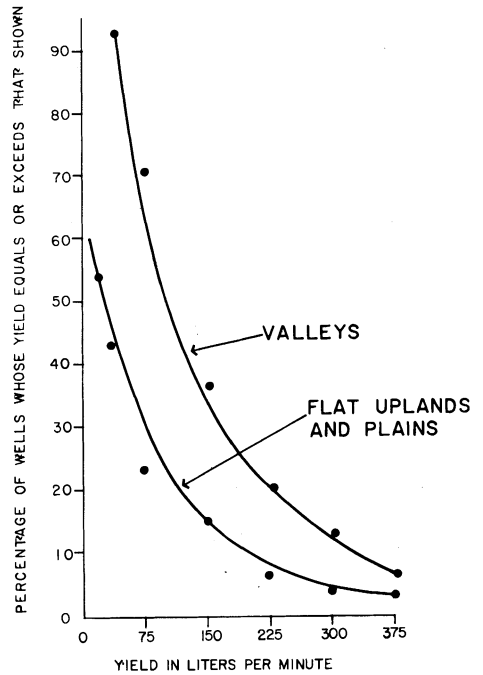


Fig. 11. Cumulative frequency distribution of well yields in various topographic positions in crystalline rocks in the Satpura Hills region.

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In the Satpura Hills region, topographic location generally exerts considerable control on well yields with mean well yields of 170 lpm in valley areas and 71 lpm in flat upland areas. These differences in well yields are expected considering the existence of local ground-water flow systems in the area. Fig. 11 is a cumulative frequency diagram of well yields for various topographic locations for wells in the crystalline rocks in the Satpura Hills region.

Aquifer Depths

Aquifer depths or depth to water-bearing fractures were recorded during drilling. Aquifer depths used in this analysis are the depths to the most productive aquifer or water-bearing fractures, a determination made by measuring pumped discharge with a V-notch weir during drilling. Table 2 summarizes the aquifer-depth data for wells in the Satpura Hills region, according to topographic location and in Coimbatore District according to rock type. Figs. 12, 13, and 14 are histograms of aquifer depths for wells in crystalline rocks of the Satpura Hills region and for wells in gneiss and charnockite in Coimbatore District.

Aquifer water-bearing fractures are generally deeper in Coimbatore District than in the Satpura Hills region. Although many wells in Coimbatore District were drilled to depths of 120 to 150 m, no water-bearing fractures were encountered deeper than 106 m.

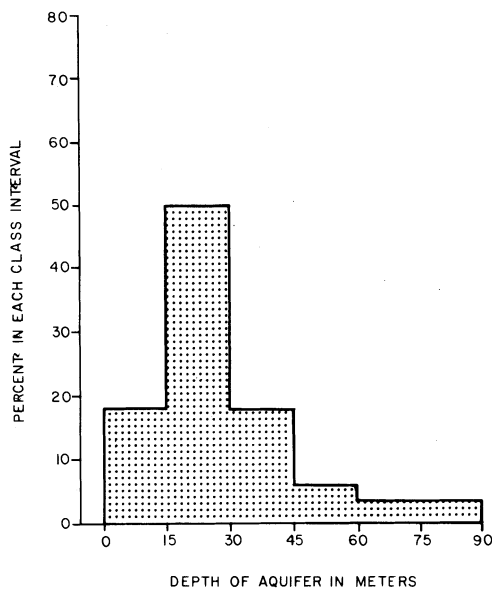


Fig.12. Aquifer depth histogram for crystalline rocks in Satpura Hills region.

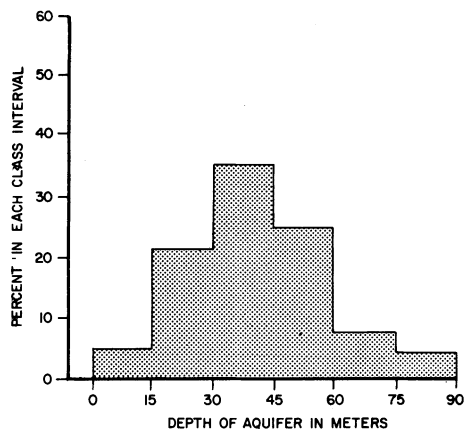


Fig.13. Aquifer depth histogram for gneiss in Coimbatore District.

