THE RELATIONSHIP OF GROUND WATER TO ALLUVIUM IN DINAJPUR AND RANGPUR, EAST PAKISTAN

by

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ABSTRACT

East Pakistan ground water occurs in complex alluvial deposits. Practically no work has been done to determine the aquifer properties and ground water conditions of the sediments, the determination of which is prerequisite for the efficient exploitation of the resource.

In the present study, an attempt has been made to determine aquifer properties and ground water conditions in Rangpur and Dinajpur by geologic interpretation and lithologic analyses in conjunction with limited pumping test analyses supplemented with water table study.

It is difficult to correlate alluvial sediments from one well to another; nevertheless, they maintain a general uniformity when the entire study area is considered. This fact is apparent also from water table contour maps which indicate homogeneity of the underlying aquifer. The coefficient of transmissivity obtained by lithologic and by pumping test analyses ranges from 7×10^4 to 13×10^4 gpd/ft, having an average of about 10×10^4 gpd/ft for the upper saturated 250 feet of the aquifer. The average permeability and specific yield of the aquifer are found to be about 400 gpd/ft^2 and 0.20, respectively.

INTRODUCTION

General Statement

East Pakistan is one of the most heavily populated and largest deltaic regions of the world. More than fifty million people live in 54,501 square miles of its area. Although almost all of the province is a fertile flood plain and deltaic land, the agricultural production is not sufficient to feed the rapidly increasing population. There are two factors that limit production: (1) winter drought and lack of irrigation facilities greatly limit winter crop production, and (2) almost every year monsoon floods and cyclones damage considerable acreage of crops primarily in the low lying and coastal areas.

To control floods and to minimize cyclonic devastation are long range programs upon which the Pakistan Government has begun work. An immediate alleviation of the food problem would be to increase the winter crop production and to bring more land under cultivation by applying systematic modern irrigation. Every year a considerable amount of foreign exchange is used in order to import food grains from other countries, but introducing modern irrigation methods, East Pakistan probably could be self sufficient in food. To do this will necessitate the development of surface as well as ground water resources.

There was a time when the Pakistani people thought that the surface water supplies were sufficient and that ground water was not needed. However, today the country must depend more on ground water than surface water. During drought, in certain parts of East Pakistan, ground water becomes the only source of water for drinking, domestic, irrigation and industrial uses.

The first tubewell irrigation project consisting of 380 tubewells, each approximately 275 feet deep, has been functioning since 1966 in the Dinajpur district, but detailed hydrological data, aquifer characteristics and other related factors have not been studied in detail.

The very favorable geology, abundant recharge possibilities, the high water table and present performance of the well field suggest that the project will be a successful one. Very soon another project of a similar nature will begin in the Rangpur district to be followed by other ground water development projects elsewhere in East Pakistan.

East Pakistan is almost entirely underlain by a great thickness of alluvial deposits. Practically no attempt has been made to determine the aquifer characteristics of these alluvial deposits. Such studies are essential for the efficient exploitation of the ground water resources of the area. The relationship of ground water to these alluvial deposits with respect to ground water storage and transmitting capacities, and the influence of rainfall on the water table and storage are unknown for the region.

Purpose and Scope

The study area constitutes about 1200 square miles within the Dinajpur and Rangpur districts. To date, practically no work has been done to determine the specific yield and transmissivity of the aquifers of this area although a tubewell project is functioning and another one at Rangpur possibly will start soon. The present study will be an attempt to determine the extent to which well logs with limited pumping test, grain size analysis and ground water level fluctuation data of the alluvium can be used to arrive at some understanding of the ground water potential and particularly the storage coefficient and transmissivity of the aquifer.

The main purpose of this study is to determine the aquifer properties from limited, but available, pumping test data and from geologic analysis. Since the results are based mostly on qualitative data, the reader is cautioned to use this report with some reservations.

Location

East Pakistan lies roughly between 20° 45' and 26° 40' north latitude and between 88° 03' and 92° 40' east longitude. It is separated from West Pakistan by about 1,000 miles of Indian territory.

The study area consists of about 1,200 square miles which lies approximately between 25° 50' and 26° 20' north latitude and between 88° and 89° east longitude; this area is part of the Dinajpur and Rangpur districts of East Pakistan (Fig. 1).

Climatology and Physiography

The climate of East Pakistan is similar over the entire region and is characterized by high temperature, heavy rainfall, often excessive humidity and marked seasonal variation in rainfall. The climate is warm during winter (November to February) and hot during summer (March to October).

East Pakistan is one of the heaviest rainfall regions of the world. Annual normal rainfall varies approximately from 216 inches in the northern part of the Sylhet district to 55 inches in the western regions of East Pakistan. Over 80 percent of the rainfall occurs from June to October and the remaining 20 percent which

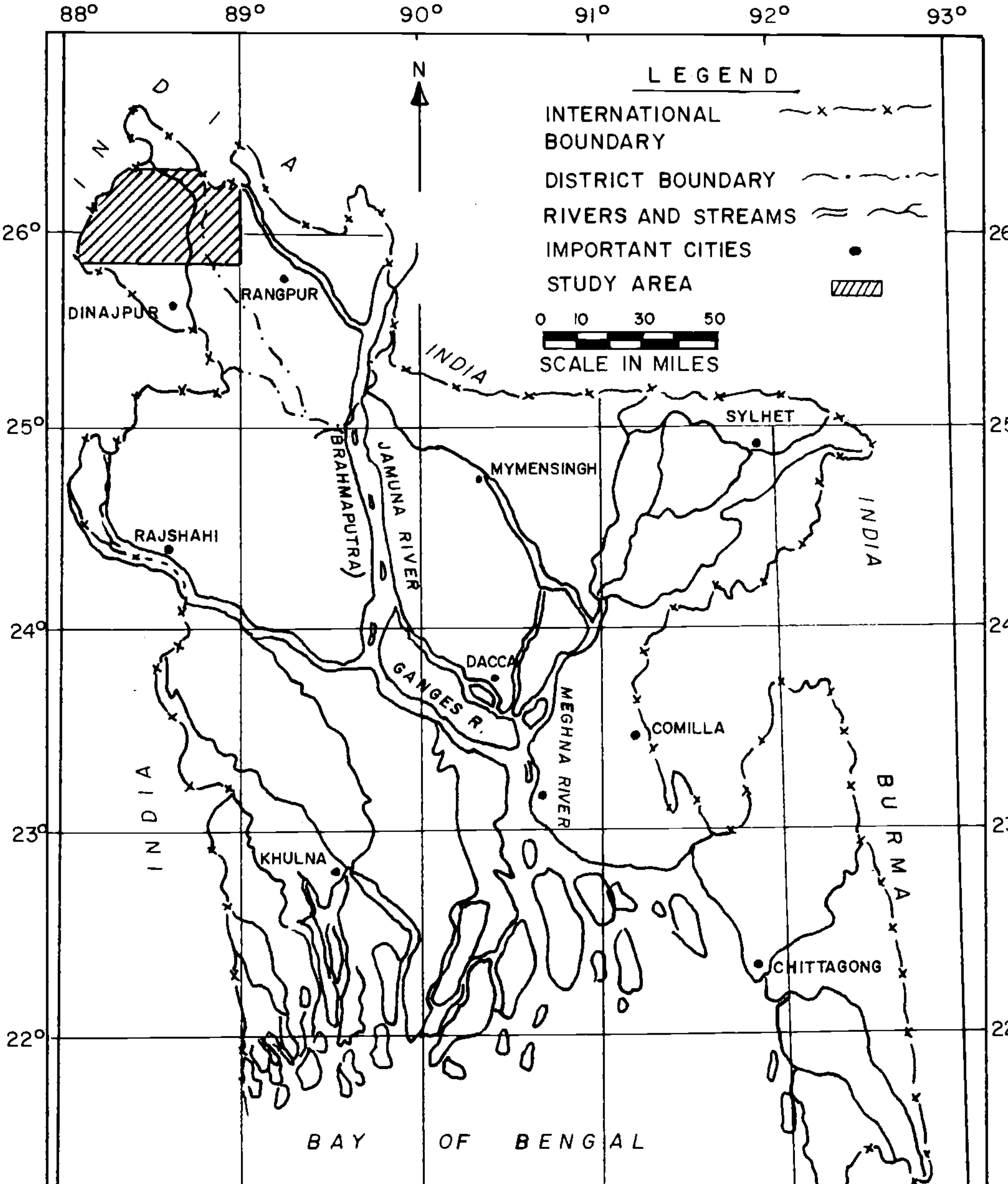


FIG. I LOCATION MAP OF EAST PAKISTAN SHOWING STUDY AREA occurs during the balance of the year does not suffice for the crops needed to feed the huge population. The mean annual rainfall in the study area is about 70 inches.

The mean temperature in the project area is about 97°F. during the period March to May and about 51°F. during the months of November to January.

The dominant characteristic of the topography of East Pakistan in general is extreme flatness with only a few hills in the northeast and eastern border regions of the country. Generally the ground slopes from north to south, and ranges from 250 feet above mean sea level at the northern boundary of the Dinajpur district to 150 feet elevation at 300 miles north of the Bay of Bengal to 50 feet elevation at 200 miles and 10 feet elevation or less near the sea coast.

The study area slopes almost uniformly from the north in a general south and southeast direction. In the northern part, the area lies about 240 feet above mean sea level and in the southeast and south the elevation is about 140 feet above sea level. The land gradient ranges from 3 feet per mile in the north to 2 feet per mile or less in the south and southeast parts of the area. The gradient becomes still less further south.

The area is mainly drained by the Karatoa, Tangon, Atrai, Purnabhaba, Tista, Dhepa, Buri Tista and Jamuneswari rivers.

GEOLOGY

General Geologic Setting of the Area

Little work has so far been done relating to the overall geology of East Pakistan. Morgan and McIntire (1959) described the general geology of East Pakistan (Bengal basin) in a publication of the Geological Society of America. Later on the Geological Survey of Pakistan (1964) published a very general geologic map of East Pakistan mostly based in large part on areal photographic information.

Following is a general geologic description of the project area based on a study of the above-mentioned publication and geologic map and the author's personal experience in the area.

The project area is a part of the Bengal Basin. This basin is filled with enormous quantities of sediment deposited during Quaternary time by the Ganges, Brahmaputra, Meghna and their numerous tributaries and distributaries. The northeastern and eastern parts of these thick alluvial deposits are bounded by interbedded Oligo-miocene sandstones and shales with occasional conglomeritic, lateritic and carbonaceous rocks. The average thickness of the alluvial fill of the basin is not known. Probably it is in the range of thousands of feet. According to surface exposures, lithology, color and age, the alluvial sediments of the Basin have been divided into Pleistocene and Recent. The Pleistocene sediments were deposited by the older courses of the Ganges and Brahmaputra. The Recent sediments were deposited by the present river systems in part by transporting, depositing, and reworking of the older sediments. The Pleistocene areas in East Pakistan are higher in elevation than the surrounding Recent to Sub-recent alluvial plains and consist of relatively compact, well-oxidized sediments with red-brown color having ferruginous concretions and generally relatively higher percentages of fine materials than the Recent sediments.

The study area consists largely of piedmont type sediments derived from the highlands of India toward the north and deposited on the gentle slopes of the Brahmaputra and Ganges Basin during Recent to Sub-recent geologic time. The streams which were usually most active for the deposition of these alluvial sediments are the Tista, Atrai, Karatoa, Purnabhaba, Raidak, Tangon, Dhepa, Jamuneswari. Reworking of the sediments of the area by these streams and other numerous channels is also an important sedimentary process in the area. The sediments of those water courses have formed extensive alluvial deposits which probably overlie sediment deposited by older courses of the rivers Ganges and Brahmaputra because their outcrops have been found to the south of the project area. It is probable that the older alluvial surface is sloping toward the north, but it is difficult to distinguish recent sediments from older ones through the study of drill hole samples. It is not known at what depth the older sediments occur.

Sub-Surface Geology

In order to reconstruct the subsurface geology of the investigated area, 61 representative bore hole logs located throughout the area were studied. Two geologic sections (Fig. 3 in the pocket) along lines AB and CD (Fig. 2) in the north-south and east-west directions, respectively, indicate the relationships of various lithologic units up to the maximum depth penetrated by the wells. The study is confined to about 300 feet depth below the ground surface. Since the data are mostly of qualitative nature, all interpretations are normally based on the qualitative characteristics of the material although an attempt was made to calculate the percent sand size, silt size, and clay size (Table 1) encountered in each bore hole. The calculation is made by assigning all the lithologic units reported on the driller's log to one of

