EVALUATION OF AQUIFER CHARACTERISTICS OF DHAKA CITY USING PUMPED WELL DATA

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Submitted by

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In partial fulfilment of the requirements for the degree of
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CERTIFICATE

This is to certify that this project work has been done by me and neither this project nor any part thereof has been submitted elsewhere for the award of any degree or diploma.

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We hereby recommend that the project work prepared by Mohammed Iqbal Hossain entitled "EVALUATION OF AQUIFER CHARACTERISTICS OF DHAKA CITY USING PUMPED WELL DATA" be accepted as fulfilling this part of the requirements for the degree of Master of Engineering (Water Resources).

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ABSTRACT

Dhaka WASA has divided the whole city into six zones to administer its operations of potable water supply and safe sewerage disposal. The construction and the development test data of 44 selected tubewells from these six zones have been analyzed to evaluate its aquifer and well specific properties. Parameters, such as, transmissivity and storativity are evaluated to characterize the aquifer properties while well efficiency and skin factor are evaluated to demonstrate its well specific parameters. Another important parameter called specific capacity is also determined to represent the productivity of both the aquifer and the well itself.

The development tests on the deep tubewells of DWASA are performed without installing piezometers. Thus, the pumping tests conducted by DWASA can be treated as a single well test. Determination of transmissivity and storativity are therefore constrained with the utilization of the well-known methods based on piezometric readings. To utilize these single well tests under the confined and/or leaky aquifer system, there are 5 suitable methods selected from literature to overcome the lack of piezometer readings. The selected 5 methods are Jacob's straight line method, Theis's recovery method, Papadopulos-Cooper's method (curve fitting), Hurr-Worthington's method and the Logan approximate method. Among these 5 methods, Jacob straight line method gives consistently higher transmissivity values than the other 4 methods. Jacob method is very sensitive to the non-linear well losses which have been found in appreciable magnitude for the most of the wells tested in Dhaka city. Papadopulos-Cooper method is valid for fully penetrated confined aquifer, mostly not the case existing for the configuration and aquifer system analysed here. Hurr-Worthington and recovery methods have been judged the most suitable methods for the aquifer system in Dhaka city. Out of these two, Hurr-Worthington method is selected to draw the iso-transmissivity lines to represent its variations instantaneously in Dhaka city. It is seen from the map (Fig. 5.1) that the south-western part and north-eastern corner of Dhaka city have higher transmissivity (700-1000 m^2/d) values than the rest of the city. The majority of the city area representing transmissivity values ranging from 400 to 500 m^2/d. The Hurr-Worthington method evaluates the transmissivity by using the corrections due to well losses

on its observed drawdowns. While the aquifer loss is dependent on the aquifer characteristics only, the well loss arises from the combined effect of screen entrance loss and frictional loss inside the pumped wells. The aquifer losses in Dhaka city are found to vary from 8.2 m to 20.9 m and the total well losses from 2.1 m to 14.7 m. As the well losses are found appreciable in Dhaka city compared to its overall drawdowns, it dictate the use of an appropriate method which takes care of these losses in its transmissivity determination. In this respect, Hurr-Worthington method may be a better option to be used for Dhaka city aquifer system. The Logan method, known as an approximation method uses the specific drawdown data for transmissivity determination is liable to produce some error under vertical leakage and transient aquifer responses.

For the selected single well methods, the storativity values can only be provided by the Papadopulos-Cooper method and its values vary from $1.5x10^{-6}$ to $9.5x10^{-5}$. It is seen from the iso-storativity map (Fig. 5.2) that the south-western part of Dhaka city have the highest storativity values than the rest of the city. The majority of the city area representing storativity values of about $2x10^{-5}$. Both the specific capacity and the well efficiency are important to measure the performance of a well. In Dhaka city,. the specific capacity of the wells varies from 219 m^2/day to 550 m^2/day and well efficiency varies from 45 to 86 percent. Low efficiency as low as 70 percent is the indication of inadequate and poor well development: Again, skin effect is to account for the head losses in the vicinity of a well. Skin factor in Dhaka city is found to vary 0.32 to 8.06.

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TABLE OF CONTENTS

			Page
Abstract			i
Acknowledgement			iii
Table of Contents			iv
List of Tables			vii
List of Figures			viii
Abbreviation			ix
Notation			x
CHAPTER	1	INTRODUCTION	
	1.1	General	1
	1.2	Objectives of the Study	3
CHAPTER	2	LITERATURE REVIEW	
	2.1	Physical Properties and Principles	4
	2.1.1	Physical Properties of Water Bearing Formation	4
	2.1.2	Groundwater Movement/Darcy's Law	7
	2.2	Previous Study	7
CHAPTER	3	STUDY AREA	
	3.1	Physical Setup of Dhaka City	12
	3.1.1	Geology of the Dhaka City	12
	3.1.2	Relief and Topography	13
	3.1.3	Land Form	13
	3.1.4	Drainage System	14
	3.2	Recharge and Discharge	14
	3.3	Climate	18
	3.4	Subsurface Geology and Aquifer System	18
	3.5	Groundwater Hydrograph	19
	3.6	Features of the DWASA Wells	20