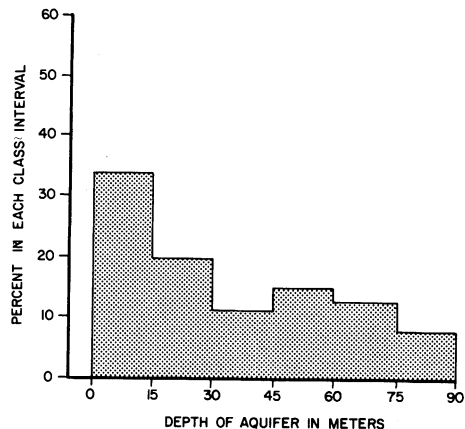


Fig.14. Aquifer depth histogram for charnockite in Coimbatore District.

Table 2 – Summary of aquifer depths in meters for wells drilled in crystalline rocks in the Satpura Hills region and Coimbatore District.

	No. of Wells	Min.	Max.	Mean	Mode	Median
<i>Satpura Hills Region</i>						
Total wells	142	7	93	29	18	23
Valleys	31	7.6	76	27	30	24
Flat uplands	108	7	93	29	22	23
<i>Coimbatore District</i>						
Gneiss	147	3	106	42	37	41
Charnockite	35	5.5	88	34		29

Well Depths

Table 3 summarizes well depth data for wells in the Satpura Hills region and Coimbatore District. On the average, wells in the Coimbatore District are deeper than in the Satpura Hills region. This is attributed to deeper depths to water and water-bearing fractures and also because a larger drill rig was used in Coimbatore District with a greater depth capacity.

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Table 3 – Summary of well depths in meters for wells drilled in crystalline rocks in the Satpura Hills region and Coimbatore District.

	No. of Wells	Min.	Max.	Mean	Mode	Median
<i>Satpura Hills Region</i>						
Total wells	159	18	95	50	61	46
Valleys	31	25	76	47	30	46
Flat uplands	125	18	95	51	61	46
<i>Coimbatore District</i>						
Gneiss	147	27	159	78	79	79
Charnockite	35	41	110	74	91	73

Geophysical Surveys

A comparison has been made in Table 4 of average well yields for wells drilled in the Satpura Hills region with and without a geophysical or hydrogeologic survey.

Table 4 – Summary of well yields in liters per minute according to method of site selection in Satpura Hills region.

	No. of Wells	Min.	Max.	Mean	Mode	Median
Survey	45	0	756	183.0	741	129.3
No. Survey	114	0	378	53.7	6.4	20.8

Relationships Between Well Parameters in Satpura Hills Region

To determine if any significant linear or non-linear relationships exist between well parameters, values of any two selected well parameters were analyzed using a computer program which calculated for values of correlation coefficient, standard error of estimate, and the slope and intercept of the best-fit line. This same program also plotted values of any two selected well parameters on a scattergram. The main objective of this analysis was to test for significant relationships between parameters such as well depth, aquifer depth, overburden depth, V-notch yield (yield measured during drilling), pump-tested yield and specific capacity. Table 5 lists values of the correlation coefficient, standard error of estimate and number of cases for each of the linear relationships that were analyzed. Judging from the results in Table 5, the only significant linear relationships are among the following

Table 5 – Results of the linear regression analysis for different well parameters for wells drilled in Satpura Hills region.

Well Parameters Checked	Correlation Coefficient	Standard Error of Estimate	Number of Cases
Well depth vs yield	-0.18	54.0	159
Well depth vs aquifer depth	0.61	44.0	142
Aquifer depth vs yield	0.07	58.2	142
Depth of overburden vs yield	-0.06	21.5	159
Depth of overburden vs aquifer depth	-0.14	21.2	142
V-notch yield vs pump-tested yield	0.89	18.7	54
V-notch yield vs specific capacity	0.72	30.8	42
Pump-tested yield vs specific capacity	0.68	38.8	47

variables: 1) V-notch yield and pump-tested yield; 2) V-notch yield and specific capacity; and 3) pump-tested yield and specific capacity.

The correlation among the parameters for the groups given above is expected and the relationship of V-notch yield with both pump-tested yield and specific capacity is significant since in the absence of a pumping test, these relationships can be used to obtain a rough estimate of the tested yield and specific capacity.

The fact that relationships among parameters such as well yield and well depth, well yield and depth of overburden, and well yield and aquifer depth show little if any correlation is also significant. The lack of a significant correlation between well yield and depth of overburden suggests that the more important factors controlling well yields are topography and fracturing in this area.

Incremental Well Yields

The results of a number of studies in crystalline rock areas in the United States and other countries are available in the literature (LeGrand 1954; Parker et al. 1964; Uhl and Sharma 1978). The data from a number of areas have been plotted on log-log paper using the variables, well depth and well yield/saturated thickness of the aquifer. This method of presentation was first used by Davis and Turk (1964) to depict the decrease in incremental well yields with depth in crystalline rock aquifers.