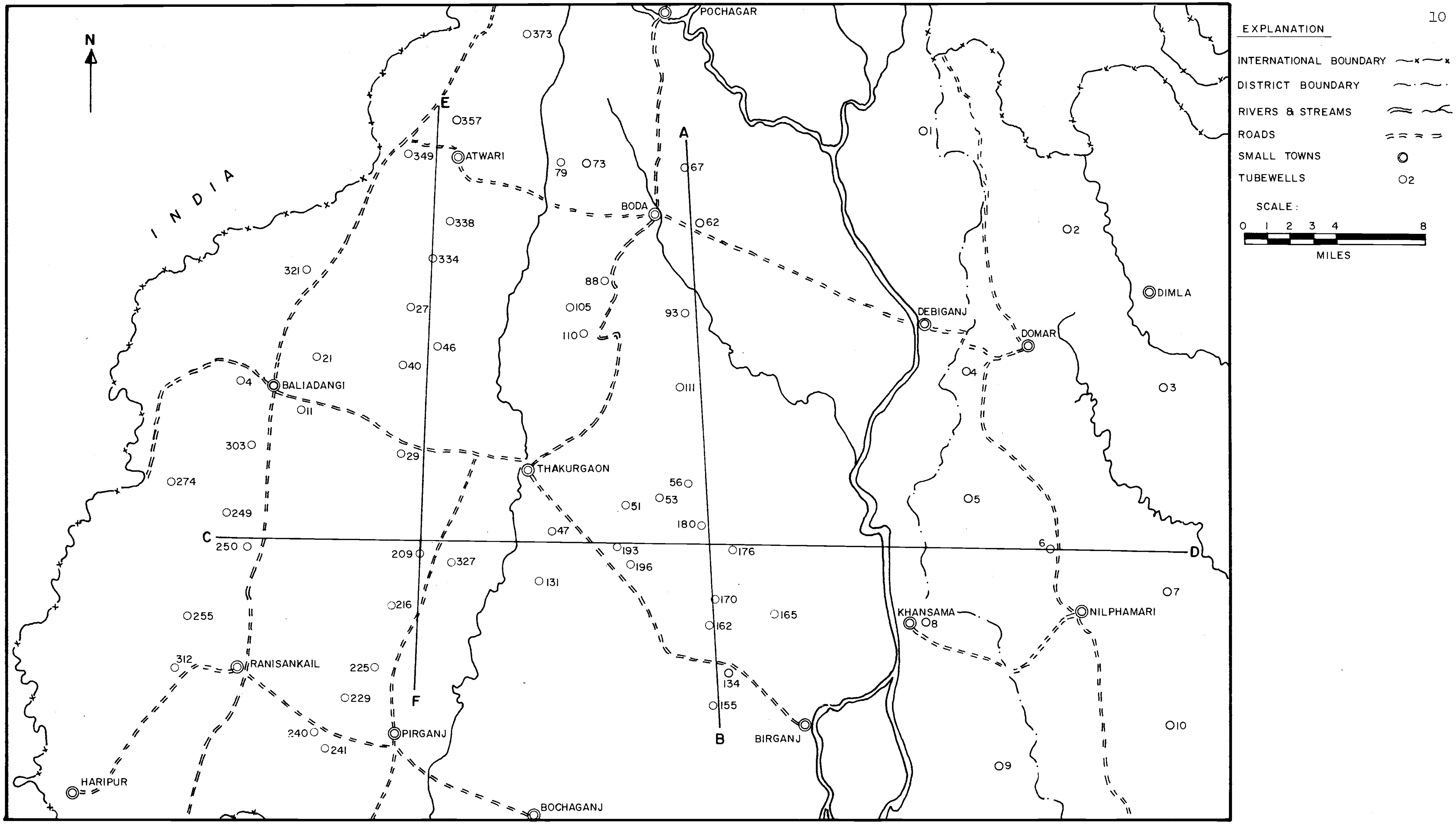


FIG. 2 MAP SHOWING THE TUBEWELL LOCATIONS AND GEOLOGIC SECTION PROFILES IN THE STUDY AREA OF DINAJPUR AND RANGPUR

TABLE 1

PERCENT SAND, SILT AND CLAY SIZE MATERIAL OF SEDIMENTS ENCOUNTERED IN TUBEWELL BORE HOLES

Location	Tubewell No.	Percent Sand	Percent Silt	Percent Clay
Dinajpur Block-A	47	76	3	21
	51	90	2	8
	53	85	7	8
	56	74	6	20
	62	86	5	9
	67	89	8	3
	73	86	4	10
	79	89	3	8
	88	96	3	1
	93	93	3	4
	98	96	2	2
	105	94	2	4
	110	94	2	4
	111	89	3	8
	122	92	3	5
Dinajpur Block-B	131	88	0	12
	134	90	1	9
	155	90	2	8
	162	87	2	11
	165	86	6	8
	170	96	2	2
	176	86	2	12
	180	84	0	16
	193	85	2	13
	196	88	0	12
Dinajpur Block-C	4	96	0	4
	11	84	2	14
	21	84	2	14
	27	97	3	0
	29	87	7	6

TABLE 1 - Contd.

Dinajpur Block-C	40	88	7	5
	46	97	3	0
	321	92	0	8
Dinajpur Block-D	209	97	3	0
	216	96	0	4
	327	98	2	0
Dinajpur Block-E	225	95	1	4
	229	97	3	0
	240	92	8	0
	241	82	0	18
Dinajpur Block-F	249	97	3	0
	250	98	2	0
	255	97	3	0
	274	98	2	0
	303	97	3	0
	312	94	2	4
Dinajpur Block-G	334	97	1	2
	338	90	2	8
	349	95	1	4
	357	98	2	0
	373	97	0	3
Testwells Rangpur	1	92	1	7
	2	86	3	11
	3	79	2	19
	4	87	1	12
	5	82	2	16
	6	93	2	5
	7	84	1	15
	8	74	1	25
	9	66	1	33
	10	83	1	16

the three categories of sand, silt, or clay, and then computing the percent total thickness of each. A textural triangular diagram (Fig. 4) was constructed from the percent sand, silt and clay size materials to show the relative position of the occurrence of points within the triangle. This diagram indicates that the material is dominantly sand, with clay of secondary importance, and silt of minor importance.

The alluvial deposits are very complex and it is very difficult to correlate the sediments from one well to another. The east-west and north-south sections demonstrate this phenomenon. The complexity of the alluvial deposits is due to local changes in the condition of deposition in space and time in the area. These fluctuating conditions of deposition formed lenses of sand, silt and clay. Only rarely do these lenses have considerable lateral extension; for the most part they can be correlated only locally. In order to detect a systematic variation of sediments, if any, from north to south or from west to east, variation diagrams (Figs. 3a, 3b, 3c) along sections AB, CD, and EF have been constructed with percent size sediments as y-axis and distance in miles from a reference point as x-axis. In each diagram there are three curves which show the relative variation of the percent sand, silt and clay size material according to position of bore holes in the

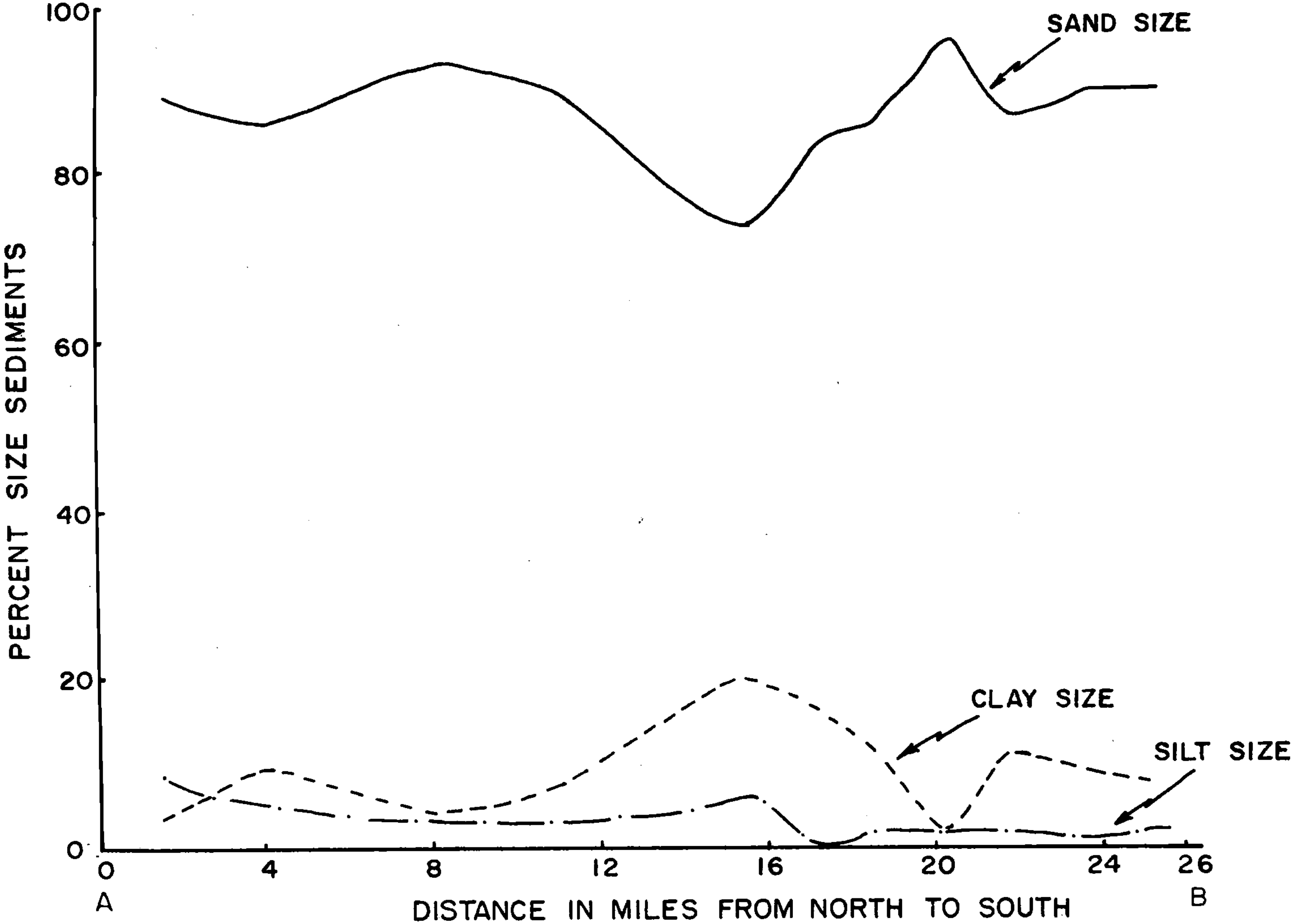


FIG. 3a VARIATION DIAGRAM SHOWING PERCENT SAND, SILT AND CLAY SIZE MATERIAL ALONG SECTION LINE AB

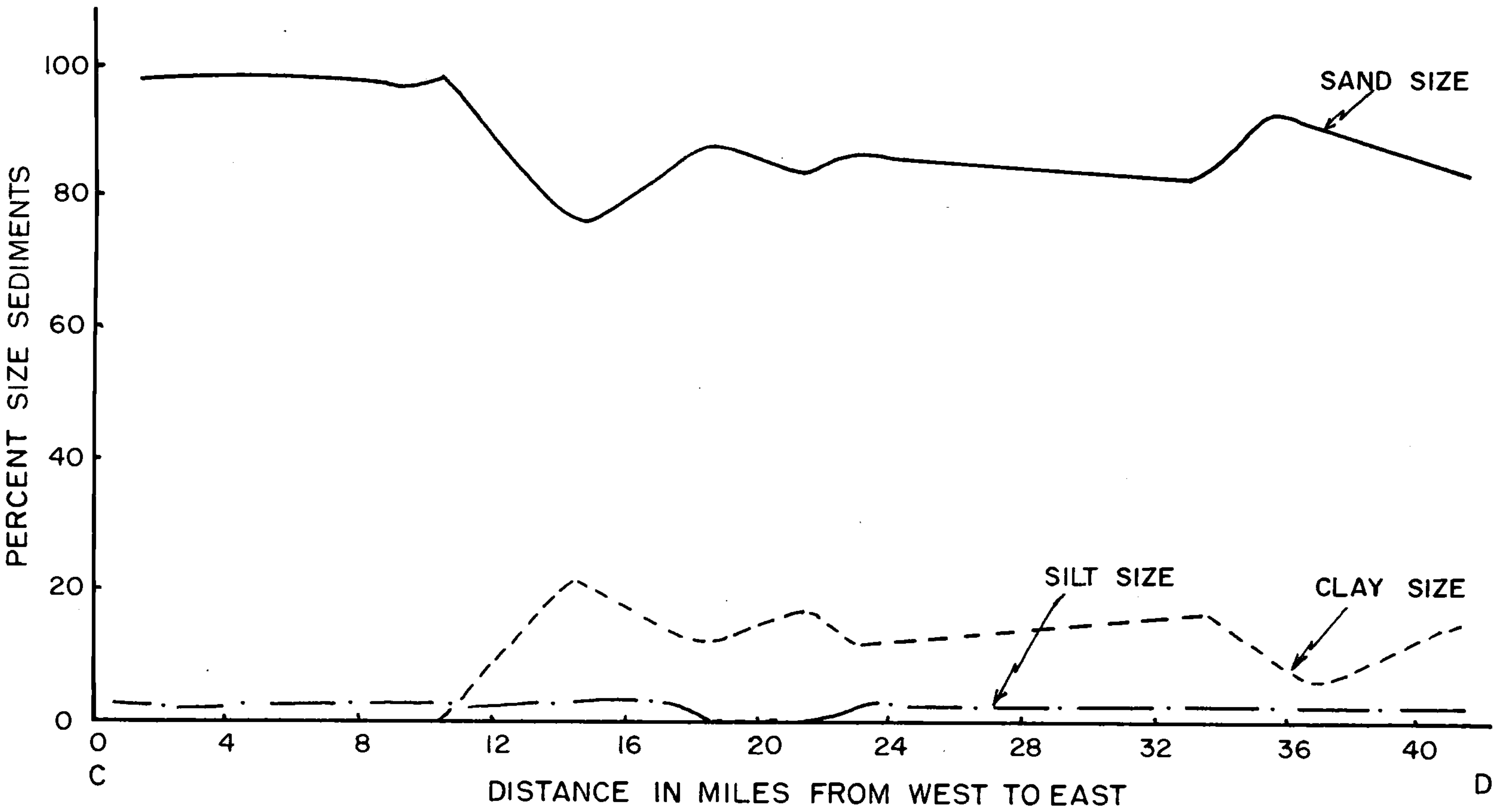


FIG. 3b VARIATION DIAGRAM SHOWING PERCENT SAND, SILT AND CLAY SIZE MATERIAL ALONG SECTION LINE CD

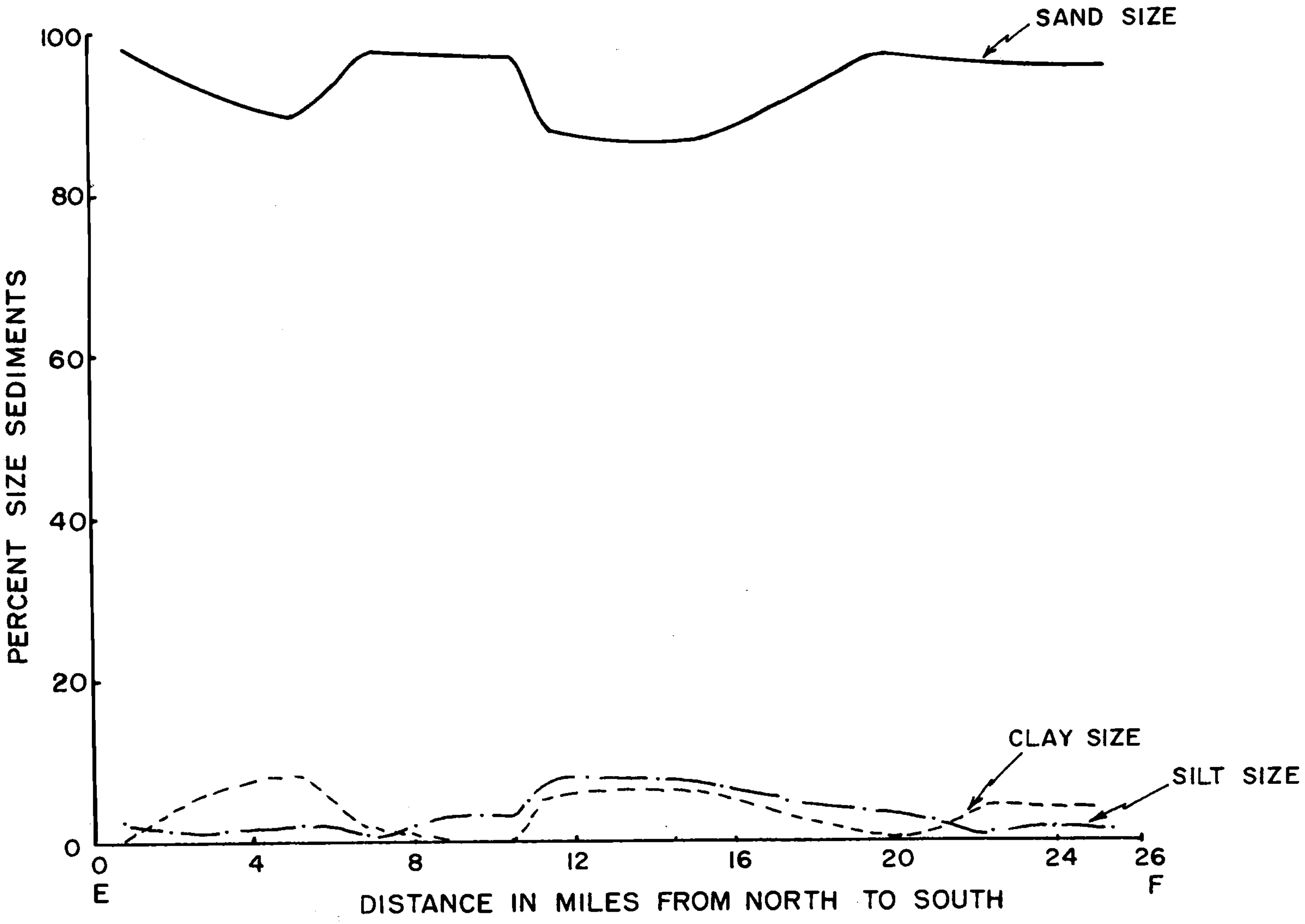


FIG. 3c VARIATION DIAGRAM SHOWING PERCENT SAND, SILT AND CLAY SIZE MATERIAL ALONG SECTION LINE EF

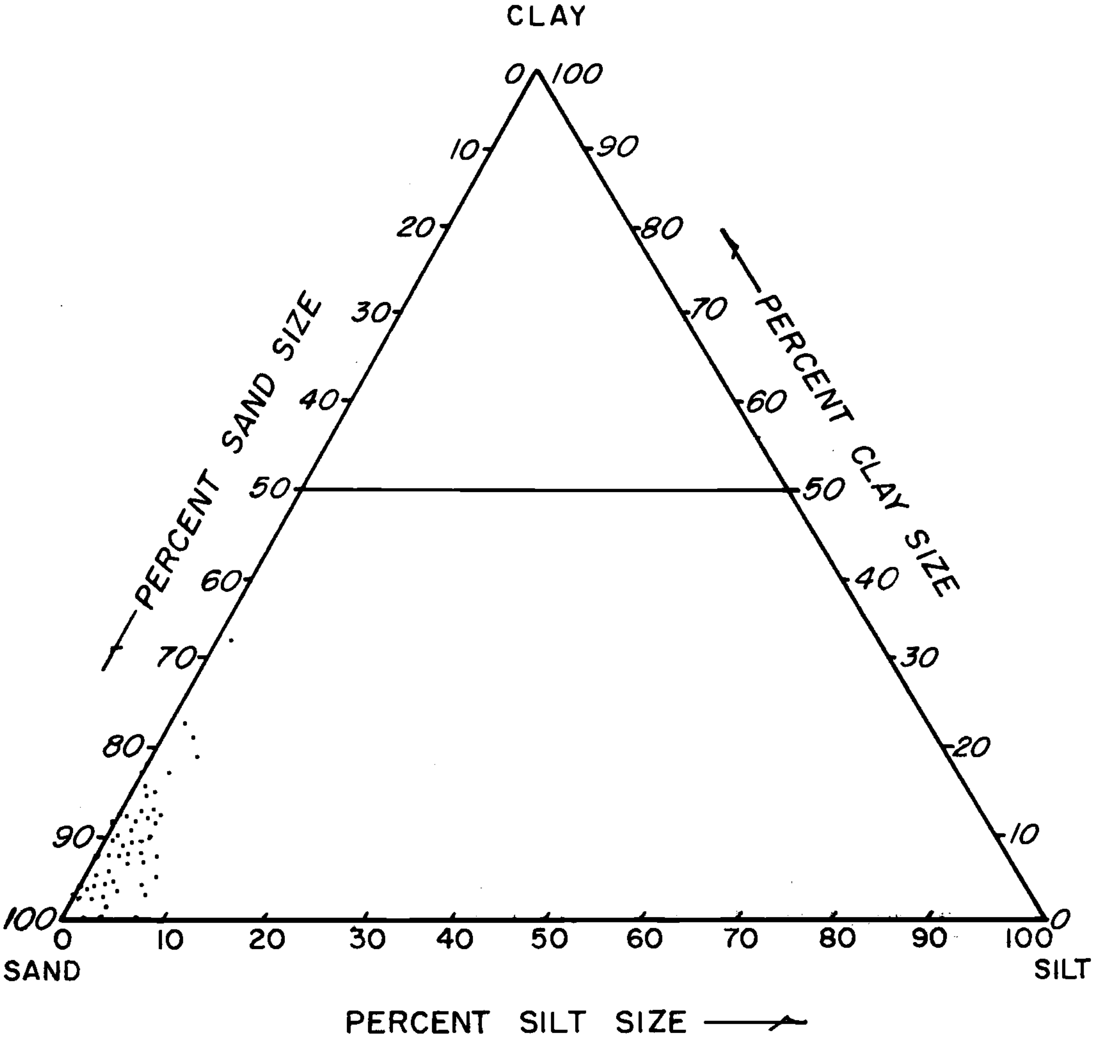


FIG. 4 TEXTURAL CHARACTERISTICS OF SIXTY ONE WELL LOG DATA

section in respect to the reference point. It is seen from these figures that the sediments up to investigated depth occur more or less at random in the area and there seems to be no systematic regional variation in the occurrence of the size ranges of material; a possible exception is an apparent small increase of clay in the west to east direction. The geologic sections and the plot of percent sand, silt and clay size material of all the wells in the entire area demonstrate the same fact. The upper part of the sediments are mostly reworked by the lateral migration of the streams and channels. This repeated scour and redeposition brought about the observed complexity. In general, the sediments up to the investigated depth were deposited in a flood plain environment on the inside of river curves or channels, and from overbank flows. As rivers moved laterally, sediments were deposited within or below the level of the bank-full stage on the point bar; while at overflow stage, the sediments were deposited on both the point bar and over the adjacent flood plain. Coarser sediments normally were deposited on the floor of the channels. The saturated thickness of the aquifer can be considered as the average thickness of the sand-size material neglecting silt and clay size, below the maximum watertable. Medium sand is the most abundant in the entire area although occurrence of coarse sand is considerable. Some scattered fine gravel occurs usually in association with coarse varieties of sand.

Occurrence of Ground Water

The movement of water in the rocks of the earth's crust is a phase of the hydrologic cycle. The rocks beneath the earth's surface contain open spaces or interstices through which water slowly moves from points of recharge to points of discharge. The source of this water is precipitation, part of which returns to the atmosphere through evapotranspiration and part of which flows directly into streams as runoff. The remainder infiltrates into the ground to accumulate within the pore space of the rock or aquifer as ground water reserve. The amount of water that can be stored in a rock material depends on the porosity which is characterized by the size, shape, sorting, packing, cementation and compaction of the grains. The capacity of the rock material to yield water to wells is determined by its permeability or ability to transmit water through the pore space of the rock material under a given hydraulic gradient. A rock consisting of silt or clay particles may have a high porosity but owing to the very small size of the interstices, the permeability may be quite low and the rock may be considered to be impermeable for practical purposes. Unconsolidated rocks composed of relatively large and uniformly sized particles will transmit water more readily. The worth of an aquifer as a fully developed source of water depends largely on two inherent characteristics: (1) its ability to store, and (2) its ability to transmit water. The storage coefficient, S, may be defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head (Ferris and others, 1962, p. 74). In unconfined aquifers the storage coefficient is essentially the same as specific yield because water is released from or taken into storage mainly due to gravity drainage or refilling of the aquifer, the effect of compressibility may be neglected. The field coefficient of transmissivity, T, is defined as the rate of flow of water under 100 percent hydraulic gradient, through a vertical strip of the aquifer one foot wide extending the full saturated thickness of the aquifer.

The field coefficient of permeability equals the transmissivity divided by the saturated thickness of the aquifer.

The evidence from bore hole logs and numerous domestic wells and observation wells makes it obvious that the entire area is underlain by a body of ground water from a depth ranging from three to fifteen feet below land surface depending on location and season of the year. The total volume of the ground water in storage is enormous because the thickness of the alluvium probably is in the range of thousands of feet. Since the wells are confined to an average depth of 275 feet, the study is limited to the upper part of the aquifer.

The aquifer in the project area can be considered as being under water table conditions, though due to the presence of clay or silt lenses in some places it may be locally artesian. Since the silt and clay layers are thin, and not laterally extensive, the confining effect, if any, probably can be neglected.

AQUIFER PROPERTIES BY LITHOLOGIC ANALYSES

Grouping of Sediments

Fifty descriptive lithologic logs representative of the entire project area were studied carefully. The average thickness of these logs is about 275 feet. Analysis of the logs reveals that about 24 alluvial lithologic units may be distinguished. Though there are some variations in the thickness of the different lithologic units, the coarser-grained units which control the occurrence and availability of the ground water in the region, maintain a general uniformity when the entire area is considered. Moreover, the project area constitutes one uniform physiographic unit and a continuous hydrologic setting. The specific yield and average permeability are therefore expected not to change much from place to place.

No previous study was made in the area to determine specific yield and permeability either by laboratory or pumping test methods. The present attempt to assign suitable values to these sediments by analyses of available lithologic and pumping test data should contribute toward the development of the ground water resources of the project area.

The following 24 lithologic units were identified in the project area: gravel, gravel with coarse sand, gravel and coarse sand, coarse sand with gravel, coarse sand, medium sand, medium sand with gravel, medium and coarse sand, medium to coarse sand with gravel, medium and fine sand, medium to fine sand with gravel, coarse to fine sand, fine sand, fine sand with gravel, coarse sand with gravel and clay, silt and fine sand, silty fine sand, medium sand with silt and clay, silt, fine sand with clay and silt, sandy clay, clay with gravel, silt and clay, and clay. Although a few mechanical analyses were performed, the units were mainly identified by visual inspection of drilling samples.

All these units do not necessarily occur in all the bore holes, but the predominant lithologic units are medium sand, medium and coarse sand, and coarse to fine sand having some scattered gravels at certain horizons. These units occur throughout the entire area and their total thicknesses do not vary much from place to place. Clay and silt lenses constituting a minor thickness of the zones also occur throughout the area.

Determination of Specific Yield

The task of assigning specific yield values to the sediments was simplified by regrouping all the previously-named lithologic units into seven categories. Then suitable specific yield values were assigned to each of these categories (Table 2) according to the range of specific yield values suggested by United States Geological Survey based on laboratory and field tests (Johnson, 1967). In assigning values it was considered that the sand and gravel as described in the logs, contain some fine materials which generally are not mentioned in the field descriptions. The samples were collected by the reverse rotary drilling method and there is every possibility in such drilling that some finer materials were washed out of the sample. Moreover, the description is based on visual hand identification.

Based on the assigned values, specific yields were calculated for the 250 feet saturated thickness of each bore hole by weighting each category according to its percent thickness of total section. Specific yields for all the 50 representative bore hole logs in the Dinajpur and Rangpur districts were calculated. The average values of the area blocks were then calculated and finally average specific yield for the entire study area was determined (Table 3).