Fig. 15 is a plot of well depth versus well yield/saturated thickness for wells in the Satpura Hills region and for wells in gneiss in Coimbatore District. The data plots indicate that for shallow wells incremental well yields are greater in the Satpura Hills region and for deeper wells incremental well yields are greater in Coimbatore District. There are a number of possible reasons for these differen-

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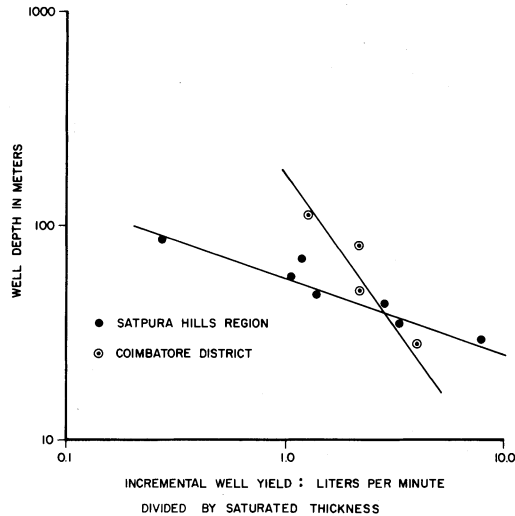


Fig.15. Incremental yield of wells in crystalline rocks of the Satpura Hills region and Coimbatore District.

ces, e.g., generally aquifer depths are deeper in Coimbatore District, and well depths are deeper in Coimbatore District. In the Satpura region, static levels are quite shallow and there is often quite intense fracturing within 30 m of ground surface.

Pumping Test Data

More than 150 pumping tests were conducted on wells in both study areas. Submersible pumps of 14.6 and 9.5 cm in diameter were used for testing. Discharge was measured by a water meter or by an orifice plate; water levels in the pumped well were measured by an electric sounder. The testing of each well was conducted in the following manner:

1. A step-drawdown test was conducted for 6 hours and consisted of 3 to 6 steps.
2. Recovery was measured for 12 hours, before starting the next phase.
3. A constant-rate test was run for 12 to 24 hours and recovery was measured for the same duration as pumping.

Step-test data were analyzed by Rorabaugh's method (1953) and by a graphical method discussed by Uhl et al. (1976). Constant-rate test data were analyzed by the Cooper-Jacob (1946) modified non-leaky artesian formula.

As testing work progressed and a number of tests were analyzed, anomalies in the test data proved helpful for interpreting differing aquifer conditions from

place to place.

In ground-water discharge areas of the Satpura Hills region, data from pumping tests in highly fractured aquifers plotted with the least variance. This is expected as a highly fractured medium would best approximate the assumptions upon which the equations describing ground-water flow are based. Aquifer dewatering is more common in ground-water recharge areas, where available drawdown is generally quite low.

Table 6 contains a summary of the results of selected constant-rate pumping tests in the Satpura Hills region. Values of aquifer transmissivity range from 1 to 380 m²/day and 12-hour specific capacities range from 0.99 to 184 lpm/m (liters per

Table 6 - Selected results of constant-rate pumping tests in crystalline-rock aquifers in Satpura Hills region.

Pump Test No.	Pumping Duration (hours)	Test Dis-charge (lpm)	Static Water Level (meters)	Pumping Water Level (meters)	Q/s, Specific Capacity at end of test (lpm/m)	Trans- missivity m ² /day, pumping	Trans- missivity m ² /day, recovery
46	10	63	4.67	23.4	3.36	15	15
60	12	212	6.45	9.65	66.2	167	167
79	12	18.9	9.70	21.62	1.6	2.6	2.7
80	12	22.6	9.45	15.4	3.8	7.3	7.5
84	12	151	5.34	18.45	11.4	37	82
89	12	208	4.57	14.02	21.9	98	114
90	6	252	1.12	18.24	14.7	53	-
91	24	680	1.98	17.0	45.2	147	147
92	12	113	1.78	17.05	7.4	49	70
93	12	223	4.98	8.08	71.9	119	121
98	12	741	2.57	21.65	38.8	71	61
99	12	741	3.61	9.76	120	146	248
100	12	159	6.45	14.89	18.8	230	230
118	12	319	3.41	8.56	61.9	270	360
126	8	49.9	3.45	30.38	1.86	4.3	3.1
127	12	90	2.21	13.72	7.82	10	15
128	12	90	2.29	11.18	10.1	20	31
131	12	225	11.08	24.67	16.6	71	78
135	12	756	+ .61	10.29	69.4	220	380
136	12	518	6.52	13.11	78.6	95	87
139	12	359	10.79	61.59	7.07	31	29
142	24	40.1	2.84	46.67	0.91	1.2	2.5
173	12	189	6.71	19.09	15.3	11	12
190	12	75.6	6.17	20.55	5.21	15	16
191	8.5	68	4.65	49.21	1.53	1.2	1.2
215	12	340	8.74	10.59	183	320	250

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minute per meter of drawdown). In general, ground-water discharge areas have been more productive locations for drilling wells than ground-water recharge areas. This is mainly due to more pronounced fracturing in ground-water discharge areas.