TABLE 2

SPECIFIC YIELD ASSIGNED TO WATER-BEARING SEDIMENTS IN THE STUDY AREA

(Modified after Johnson, 1967)

Group	Description of Material	Specific Yield in Percent
1.	Gravel, gravel with coarse sand, gravel and coarse sand, coarse sand with gravel. (All gravels are fine.)	25
2.	Coarse sand, medium sand, medium and coarse sand, medium sand with gravel, medium to coarse sand with gravel.	22
3.	Medium and fine sand, medium to fine sand with gravel, coarse to fine sand.	20
4.	Fine sand, fine sand with gravel, coarse sand with gravel and clay.	10
5.	Silt and fine sand, silty fine sand, medium sand with silt and clay.	7
6.	Silt, fine sand with clay and silt, sandy clay, clay with gravel, silt and clay.	5
7.	Clay. (Usually plastic and compact.)	1

TABLE 3

SPECIFIC YIELD OF THE WATER-BEARING SEDIMENTS OF RANGPUR AND DINAJPUR STUDY AREA

Area Block and Tube-Well Number	Total Saturated Thickness Considered (feet)	Average Thickness of Group (feet)							Calculated Specific Yield (Percent)
		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	
Block-A 51, 53,56,62, 67,73,79, 88,93,110, 111 and 122.	250	23	144	55	6	3	3	1	19.82
Block-B 131, 134, 155, 162, 165, 176, 180, and 193.	250	26	188	8	6.23	1.32	0.65	20	20
Block-C 4, 21, 27, 29, and 40.	250	50	130	40	11	2	4	13	20.2
Block-D 209, 216, and 327	250	13	214	20	0	0	0	3	20.5
Block-E 225, 229, and 241.	250	13	189	22	13	0	0	13	20

TABLE 3 - Contd

Block-F 249, 250, 255, 274, 303, and 312	250	23	193	22	3	0	0	9	21
Block-G 388, 349 and 357	250	145	76	10	6	0	0	19	22
Rangpur Test-Wells 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10.	250	116	66	25	6	0	7	31	19.9
					Average specific yield (percent)				20

Determination of Transmissivity

Transmissivity calculated from available pumping test data is analyzed in the next section. In this section an attempt will be made to apply a method developed by the Hydrological laboratory of the U. S. Geological Survey (Johnson, 1963) in which transmissivity is estimated from the logs of test holes and laboratory data.

Sediments apparently having more or less the same lithology, but occurring under different geologic environments, have permeability values considerably different. Relationships between hydrologic properties and lithologic description of sediments established in one environment may not be necessarily exactly applicable to others. It is always better to first establish such relationships in one or two representative bore holes by comparing the lithology with the results obtained by laboratory and pumping test methods. Lithologic analysis can then be extrapolated with reasonable confidence over the entire project area to determine aquifer properties. However, in this report, average values for the relationship were taken from Johnson (1963) and some modification based on the judgment of the writer.

Transmissivity of the project area was calculated from 50 representative test hole logs for an average saturated thickness of 250 feet by the following methods:

(1) Each lithologic unit was studied on the basis of visual description and some limited mechanical analysis data to get an idea of particle size, median diameter, and effective size. (2) Twenty-four described lithologic units were divided into seven groups according to their related physical properties. (3) Permeability values were assigned to each of these seven lithologic groups (following Johnson, 1963), depending on the lithologic description (Table 4). (4) Since the wells are located according to area blocks, the transmissivities were calculated and averaged for each of eight area blocks. The thickness of each lithologic group in each well of the block was first estimated separately, then they were added and averaged for all the wells considered in each block. The average thickness of each lithologic group thus calculated was then multiplied by the assigned permeability value for the group to obtain the group coefficient of transmissivity. (5) The group transmissivities were added to obtain an estimate of the coefficient of transmissivity for the full saturated average thickness of 250 feet. This procedure was repeated for all the eight area blocks. Finally, average transmissivity for the entire project area was estimated. The calculations and results obtained by this method are given in Table 5. As is seen from this table, the average transmissivity value is 85,000 gpd/ft,

ranging from 72,000 to 108,000 gpd/ft. The average permeability is 340 gpd/ft^2.

TABLE 4

ASSIGNED PERMEABILITY VALUES OF WATER-BEARING SEDIMENTS OF DINAJPUR AND RANGPUR

(Modified after Johnson, 1963)

Group	Description of Material	Coefficient of Permeability
1.	Gravel, gravel with coarse sand, gravel and coarse sand, coarse sand with gravel. (All gravels are fine)	550
2.	Coarse sand, medium sand, medium and coarse sand, medium sand with gravel, medium to coarse sand with gravel.	350
3.	Medium and fine sand, medium to fine sand with gravel, coarse to fine sand.	150
4.	Fine sand, fine sand with gravel, coarse sand with gravel and clay.	30
5.	Silt and fine sand, silty fine sand, medium sand with silt and clay.	10
6.	Silt, fine sand with clay and silt, sandy clay, clay with gravel, silt and clay.	3
7.	Clay (usually plastic and compact)	0.001

TABLE 5

DETERMINATION OF TRANSMISSIVITY BY LITHOLOGIC ANALYSES

Lithologic Group (Table 4)	Block-A Thickness (in ft) x Permeability (P) = T	Block-B Thickness x P = T	Block-C Thickness x P = T	Block-D Thickness x P = T	Block-E Thickness x P = T
1	23 x 550 = 12,650	26 x 550 = 14,300	50 x 550 = 27,500	13 x 550 = 7,150	13 x 550 = 7,150
2	144 x 350 = 50,400	188 x 350 = 65,800	130 x 350 = 45,500	214 x 350 = 74,900	189 x 350 = 66,100
3	55 x 150 = 8,250	8 x 150 = 1,200	40 x 150 = 6,000	20 x 150 = 3,000	22 x 150 = 3,300
4	6 x 30 = 180	6 x 30 = 180	11 x 30 = 330	0	13 x 30 = 390
5	3 x 10 = 30	1 x 10 = 10	2 x 10 = 20	0	0
6	3 x 3 = 9	1 x 3 = 3	4 x 3 = 12	0	0
7	16 x .001 = .016	20 x .001 = .02	13 x .001 = .013	3 x .001 = .003	13 x .001 = .013
Transmissivity in gpd/ft	71,519	81,493	79,362	85,050	76,940
	≈ 72,000	≈ 81,000	≈ 79,000	≈ 85,000	≈ 77,000

Average saturated thickness of the aquifer considered for calculation of transmissivity is about 250 feet and the average transmissivity estimated is 85,000 gpd/ft. The average permeability of the aquifer up to the depth considered thus comes out to be 340 gpd/ft.^{2}

TABLE 5 - Contd.

Lithologic Group (Table 4)	Block-F Thickness (in ft) x Permeability (P) = T	Block-G Thickness x P = T	Rangpur Test Wells Thickness x P = T	Average of Entire Area Thickness x P = T
1	23 x 550 = 12,650	145 x 550 = 79,750	116 x 550 = 63,800	51 x 550 = 28,050
2	193 x 350 = 67,550	76 x 350 = 26,400	66 x 350 = 23,100	150 x 350 = 52,600
3	22 x 150 = 3,300	10 x 150 = 1,500	25 x 150 = 3,750	26 x 150 = 3,900
4	3 x 30 = 90	0	6 x 30 = 180	6 x 30 = 180
5	0	0	0	1 x 10 = 10
6	0	0	7 x 3 = 21	2 x 3 = 6
7	9 x .001 = .009	19 x .001 = .019	31 x .001 = .031	14 x .001 = .014
Transmissivity in gpd/ft	83,590 ≈ 84,000	107,650 ≈ 108,000	90,851 ≈ 91,000	84,746 ≈ 85,000

AQUIFER PROPERTIES BY PUMPING TEST ANALYSES

General

The accuracy of results of a pumping test analysis depends largely on how accurate and purposeful the pumping test data are and how closely the real aquifer resembles the ideal mathematical model on which all the equations of flow to wells depend. Many equations of flow to a pumping well are available in the literature with each taking care of one factor or the other and all equations are based on ideal mathematical models. But in nature, it is rarely found that an aquifer satisfies all the conditions of an ideal mathematical model, and, moreover, sometimes data are inadequate and are not being collected in a planned way to fit them in a certain mathematical model. The selection of any given flow-system model to represent the field conditions is, therefore, a matter of judgment left to the analyst, who must be aware of the geo-hydrologic boundaries of the aquifer in order to get accurate results as far as practical.

In the study area of Rangpur and Dinajpur about 390 tubewells have so far been drilled for irrigation, but practically no systematic and purposeful pumping test was done in order to determine aquifer characteristics precisely. Except for some test wells in Rangpur, the only data available are discharge and drawdown of pumping wells. In Rangpur, an attempt had been made to install some observation wells around the pumping well to collect data, but these data are also not adequate. Moreover, the thickness of the aquifer is not yet ascertained which complicates the situation still further. In this report an attempt is made to analyze the data in several ways, trying to fit them in certain mathematical models which are nearest to the field conditions.

Theim Method of Determining Transmissivity from Pumping Wells

If we know the discharge and drawdown of the pumped well we can determine the transmissivity by Theim equation assuming steady-state was reached. Seventy-five (75) representative pumping wells have been selected in the entire study area to determine transmissivity. Johnson, Moston, and Versaw (1966, p. H-24) present Theim equation as follows:

$$T = \frac{527.7\ Q\ \log_{10} r_e/r_w}{s_1 - s_2} \qquad (1)$$

where r_e = effective radius of cone of influence at a certain period of pumping where there is no drawdown (ft).

r_w = effective radius of pumping well in ft.

s_1 = drawdown at the pumped well in ft.

s_2 = drawdown at r_e which is zero.

T = coefficient of transmissivity in gallons per day per foot.

Q = discharge of the well in gallons per minute.

According to Johnson and others (1966, p. H-24), the values of r_e may vary from 100 to 10,000 feet depending on the pumping period and the storage coefficient. The radius will be small for water table conditions and will be large for artesian conditions. Since transmissivity in equation (1) varies with the logarithm of r_e/r_w, large variations in estimated radii (r_e) results in only small differences in the computed value of the transmissivity.

Since the aquifer of Dinajpur and Bangpur relating to this study are under water table conditions, the values of r_e will be small. Now r_e in the case of Rangpur tubewells after 72 hours of pumping was found to be approximately 3000 feet (see Fig. 6). In the case of Dinajpur wells which were usually pumped for about 12 hours, a value for r_e of 1000 feet can be assumed.

The effective radius of the wells was roughly estimated to be about 10 inches $\approx$ 0.83 feet which is one inch less than the radial distance from the center of the well to the end of the gravel packing. The diameter of each well casing is 10 inches which was installed within the 22 inches diameter bore hole. The annular space was gravel packed. The principal purpose of the gravel packing is to increase the effective radius of the well by increasing permeability around the wells. The effective radius may be defined as the distance measured radially from the axis of the well to the distance just outside the well screen where the drawdown is the same. Since the drawdown in the well and drawdown at the extreme end of the gravel packing are not exactly the same, 0.83 feet effective radius was approximated. Again, since transmissivity varies with logarithm of r_e/r_w, a small variation in the estimated r_w will not effect T values appreciably.

Substituting the values of r_e and r_w in equation (1), two equations were derived: one for Dinajpur wells and the other for Rangpur wells:

$$T = \frac{527.7\ Q \log 1000/0.83}{s_w} \approx 1620 \times \frac{Q}{s_w} \tag{2}$$

for Dinajpur wells.

$$T = \frac{527.7\ Q \log 3000/0.83}{s_w} \approx 1870 \times Q/s_w \tag{3}$$

for Rangpur wells.

where Q/s_w = specific capacity of the well.

Equations (2) and (3) are used to calculate transmissivity for 66 Dinajpur wells and 9 Rangpur wells. In calculating T, adjusted specific capacity of the well was used (see Table 6).

The drawdown in a pumping well is represented by the following relationship according to Jacob (1946):

$$s_w = BQ + CQ^2$$

where s_w = drawdown in the pumping well

BQ = formation loss

CQ^2 = well loss

Q = discharge

Well loss = CQ^2

where C = well loss constant in $\sec^2/\mathrm{ft}^5$

Q = discharge in cubic ft/sec.

The value of "C" was computed from the data collected during the step drawdown pumping test of the area by the following equation: (Walton, 1962, p. 27)

$$C_1 = \frac{\Delta s_2/\Delta Q_2 - \Delta s_1/\Delta Q_1}{\Delta Q_1 + \Delta Q_2} \quad \text{- - - Step 1 and 2} \qquad (4)$$

$$C_2 = \frac{\Delta s_3/\Delta Q_3 - \Delta s_2/\Delta Q_2}{\Delta Q_2 + \Delta Q_3} \quad \text{- - - Step 2 and 3} \qquad (4a)$$

where Δs terms in feet represent increment of drawdown produced by each increase of discharge (ΔQ) in the rate of pumping in cfs.

If the properties of the gravel packing and well screen openings remain constant at various values of Q, then C_1 should equal C_2. The step drawdown tests were performed as part of the well development operation, and involved some change in the properties of the gravel pack. For the most part, however, C_1 and C_2 were nearly the same, and the values shown in Table 6 are averages of C from the two calculations.

The following paragraph is quoted from Walton (1962, p. 27):

> The above equations assume that the well is stable and that C does not change during the step drawdown test. The value of C computed for steps 1 and 2 may be greater or less than that computed for steps 2 and 3 if the well is unstable. Sand and gravel often under the influence of a high rate of pumping may result in either the development or clogging of the pores of the aquifer immediately behind the well screen. If the value of C for steps 2 and 3 is considerably less than that for steps 1 and 2, it is probable that development has occurred during the step drawdown test. A large increase in the value of C with higher pumping rate indicates clogging of the well screen or well wall. If the development during the pumping period is large $\Delta s_2/\Delta Q_2$ will be greater than $\Delta s_3/\Delta Q_3$. Thus it is possible to appraise the stability of a well with step drawdown data. Maximum yield per foot of drawdown cannot be obtained unless development is sufficient to remove fine materials which clog the screen. The value of C of a properly developed and designed well is generally less than 5 sec^2/ft^5. Values of C between 5 and 10 sec^2/ft^5 indicate mild deterioration and clogging is severe when C is greater than 10 sec^2/ft^5.

In calculating the transmissivity of the aquifer from 75 tubewells of the entire project area, the well loss of individual wells, if any, was taken into consideration (Table 6). The transmissivity values thus obtained for each well and arithmetic average of each block have been tabulated in Table 6. The arithmetic average transmissivity of the entire study area as calculated from the transmissivity values of 75 tubewells is 95,000 gpd/ft.

In order to see at a glance the variations of transmissivity and specific capacity as calculated from 75 tubewells, Table 7 and Fig. 5 were constructed from the data of Table 6. From Table 7 it appears that the transmissivity in the area varies from 4.5 to 16.2 x 10^4 gpd/ft., but 68 percent of the cases are between the transmissivity range 7 to 13 x 10^4, having the highest individual occurrence between the transmissivity range 9 to 10 x 10^4 gpd/ft.