Table 7 contains a summary of the results of selected constant-rate pumping tests in Coimbatore District. In this study area, values of aquifer transmissivity range from 3 to 490 m²/day, and 12-hour specific capacities range from 3 to 280 lpm/m.

Table 7 – Selected results of constant-rate pumping tests in crystalline-rock aquifers in Coimbatore District.

Pump Test No.	Test Discharge (lpm)	Static Water Level (meters)	Pumping Water Level (meters)	Q/s, Specific Capacity at end of test (lpm/m)	Transmissivity m ² /day, pumping	Transmissivity m ² /day, recovery
221	75	17.99	32.62	5.13	5.3	5.6
222	378	28.05	33.31	71.8	330	202
223	340	24.87	35.32	32.5	22	29
226	378	28.51	39.61	34	14	28
228	49	48.48	56.5	6.1	64	43
230	60	30.18	45.78	3.85	8.7	26
232	128	39.02	42.81	33.7	62	62
234	360	25.61	44.05	19.5	106	155
236	68	31.48	47.48	4.25	2.9	1.9
240	45	13.19	20.5	6.15	6.2	5.6
241	227	12.2	14.23	112	139	237
242	283	12.45	32.55	14.1	100	103
246	227	23.98	30.18	36.6	158	196
249	283	25.38	32.21	41.4	246	96
251	242	33.59	34.45	280	420	241
259	38	18.8	27.82	4.21	3.7	5.6
261	510	33.05	37.86	106	230	178

Fig. 16 contains frequency plots of 12-hour specific capacities for the Satpura Hills region and Coimbatore District. From a comparison of the two plots, it is noted that specific capacities in Coimbatore District are on the average slightly higher than specific capacities in the Satpura Hills region. In conclusion, production wells that were to be equipped with power pumps were tested; therefore, these plots represent the specific capacity frequency of the more productive wells in the area. If all of the wells that were drilled had been tested, then the plots would be displaced downward from the plots shown.

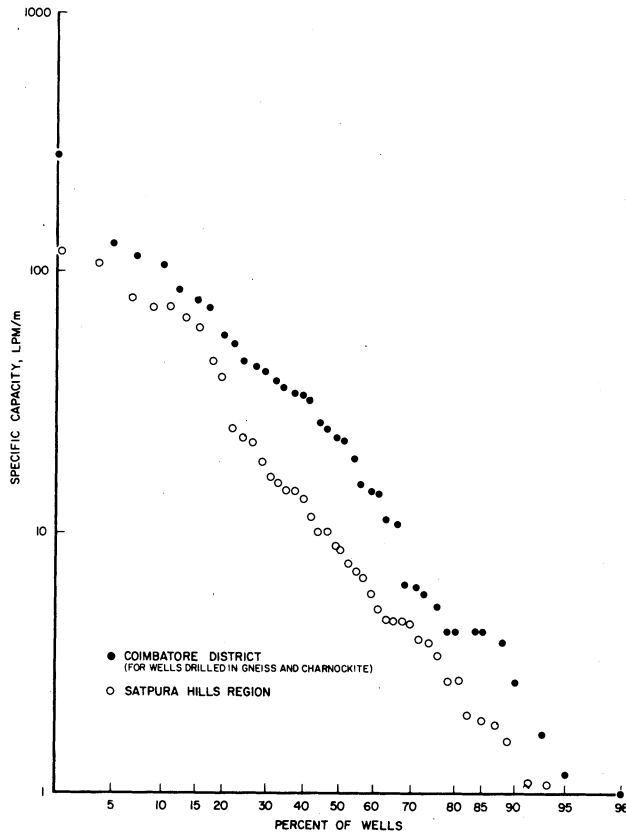


Fig.16. Specific capacity frequency plots for wells drilled in crystalline rock aquifers in the Satpura Hills region and Coimbatore District.

Conclusions

The recent drilling of more than 600 tube wells in the Satpura Hills region and Coimbatore District, by the E.L.C. Water Development Project, provided the data base for this study.