TABLE 6

WELL LOSS CORRECTION, SPECIFIC CAPACITY AND TRANSMISSIVITY VALUES

Location (block)	Tube Well No.	Discharge (gpm)	Drawdown (s) (ft)	Specific Capacity of well (gpm/ft)	Well Loss Constant (C)	Well Loss (CQ^2) (ft)	Corrected Drawdown ($s-CQ^2$) (ft)	Adjusted Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Arithmetic Average Transmissivity of block (gpd/ft)
Dinajpur-Block-A	47	2110	35.81	58.90	0	0	35.81	58.90	95x10^3	85x10^3
	51	1375	41.50	33.15	1	9.4	32.1	42.80	69x10^3	
	53	1435	45.00	31.90	0.9	9.2	35.80	40.10	65x10^3	
	56	1410	41.00	34.40	1	11	30.00	47.00	76x10^3	
	59	1450	24.70	58.60	0.51	5.35	19.40	74.80	121x10^3	
	61	1410	38.80	36.35	0.50	2.82	37.00	38.20	62x10^3	
	62	2110	37.00	57.00	0	0	37.00	57.10	92x10^3	
.	67	1400	52.30	26.80	1	9.7	42.60	32.80	53x10^3	85x10^3
	71	1240	47.50	26.10	1.2	9.1	38.40	32.30	52x10^3	
	73	1480	46.93	31.52	0	0	46.93	31.60	51x10^3	
	79	1430	52.00	27.50	0.85	8.6	43.4	32.90	53x10^3	
	88	1960	34.8	56.30	0.8	15.2	19.6	100.0	162x10^3	
	93	1910	36.66	52.20	0.8	12.2	24.46	78.10	126x10^3	
	95	1520	19.70	77.10	0	0	19.70	77.10	125x10^3	
	98	1970	31.50	62.60	0	0	31.50	62.60	102x10^3	
	105	1370	42.00	32.63	0.4	4	38.0	36.0	58x10^3	
	110	1190	41.40	28.75	0.76	5.4	36.0	33.0	53x10^3	
	122	2380	32.11	74.10	0	0	32.11	74.10	120x10^3	

TABLE 6 - Contd.

Dinajpur Block-B	124	2000	23	87.00	0	0	23	87	$141x10^3$	
	128	1880	38.5	48.85	0.5	9	29.5	63.7	$103x10^3$	
	130	2000	36.0	55.60	0	0	36.0	55.6	$90x10^3$	
	134	1900	22.73	83.60	0	0	22.73	83.6	$135x10^3$	$93x10^3$
	155	1740	31.3	55.60	0	0	31.3	55.6	$90x10^3$	
	162	1870	42.1	44.40	0.5	8.5	33.6	55.6	$90x10^3$	
	165	1810	33.68	53.70	0	0	33.68	54.0	$87x10^3$	
	170	1740	38.60	45.10	1	7	31.6	55.1	$89x10^3$	
	171	1400	42.9	32.63	1.17	11.3	31.6	44.3	$72x10^3$	
	176	1410	28.92	48.60	0	0	28.92	48.6	$79x10^3$	$93x10^3$
	180	1115	29.52	51.90	1	8	21.52	52.0	$84x10^3$	
	193	1450	31.0	48.70	0	0	31.0	47.0	$76x10^3$	
	196	1890	39.0	48.50	0	0	39.0	48.5	$79x10^3$	
	221	1960	37.0	53.00	0	0	37.0	53.0	$86x10^3$	
Dinajpur Block-C	4	1240	47.72	26.00	1	8	39.72	31.2	$51x10^3$	
	11	1440	26.0	55.40	0.5	6	20.0	72.0	$117x10^3$	
	21	1960	22.79	86.00	0	0	22.79	86.0	$139x10^3$	
	26	1980	36.8	53.85	0	0	36.8	53.8	$87x10^3$	$87x10^3$
	27	1350	36.81	36.65	0.5	5	31.81	42.5	$69x10^3$	
	29	1390	42.9	32.35	0.65	6	36.9	37.7	$61x10^3$	
	30	1120	41.7	26.85	1.6	10.9	30.8	36.4	$59x10^3$	
	40	1230	35.45	34.70	0	0	35.45	34.7	$56x10^3$	
	46	1800	31.00	58.10	0.5	8	23.0	78.3	$127x10^3$	
	298	1890	33.0	57.30	0	0	33.0	57.3	$92x10^3$	
	318	1450	24.0	60.40	0	0	24.0	60.4	$98x10^3$	

TABLE 6 - Contd.

Dinajpur Block-D	202	2120	35.0	60.60	0	0	35.0	60.6	98x10^3	113x10^3
	205	2020	26.0	77.70	0	0	26.0	77.7	126x10^3	
	209	1890	29.78	63.50	0.23	4	26.0	72.6	117x10^3	
	216	1950	30.56	63.60	0	0	30.56	63.6	103x10^3	
	327	1890	29.8	63.40	0.25	4.4	25.4	74.4	120x10^3	
Dinajpur Block-E	225	1890	39.62	47.65	0.25	4.4	35.22	53.6	87x10^3	108x10^3
	240	1960	24.0	81.65	0	0	24.0	81.6	132x10^3	
	241	1960	30.03	64.65	0	0	30.03	64.7	105x10^3	
Dinajpur Block-F	247	1830	32.5	56.40	0.5	8	24.5	74.7	121x10^3	120x10^3
	249	1930	23.68	81.40	0	0	23.68	81.4	132x10^3	
	250	1960	30.4	64.40	0	0	30.4	64.5	104x10^3	
	255	1890	20.0	94.50	0	0	20.0	94.5	153x10^3	
	274	1980	36.7	53.90	0.7	14	24.7	80.0	129x10^3	
	289	1890	40.6	46.60	0.5	9	31.6	59.8	97x10^3	
	303	1960	23.82	82.20	0	0	23.82	82.2	133x10^3	
	311	1800	38.0	47.40	0.5	8	30.0	60.0	97x10^3	
	312	1870	26.6	70.40	0	0	26.6	70.4	114x10^3	
Dinajpur Block-G	334	1740	32.5	53.60	0.4	6	26.5	65.6	106x10^3	65x10^3
	338	845	48.0	17.60	5.2	18.2	29.8	28.4	46x10^3	
	349	900	51.23	17.55	6	25	27.23	33.0	53x10^3	
	356	810	35.0	23.15	5	16	19.0	42.6	69x10^3	
	357	752	60.5	12.43	12	33.5	27.0	27.8	45x10^3	
	373	930	50.5	18.42	7	30.0	20.5	45.3	73x10^3	

TABLE 6 - Contd.

WELL LOSS CORRECTION, SPECIFIC CAPACITY AND TRANSMISSIVITY VALUES

Location (block)	Tube Well No.	Discharge (gpm)	Drawdown (s) (ft)	Specific Capacity of Well (gpm/ft)	Well Loss Constant (C)	Well Loss (CQ^2) (ft)	Corrected Drawdown ($s-CQ^2$) (ft)	Adjusted Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Arithmetic Average Transmissivity of block (gpd/ft)
Rangpur Test Wells	1	1520	51.33	29.70	1.34	15	36.33	41.8	$78x10^3$	$85x10^3$
	2	1800	41.0	43.90	0.1	1.6	39.4	45.7	$86x10^3$	
	4	1880	53.79	34.90	1	10.79	43.0	43.7	$82x10^3$	
	5	1660	37.26	44.50	0	0	37.26	44.5	$83x10^3$	
	6	1870	36.9	50.60	0	0	36.9	50.6	$95x10^3$	
	7	1740	33.35	52.20	0	0	33.35	52.2	$98x10^3$	
	8	1740	32.47	53.60	0	0	32.47	53.6	$100x10^3$	
	9	1660	41.39	40.10	0	0	41.39	40.1	$75x10^3$	
	10	1660	53.79	30.85	1	10.79	43.0	38.6	$72x10^3$	

TABLE 7

TRANSMISSIVITY AND SPECIFIC CAPACITY RANGES AND NUMBER OF CASES (NO. OF TUBEWELLS)

Number of Cases	Transmissivity Range gpd/ft	Number of Cases	Specific Capacity Range gpd/ft of Drawdown
2	4.5 to $5\text{x}10^4$	4	12.43 to 20
10	5 to $6\text{x}10^4$	8	20 to 30
6	6 to $7\text{x}10^4$	12	30 to 40
9	7 to $8\text{x}10^4$	12	40 to 50
12	8 to $9\text{x}10^4$	20	50 to 60
13	9 to $10\text{x}10^4$	8	60 to 70
7	10 to $11\text{x}10^4$	4	70 to 80
5	11 to $12\text{x}10^4$	6	80 to 90
10	12 to $13\text{x}10^4$	1	90 to 94.50
5	13 to $14\text{x}10^4$		
1	14 to $15\text{x}10^4$		
1	15 to $16\text{x}10^4$		
1	16 to $16.2\text{x}10^4$		

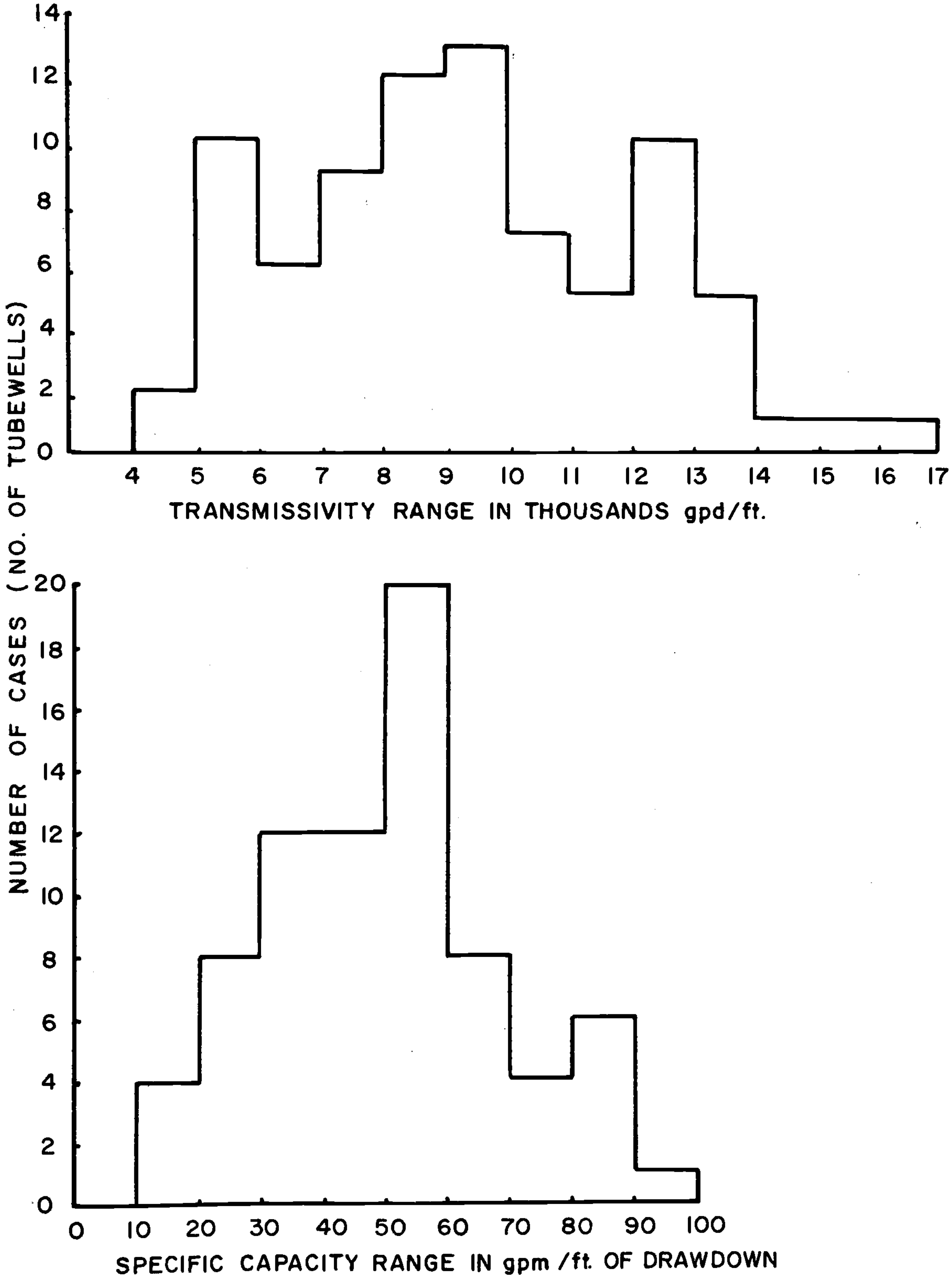


FIG. 5 BAR GRAPH SHOWING THE TRANSMISSIVITY AND SPECIFIC CAPACITY RANGE

The Theim method of determining the transmissivity of a water-bearing material may also be applied to the analysis of the decline in water level during the pumping period in two or more observation wells near a pumping well. The method is based on the assumption that approximate steady state flow is established close to the well where the observation wells are located. The Theim formula may be written (Ferris and others, 1962, p. 91) as follows:

$$T = \frac{527.7Q \log_{10} (r_2/r_1)}{s_1 - s_2} \qquad (5)$$

where r_1 and r_2 = distances from the pumped well to the first and second observation wells in feet

s = observed drawdown of water level in the observation well in feet.

Other terms as defined earlier.

In the above equation, Δs is that value of s_1 and s_2 for which the value of $\log_{10} (r_2/r_1)$ is unity; i.e., Δs corresponds to one log cycle of r_2/r_1. The equation then becomes:

$$T = \frac{527.7Q}{\Delta s} \qquad (6)$$

The apparent coefficient of storage can be determined from the distance drawdown plot by the following equation (Babcock and Visher, 1951, p. 15):

$$S = \frac{0.3\ Tt}{r_e^2} \qquad (7)$$

where S = apparent coefficient of storage

t = time since pump started in days

r_e = maximum extent of cone of depression at time t where drawdown is zero

T = transmissivity

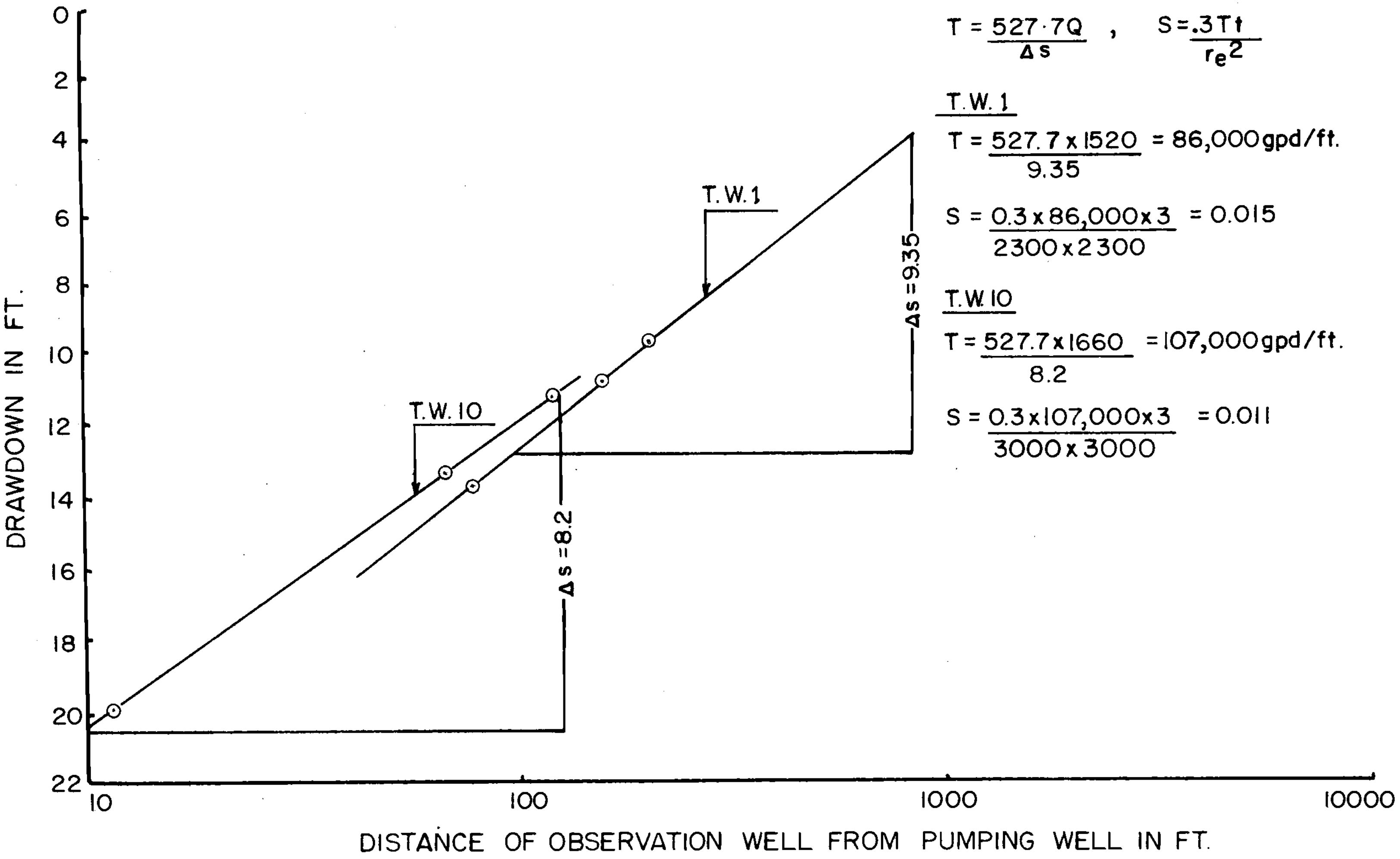
In order to determine the transmissivity and storage coefficient in the study area by the above-mentioned equations, data for Rangpur test well Nos. 1 and 10 were analyzed (Fig. 2). Tests were run continuously for three days for each of the wells. For each well there were three observation wells located 82, 164 and 213 feet from the test well No. 1, and 11.5, 70.5 and 131 feet from the test well No. 10. The discharges of the test wells, drawdown at equilibrium and distances of the respective observation wells measured during the pumping test are given in Table 8. The values of drawdown were plotted on the arithmetic scale and distances on the logarithmic scale of semi-log paper. Then Δs value was determined by inspection of the semi-log graph plot for one log cycle. The corresponding Δs and Q values are then substituted in equation (6) to solve for T (see Fig. 6). By this method, average transmissivity was calculated to be 96,000 gpd/ft.

In order to calculate S, in the semi-log graph (Fig. 6), r_e is found by inspection which is 2300 and 3000 feet for test well Nos. 1 and 10, respectively. These are the values of r (distance) for which drawdown equals zero. Then by substituting the values of T, t and r_e in equation (7), S was determined (see Fig. 6). The average calculated value of S (storage coefficient) is 0.013, which does not represent the S value of an unconfined aquifer. The reason is that pump test was short during which period the drainage was not complete and as a result the computed storage coefficient is low. Usually it is very difficult to get the desired S value because of slow drainage problem in unconfined aquifer. It takes a long time, even months, depending on the type of material for the drainage to be complete. However, the problem of delayed drainage could be treated at the present time by type curve method if requisite data were available. Unfortunately, in the study area, there are no such data so as to analyze by type curve method.

TABLE 8

DATA SHEET FOR DISTANCE AND DRAWDOWN OF OBSERVATION WELLS AND T AND S VALUES

Location and Tubewell No.	Discharge (gpm)	Observation Well No.	Drawdown (ft)	Distance of Observation Well from Pumping Well (ft)	Transmis-sivity (gpd/ft)	Coefficient of storage
Rangpur Test Well No. 1	1520	P-1	13.80	82	86,000	0.015
		P-6	10.80	164		
		P-3	9.67	213		
Rangpur Test Well No. 10	1660	P-1	19.87	11.5	107,000	0.011
		P-2	13.49	70.5		
		P-4	11.22	131		



$$T = \frac{527 \cdot 7Q}{\Delta s} \quad , \quad S = \frac{.3Tt}{r_e^2}$$

T.W. 1

$$T = \frac{527.7 \times 1520}{9.35} = 86{,}000 \text{ gpd/ft.}$$

$$S = \frac{0.3 \times 86{,}000 \times 3}{2300 \times 2300} = 0.015$$

T.W. 10

$$T = \frac{527.7 \times 1660}{8.2} = 107{,}000 \text{ gpd/ft.}$$

$$S = \frac{0.3 \times 107{,}000 \times 3}{3000 \times 3000} = 0.011$$

FIG. 6 SEMI-LOG GRAPH FOR PUMPING TEST OF WELLS 1 AND 10 (RANGPUR) SHOWING DRAWDOWNS IN THE WELLS PLOTTED AGAINST THE DISTANCE OF THE OBSERVATION WELLS

Residual Drawdown and Recovery Methods

In order to determine transmissivity, the time-residual drawdown measurements of tubewells 105-A, 196-B and 250-F of Dinajpur (Fig. 2) were analyzed. Each tubewell was pumped continuously for 690 minutes and then the time-residual drawdown data were collected for 30 minutes after the pump was stopped. The discharge of the well was not constant throughout all 690 minutes of pumping but pumping was done at a constant rate for about 3/4 of the total pumping time at the later part of the test. This discharge was used in the determination of T.

The residual drawdown at any time during the recovery period is the difference between the observed water level and the water level extrapolated from the observed trend prior to the end of the pumping period (Ferris and others, 1962, pp. 100-101). Since the recovery measurements were made for only 30 minutes in each well and the drawdown at the end of pumping period reached almost steady state, no extrapolation of drawdown appears to be necessary. The relevant data used in the analysis are tabulated in Table 9.

The Theis recovery formula for determining T is applied in much the same manner as the modified non-equilibrium formula: (Ferris and others, 1962, p. 101)

$$T = \frac{264Q}{s} \log_{10} t/t' \qquad (8)$$

where t = time since pump started

t' = time since pump stopped

s' = residual drawdown.

The most suitable procedure is to plot the residual drawdown s' on the arithmetic scale and t/t' on logarithmic scale (Fig. 7). For convenience, the value of $\Delta s'$ (change in residual drawdown) is determined for the value where $\log_{10} t/t'$ is unity and the equation (8) thus reduces to:

$$T = \frac{264Q}{\Delta s'} \qquad (9)$$

Transmissivity values calculated with equation (9) are 77,000; 88,000; and 99,000 gpd/ft, respectively, from wells 105-A, 196-B and 250-F. The average is 85,000 gpd/ft.

A simpler, but less accurate method, for the determination of T from time-recovery data is by the following equation: (Edward E. Johnson, Inc., 1966, p. 139):

$$T = \frac{264Q}{\Delta s} \qquad (10)$$

where Δs = change in water level recovery per logarithmic cycle of time since pumping stopped.

T and Q are as defined earlier.

The time recovery data from Table 9 for wells 105-A, 196-B and 250-F were plotted on semi-logarithmic paper (Fig. 8)

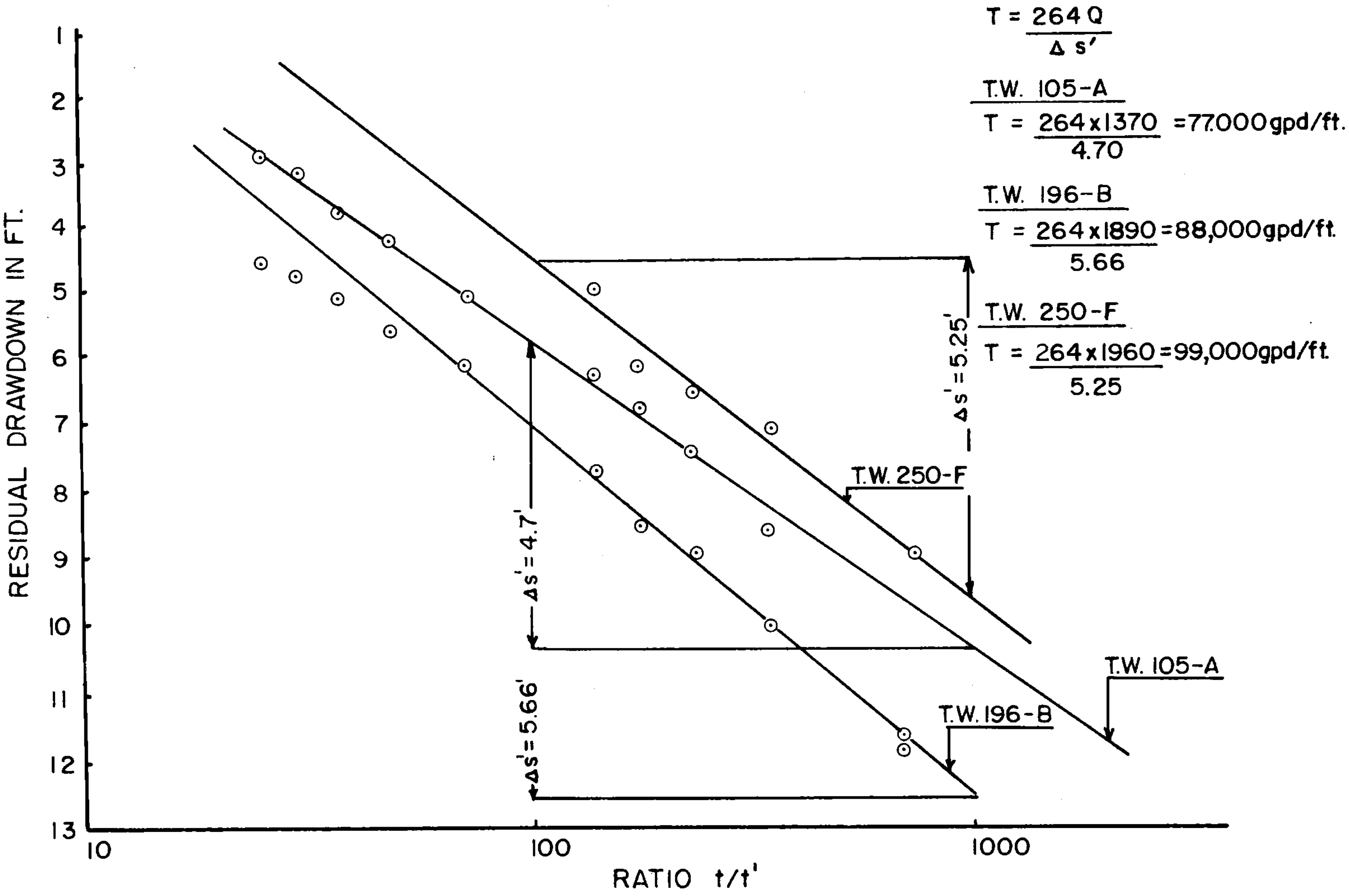
TABLE 9

DATA SHEET OF TIME - RESIDUAL DRAWDOWN AND RECOVERY

Location and Tubewell No.	Discharge (gpm)	Time (t) since pump test started (min)	Time (t′) since pump stopped (min)	Ratio t/t′	Drawdown of the well when the pump is stopped (ft)	Residual drawdown (ft)	Recovery (ft)
Dinajpur T.W. 105-A	1370	690	0	-	44.70	44.70	0
		691	1	691	44.70	11.71	32.99
		692	2	346	44.70	8.62	36.08
		693	3	231	44.70	7.41	37.29
		694	4	174	44.70	6.72	37.98
		695	5	139	44.70	6.20	38.50
		700	10	70	44.70	5.03	39.67
		705	15	47	44.70	4.16	40.54
		710	20	36	44.70	3.70	41.00
		715	25	29	44.70	3.18	41.52
		720	30	24	44.70	2.85	41.85
Dinajpur T.W. 196-B	1890	690	0	-	40.40	40.40	0
		691	1	691	40.40	11.92	28.48
		692	2	346	40.40	10.05	30.35