The distribution of well yields are similar in the crystalline rocks of the Satpura Hills region and in gneiss in Coimbatore District. This similarity is interesting since depths to water are deeper in Coimbatore District and the weathered zone or saprolite is, for the most part, unsaturated in Coimbatore District. One possible explanation for the similarity in distribution is that the main feature affecting or controlling well yields is the degree of fracturing and not the thickness and permeability of the saprolite. However, in the areas in Coimbatore District where

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ground-water pumpage is greater than recharge, well yields will decrease with time as water levels decline, and very possibly long-term yields will be, on the average, greater in the Satpura Hills region.

Well yields in charnockite are considerably lower than in gneiss in Coimbatore District. Topographic location exerts a considerable influence on well yields in the Satpura Hills region; the most productive wells are in valleys or ground-water discharge areas. Data were insufficient to quantify topographic influence on well yields in Coimbatore District.

Depths to productive water-bearing fractures or aquifer depths are, on the average, deeper in Coimbatore District, but the difference is not that significant. The deepest water-bearing fractures were encountered at a depth of 106 m in Coimbatore District and 93 m in the Satpura Hills region.

Incremental well yields decrease with depth in both areas and ground-water circulation is considered to be quite shallow.

In general, the distribution of aquifer transmissivities and specific capacities are similar for both areas and range over two orders of magnitude.

In conclusion, there is a need for the establishment of ground-water management criteria to prevent a depletion of this resource in Coimbatore District. In the Satpura Hills region, more investment in ground-water development could significantly increase agricultural irrigation and economic development in this area.

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References

- AFPRO (Action for Food Production, Coimbatore, India) (1973) Interim Report on the hydrogeological survey of the Noyil River Basin, Coimbatore District, Tamil Nadu, India.
- Cooper, H. H. , Jr., and Jacob, C.E. (1946) A generalized graphical method for evaluating formation constants and summarizing well field history. *Trans. Am. Geophys. Union*, Vol. 27.
- Davis, S.N., and Turk, L.J. (1964) Optimum depth of wells in crystalline rocks. *Ground Water*, Vol. 2, No. 2.
- Domenico, P.A. (1962) *Concepts and Models in Ground Water Hydrology*. McGraw-Hill, New York.

- Ground Water and Wells* (1966) UOP Division, St. Paul, Minnesota.
- Hubbert, M.K. (1940) The theory of ground water motion. *Jour. Geol.*, Vol. 48.
- Landers, R.A., and Turk, L.J. (1973) Occurrence and quality of ground water in crystalline rocks of the Llano area, Texas. *Ground Water*, Vol. 11, No. 1.
- LeGrand, H.E. (1954) Geology and ground water in the Statesville area, North Carolina. North Carolina Division Mineral Resources, Bulletin 68, 68 pp.
- Meinzer, O.E. (1923) Occurrence of ground water in the United States. U.S. Geological Survey, Water-Supply Paper 489.
- Nie, N.H., Hull, C.H., Jenkins, J.G., Steinbrenner, K., and Bort, D.H. (1975) *Statistical Package for the Social Sciences*. McGraw-Hill, New York.
- Parizek, R.R., and Siddiqui, S.H. (1970) Determining the sustained yields of wells in carbonate and fractured aquifers. *Ground Water*, Vol. 8, No. 5.
- Parker, Gerald G., Hely, A.G., Keighton, W.B., and Olmsted, F.B. (1964) Water resources of the Delaware River Basin. U.S. Geological Survey, Professional Paper 381, 200 pp.
- Rorabaugh, M.I. (1953) Graphical and theoretical analysis of step-drawdown test of artesian wells. *ASCE Proc.*, Vol. 79, No. 362.
- Royal Institute of Technology, Stockholm. Water resources and water supply in Coimbatore District, Tamil Nadu, India. Department of Land Improvement and Drainage School of Surveying.
- Shrivastav, P.N. (1970) *Betul District Gazetteer*. District Gazetteers Department, Madhya Pradesh, India.
- Toth, J.A. (1963) A theoretical analysis of ground-water flow in small drainage basins. *Jour. Geophys. Research*, Vol. 68, No. 16.
- Uhl, V.W., Jr., Joshi, V.G., Alpheus, A., and Sharma, G.K. (1976) The application of step-drawdown pumping tests to water wells in consolidated-rock aquifers. *Indian Geohydrology*, Vol. 11, Nos. 3 and 4.
- Uhl, V.W., Jr., and Sharma, G. K. (1978) Results of pumping tests in crystalline-rock aquifers. *Ground Water*, Vol. 16, No. 3.

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