TABLE 9 - Contd

Dinajpur T.W. 196-B (Contd)		693	3	231	40.40	9.0	31.40
		694	4	174	40.40	8.53	31.87
		695	5	139	40.40	7.78	32.62
		700	10	70	40.40	6.12	34.28
		705	15	47	40.40	5.55	34.85
		710	20	36	40.40	5.06	35.34
	1890	715	25	29	40.40	4.74	35.66
		720	30	24	40.40	4.50	35.90
Dinajpur T.W. 250-F	1960	690	0	-	24.50	24.50	0
		691	1	691	24.50	8.86	15.64
		692	2	346	24.50	7.13	17.37
		693	3	231	24.50	6.52	17.98
		694	4	174	24.50	6.12	18.38
		695	5	139	24.50	4.98	19.52
		700	10	70	24.50	1.64	22.86
		705	15	47	24.50	1.28	23.22
		710	20	36	24.50	0.93	23.57
		715	25	29	24.50	0.76	23.74
		720	30	24	24.50	0.70	23.80



$$T = \frac{264\,Q}{\Delta s'}$$

T.W. 105-A

$$T = \frac{264 \times 1370}{4.70} = 77000 \text{ gpd/ft.}$$

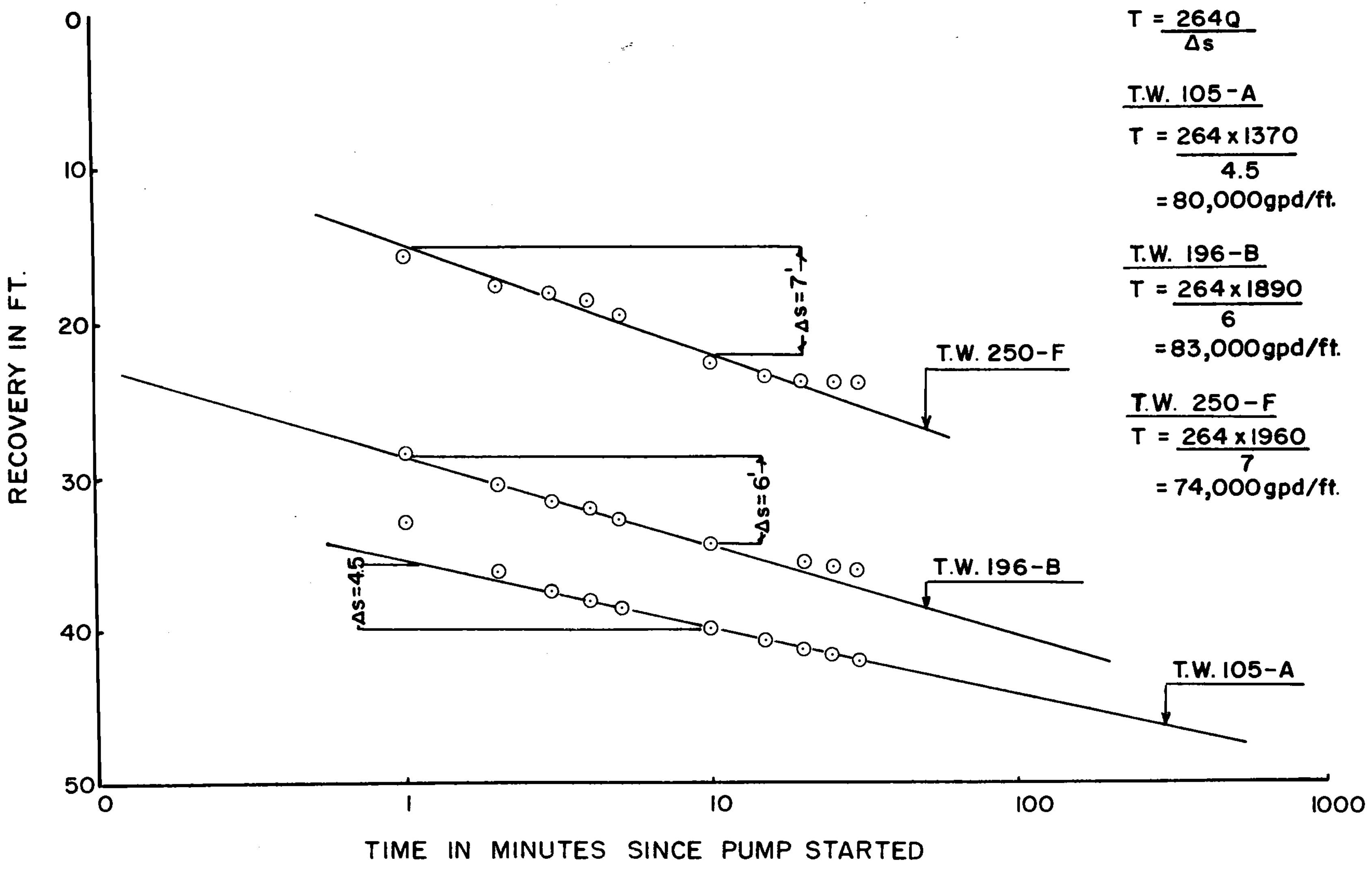
T.W. 196-B

$$T = \frac{264 \times 1890}{5.66} = 88{,}000 \text{ gpd/ft.}$$

T.W. 250-F

$$T = \frac{264 \times 1960}{5.25} = 99{,}000 \text{ gpd/ft.}$$

FIG. 7 RESIDUAL DRAWDOWN PLOTTED AGAINST THE RATIO t/t'



$$T = \frac{264Q}{\Delta s}$$

T.W. 105-A

$$T = \frac{264 \times 1370}{4.5} = 80{,}000 \text{gpd/ft.}$$

T.W. 196-B

$$T = \frac{264 \times 1890}{6} = 83{,}000 \text{gpd/ft.}$$

T.W. 250-F

$$T = \frac{264 \times 1960}{7} = 74{,}000 \text{gpd/ft.}$$

FIG. 8 TIME — RECOVERY CURVE PLOTTED ON SEMI-LOG PAPER and the transmissivity determined by applying equation (10). The transmissivity values are 80,000; 83,000; and 74,000 gpd/ft obtained, respectively, from wells 105-A, 196-B and 250-F having the average 80,000 gpd/ft.

GROUND WATER FLUCTUATIONS

Ground water fluctuations, configuration of ground-water contour maps, direction and rate of ground water movement divulge valuable information concerning the source, availability of recharge and areas of discharge, prediction of general geologic characteristics and permeability and areas of detrimentally high or low ground water levels, etc. The hydraulic gradient under which the water moves may be used with other data to obtain a relative measure of the transmissivity of the aquifer. The stage of the water table indicates the quantity of water in storage in the ground water reservoir in much the same manner as the water level in a surface reservoir indicates the amount of water in storage in the reservoir. Thus the changes in the ground water level indicate changes in storage in the ground water reservoir. Fluctuations of the water level show the net recharge to and discharge from the ground water reservoir for a given period. The recharge is usually contributed by rainfall, irrigation seepage, streams and other surface water bodies and subsurface inflow. The discharge is due to the withdrawal of water by pumping, to natural outflow and to evapotranspiration.

The rise of water level in the Rangpur and Dinajpur north area is largely due to infiltration of the rainwater into the water table. This fact is demonstrated by Fig. 9 on which water table fluctuations and weekly rainfall histograms of three representative stations of the study area are shown. The water table fluctuation curves indicate that the rise of water table is mainly due to rainfall and the amount of rise is approximately proportional to the amount of rainfall in the area. According to International Engineering Company (1964), factors such as porosity and permeability, vegetable cover and the type of rainfall are favorable to recharge in the area. Measurements in the wells show that the water table is always above the river levels except at very high river stages. Most streams in East Pakistan and particularly those which traverse areas with pervious sandy soil gain in a downstream direction, though there is no direct surface runoff. These increases must be due to the seepage of ground water from the aquifer to the streams. This fact is evidenced by actual measurements of the discharges in the upstream and downstream positions. Since almost all the streams in the area appear to be mostly fed by ground water, lowering of the water table due to overpumping may result in a decrease in the discharge of the streams.

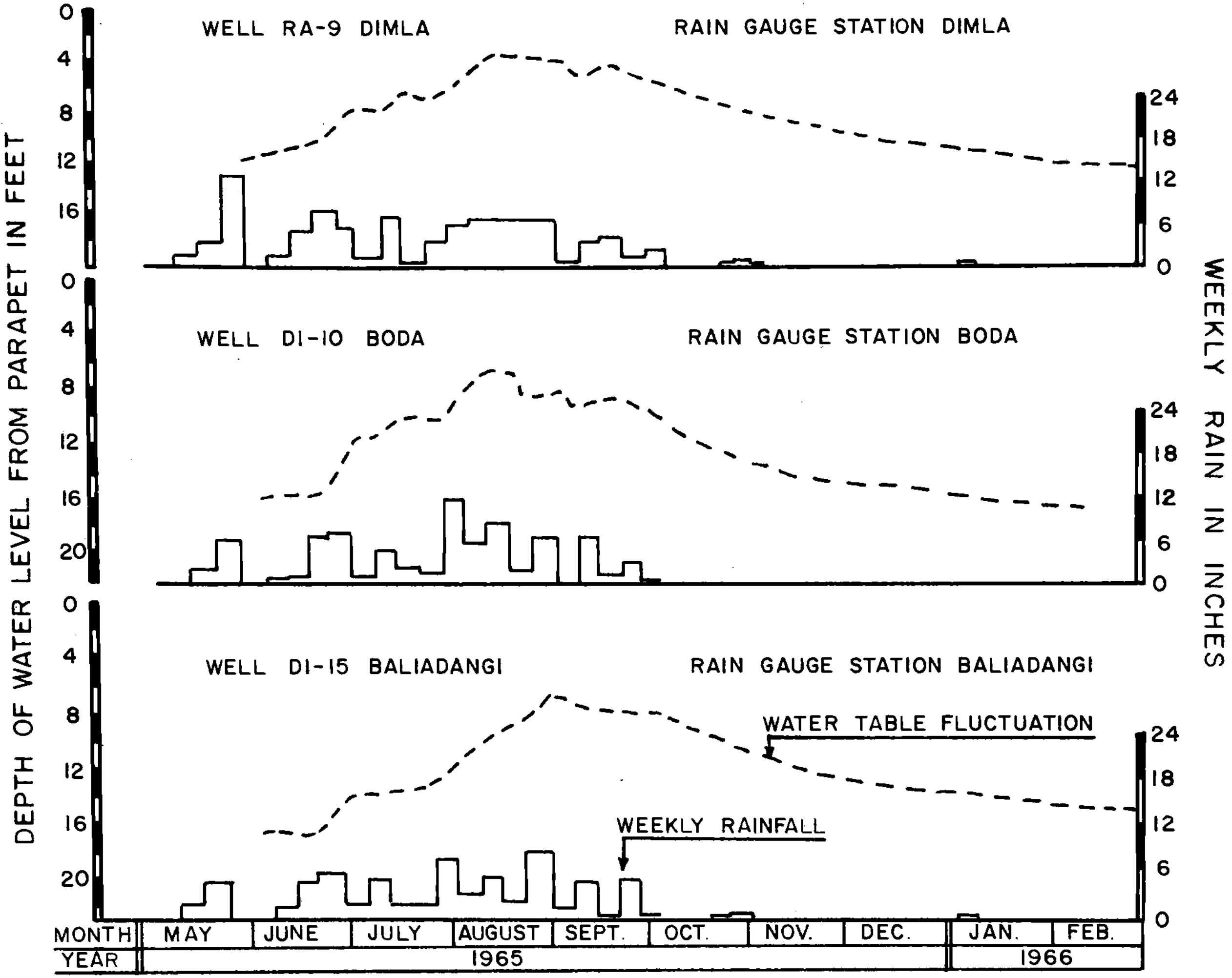


FIG. 9 WATER TABLE FLUCTUATIONS OF WELLS AND WEEKLY RAINFALL IN THE SAME AREA

Since the water table contour maps (Figs. 10 and 10a) are generalized and based on inadequate control points, all the interpretations are tentative. The contour maps and physiographic setting of the area suggest that considerable amount of recharge probably is contributed to the alluvium through movement of ground water from the upper high regions of the north including Himalayan foothill terrain. At the same time, a considerable amount of water from the aquifer is lost as natural drainage at the south and southeast ends of the project area and by evapotranspiration.

In order to get an idea of the disposition of the water from the ground water storage in the region, the following approximate quantitative analysis was made for an area of 1 mile width extending 8 miles from the east bank of the Tangon river to the ground water divide towards the east of Thakurgaon. The approximate period during which the change in storage takes place in the area is 200 days, considering no rainfall during this period.

$$\begin{aligned}&\text{change in ground water storage } (\Delta S)\\ &= \text{effluent seepage from aquifer to stream}\\ &+ \text{evapotranspiration}\end{aligned} \qquad (11)$$

Since the flow system in the area is more or less uniform, the underflow in is approximately equal to underflow out; therefore, the net underflow can be considered zero. The change in storage is due to effluent seepage and evapotranspiration.

Computation of change in storage for an average 10 feet change in elevation of the water table having the storage coefficient of 0.20 for the area:

$$\Delta S = (5280)^2 \times 8 \times 0.20 \times 10$$
$$= 44.7 \times 10^7 \text{ ft}^3$$

Determination of effluent seepage from the aquifer to stream:

According to Karim (1968), during the dry season the average subsurface seepage to the stream from the aquifer per mile length of the Tangon river near Thakurgaon is about 4 cfs or 2 cfs for the eastern half of the stream.

$$\text{effluent seepage} = 2 \times 86{,}400 \times 200$$
$$= 3.456 \times 10^7 \text{ ft}^3$$

Now substituting these values in equation (11) we can determine the evapotranspiration:

$$44.7 \times 10^7 = 3.456 \times 10^7 + \text{evapotranspiration}$$

$$\therefore \text{total volume of evapotranspiration} = 44.7 \times 10^7 - 3.456 \times 10^7 = 41.244 \times 10^7 \text{ ft}^3$$

Since the area considered in the calculation is 22.3×10^7 sq. feet, the average depth of evapotranspiration = 1.85 feet. It is recognized that this computation is based on other quantities whose precise values are still unknown. However, even this computation shows that on a relative basis, the quantity of water that is seasonally added to or removed from storage is far greater (by about a factor of 50) than the amount of underflow that passes across any section in the same seasonal interval. Also, these figures indicate that the amount of water discharged to streams per mile length of stream is about three times greater than the amount of underflow. Hence, the gradient toward the streams should be greater than the average gradient southward. This is not shown on the contour maps (Figs. 10 and 10a) because insufficient water level data are available near the streams. However, the general evenness of the contours indicates that the aquifer is relatively homogeneous.

The seasonal change in water table is from about a few inches to about 15 feet below land surface as indicated by Table 10 which gives the seasonal extremes in many wells for 1965.

TABLE 10

WATER TABLE RECORDS IN DINAJPUR AND RANGPUR NORTH, 1965

Observation Well No.	Approximate elevation above mean sea level of land surface at well from topographic map (ft)	Depth of water below land surface at maximum level in summer (ft)	Depth of water below land surface at minimum level in winter (ft)	Elevation of water table at maximum level (ft)	Elevation of water table at minimum level (ft)
Rangpur District					
3	197	2.1	10.5	194.9	186.5
4	202	1.5	5.5	200.5	196.5
5	190	3.5	10.7	186.5	179.3
6	189	3.2	8.5	185.8	180.5
8	189	1.8	7.9	187.2	180.1
9	176	1.0	8.5	175.0	167.5
13	180	5.8	12.3	174.2	167.7
14	170	1.3	7.2	168.7	160.8
15	159	5.1	10.2	153.9	148.8
Nilphamari	148	2.50	11.0	145.5	137.0

TABLE 10 - Contd.

Dinajpur District					
7	212	0.6	9.1	211.4	202.9
8	225	1.0	9.9	224.0	215.1
9	196	1.5	11.7	194.5	184.3
10	214	3.2	13.2	210.8	200.8
11	206	4.6	13.8	201.4	192.2
12	207	1.7	12.2	205.3	194.8
13	179	1.6	13.7	177.4	165.3
14	187	5.0	15.5	182.0	171.5
15	172	4.3	15.1	167.7	156.9
16	160	1.0	9.1	159.0	150.9
17	181	4.0	13.8	177.0	167.2
18	170	7.9	17.5	162.1	152.5
19	189	2.8	12.0	186.2	177.0
20	183	0.4	4.5	182.6	178.5
21	180	-	11.3	-	168.7
30	194	-	13.7	-	180.3
32	185	-	15.4	-	169.6
33	205	-	11.8	-	193.2
Khansama	155	3.10	14.35	151.9	140.65
Birganj	145	4.57	14.82	140.43	130.18

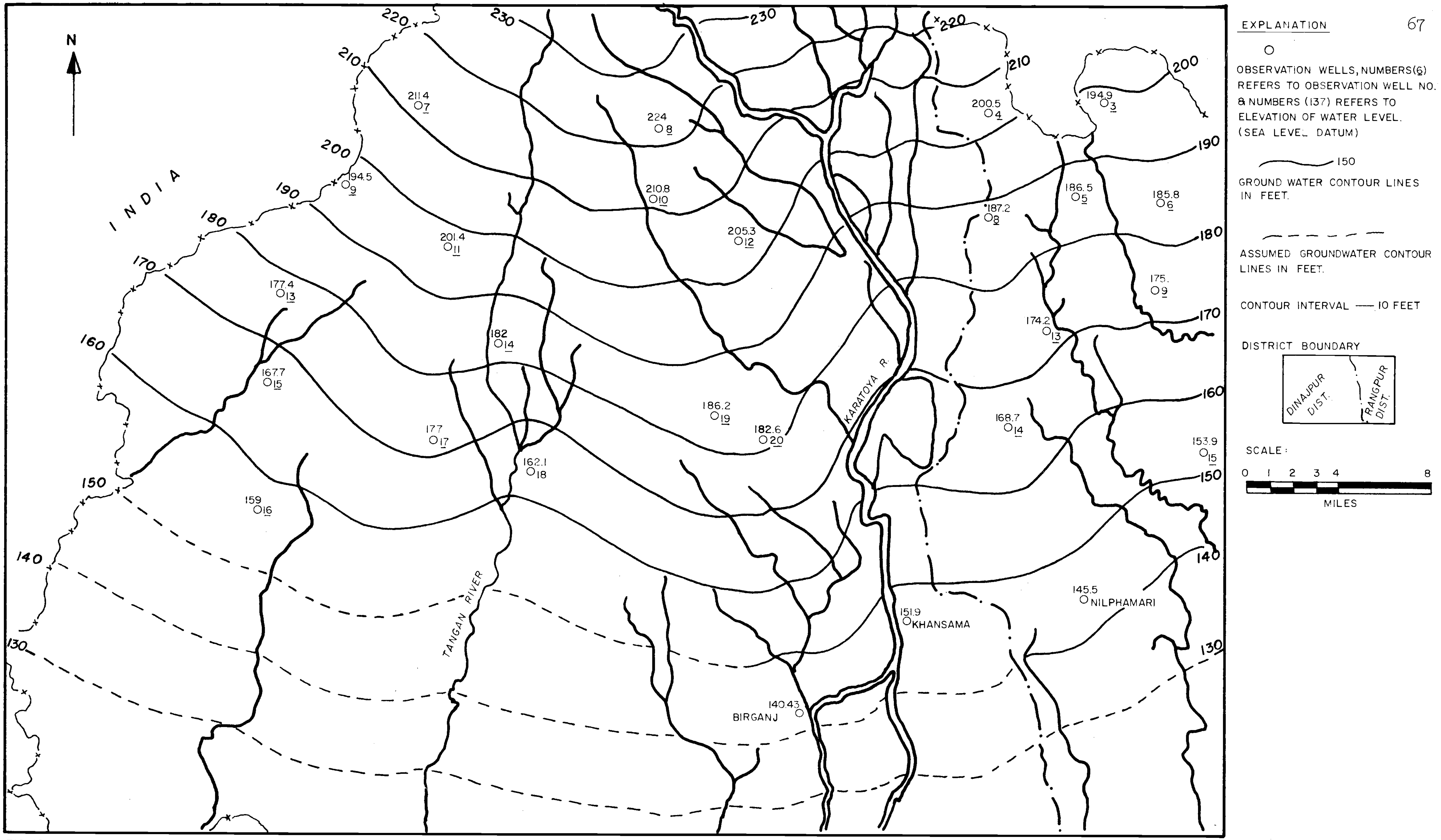


FIG. 10 GROUNDWATER CONTOUR MAP, MAXIMUM LEVEL (1965) OF THE NORTHERN PART OF RANGPUR AND DINAJPUR DISTRICTS

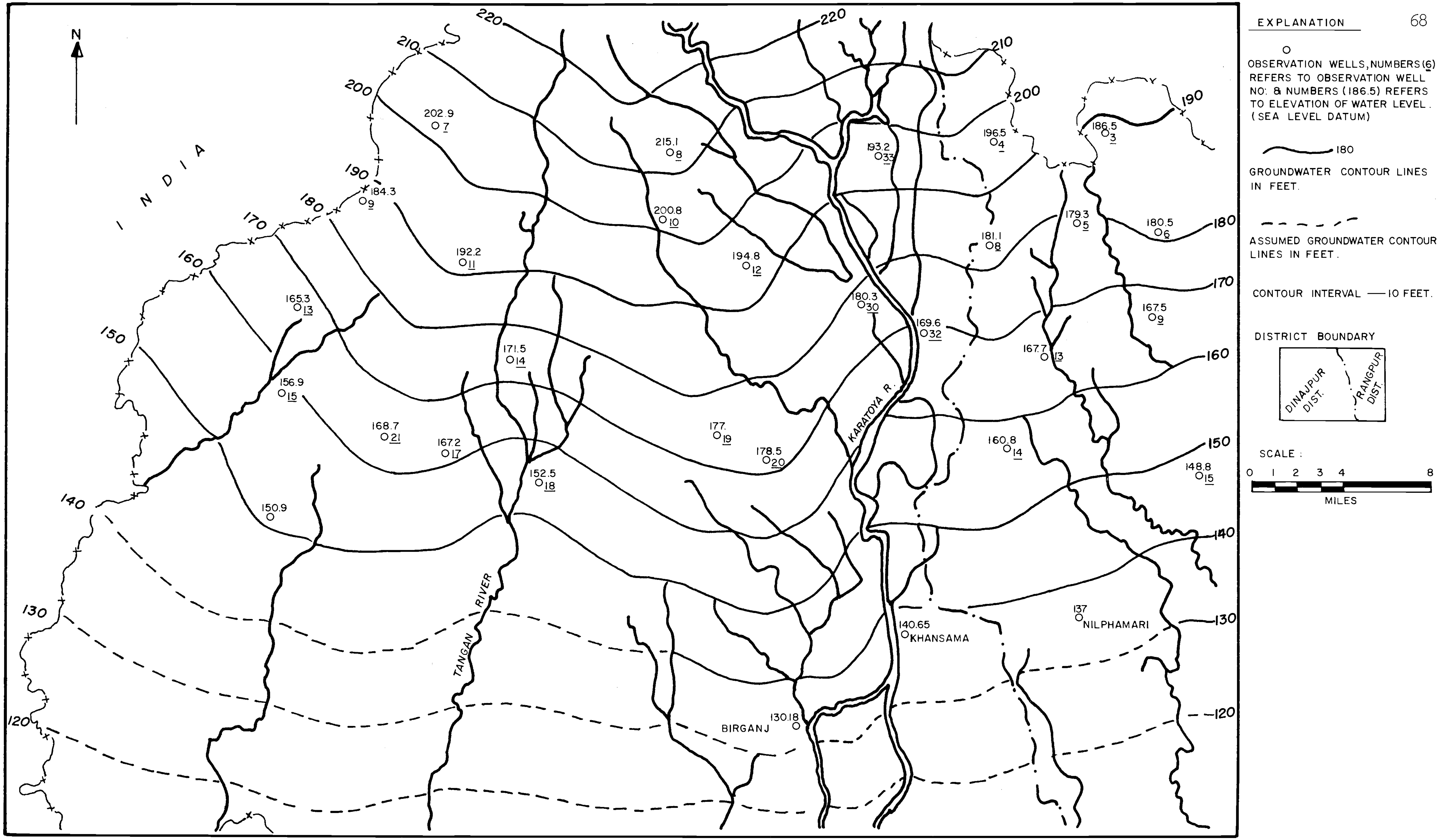


FIG. 10a GROUNDWATER CONTOUR MAP, MINIMUM LEVEL (1965), OF THE NORTHERN PART OF RANGPUR AND DINAJPUR DISTRICTS

SUMMARY OF RESULTS AND CONCLUSIONS

The transmissivity obtained by lithologic analysis ranges from 7.2 to 10.8 x 10^4 gpd/ft. These results must be regarded as approximate or semi-quantitative because the logs on which they are based are essentially qualitative, being field descriptions supported by only a few mechanical analyses. Also the assigned permeability values were based on averages modified to better apply to local conditions as judged by the writer.

The transmissivity estimated by analyzing discharge-drawdown data of 75 pumping wells by applying the Theim method ranges from 4.5 to 16.2 x 10^4 gpd/ft. Sixty-eight percent of the cases are between the transmissivity of 7 to 13 x 10^4 gpd/ft. Since transmissivity calculated by this method is directly proportional to the specific capacity, any variation of specific capacity due to extraneous factors will cause an error in the calculation of transmissivity. These factors may be due to differences in (1) depth of installation of tubewells, (2) local hydrogeologic boundaries, and (3) the construction and development of wells such as open area, positions of well screen, and variations in gravel packing.

Subsurface geologic information indicates that the water-bearing zone is generally uniform in gross lithologic character over the entire area. This is suggested in the uniform nature of the water table surface. Therefore, it is expected that the transmissivity of the aquifer should not vary much from one place to another. Abnormally high and low values are considered to be due to one or more of the above factors and are, therefore, not representative of that area.

The Theim steady state (using observation wells), residual drawdown and recovery methods, give average values of 9.6×10^4, 8.5×10^4 and 8×10^4 gpd/ft, respectively.

Though each method has inherent weaknesses, all methods give approximately the same results, that is, transmissivity values vary within the range of 7 to 13×10^4 gpd/ft with an average of 10×10^4 gpd/ft. Hence we may believe that this approximation is reasonably close to true transmissivity for the upper saturated 250 feet of the aquifer. Because of the short duration of the pump tests and the influence of silt and clay lenses at depth, flow beneath 250 feet was neglected.

The true transmissivity for the total thickness of the aquifer will be more than the above estimated value and will depend on the total thickness and the average permeability of the aquifer at depth. Since the aquifer is very thick it is not economically feasible to install fully penetrating wells. However, the true transmissivity can be determined from partially penetrating wells by running pumping tests for longer periods. By such pumping tests, true storage coefficient can also be determined.

The storage coefficient values computed from pumping test and lithologic analyses are 0.013 and 0.20, respectively. The low value obtained from the pumping test analysis is due to slow drainage in the aquifer during the short pumping period. In the United States of America, the storage coefficient values of similar types of material as in the study area normally vary from 0.18 to 0.22. Hence an effective storage coefficient of 0.20 (specific yield 20 percent), calculated from detailed lithologic analysis, is reasonable for the type of aquifer and aquifer material in the entire study area when long term pumping is considered.

It may be concluded, therefore, that in the present study, an attempt has been made to utilize the limited and often inadequate data in the best manner possible in order to interpret the hydrogeologic framework of the area. This sort of study is the first of its kind in the area and certainly should help future studies, not only in the Rangpur and Dinajpur area, but in all of East Pakistan.

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FIG. 3 GEOLOGIC SECTIONS ALONG LINES AB AND CD

(SEE INDEX MAP – FIG. 2)

SCALE :

HORIZONTAL : 1" = 2 MILES
VERTICAL : 1" = 25 FEET

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