Page

	3.6.1	Well Design	21
	3.6.2	Construction of Deep Tubewells	23
CHAPTER	4	METHODOLOGY	
	4.1	Introduction	25
	4.2	Collection of Data	25
	4.3	Selection of Tubewells	26
	4.4	Single Well Pumping Test	27
	4.4.1	Jacob Straight Line Method	27
	4.4.2	Theis Recovery Method	34
	4.4.3	Papadopulos-Cooper Method	37
	4.4.4	Hurr-Worthington Method	39
	4.5	Logan Approximation Method	42
	4.6	Well Performance Test	43
	4.6.1	Step Drawdown Test	44
	4.6.2	Hantush-Bierschenk Method	45
	4.7	Determination of Different Types of Losses	47
	4.8	Specific Capacity of the Well	47
	4.9	Well Efficiency	48
	4.10	Determination of Skin Factor	48
CHAPTER	5	RESULTS AND DISCUSSION	
	5.1	Transmissivity	50
	5.2	Storativity	58
	5.3	Different Types of Losses	60
	5.4	Specific Capacity and Well Efficiency	61
	5.5	Skin Factor	61
	5.6	Limitations of the Study	66

Page

CHAPTER	6	CONCLUSIONS AND RECOMMENDATIONS	
	6.1	Conclusions	69
	6.2	Recommendations	70
REFERENCES			71
APPENDIX-A		Sample Calculations	74
APPENDIX-B		Time-Drawdown Curves for Jacob Method	78
APPENDIX-C		Time-Drawdown Curves for Papadopulos-Cooper Method	84
APPENDIX-D		Time-Drawdown Curves for Theis Recovery Method	90
APPENDIX-E		Tables for Determining Transmissivities by Hurr-Worthington Method	96
APPENDIX-F		Specific Drawdown- Discharge Curves for Hantush-Bierschenk Method	103
APPENDIX-G		Pumping Test and Recovery Test Data	108

LIST OF TABLES

Table	Description	Page
Table 3.1	Gravel Size Used in DWASA Wells as Pack Material	22
Table 4.1	Selected Number of Well in DWASA MODS Zone	26
Table 5.1	Transmissivity and Storativity Values for Zone 1	51
Table 5.2	Transmissivity and Storativity Values for Zone 2	51
Table 5.3	Transmissivity and Storativity Values for Zone 3	51
Table 5.4	Transmissivity and Storativity Values for Zone 4	52
Table 5.5	Transmissivity and Storativity Values for Zone 5	52
Table 5.6	Transmissivity and Storativity Values for Zone 6	52
Table 5.7	Range of Transmissivity Values for Zone 1 by the Selected 4 Methods	54
Table 5.8	Range of Transmissivity Values for Zone 2 by the Selected 4 Methods	54
Table 5.9	Range of Transmissivity Values for Zone 3 by the Selected 4 Methods	54
Table 5.10	Range of Transmissivity Values for Zone 4 by the Selected 4 Methods	55
Table 5.11	Range of Transmissivity Values for Zone 5 by the Selected 4 Methods	55
Table 5.12	Range of Transmissivity Values for Zone 6 by the Selected 4 Methods	55
Table 5.13	Comparison of Transmissivity Values with the Previous Studies	57
Table 5.14	Comparison of Storativity Values with the Previous Studies	58
Table 5.15	Different Types of Losses (Zone 1) at an Operating Discharge 7348 m^3/d	62
Table 5.16	Different Types of Losses (Zone 2) at an Operating Discharge 7348 m^3/d	62
Table 5.17	Different Types of Losses (Zone 3) at an Operating Discharge 7348 m^3/d	62
Table 5.18	Different Types of Losses (Zone 4) at an Operating Discharge 7348 m^3/d	63
Table 5.19	Different Types of Losses (Zone 5) at an Operating Discharge 7348 m^3/d	63
Table 5.20	Different Types of Losses (Zone 6) at an Operating Discharge 7348 m^3/d	63
Table 5.21	Different Well and Aquifer Parameters for Zone 1	64
Table 5.22	Different Well and Aquifer Parameters for Zone 2	64
Table 5.23	Different Well and Aquifer Parameters for Zone 3	64
Table 5.24	Different Well and Aquifer Parameters for Zone 4	65
Table 5.25	Different Well and Aquifer Parameters for Zone 5	65
Table 5.26	Different Well and Aquifer Parameters for Zone 6	65

Table	Description	Page
Table 5.27	Different Types of Losses (Zone 1) at an Operating Discharge 4898 m^3/d	68
Table 5.28	Different Types of Losses (Zone 2) at an Operating Discharge 4898 m^3/d	68
Table 5.29	Different Types of Losses (Zone 3) at an Operating Discharge 4898 m^3/d	68
Table 5.30	Different Types of Losses (Zone 4) at an Operating Discharge 4898 m^3/d	69
Table 5.31	Different Types of Losses (Zone 5) at an Operating Discharge 4898 m^3/d	69
Table 5.32	Different Types of Losses (Zone 6) at an Operating Discharge 4898 m^3/d	69

LIST OF FIGURES

Figure	Description	Page
Fig. 3.1	Topography of Dhaka City	15
Fig. 3.2	Landform of Dhaka City	16
Fig. 3.3	Drainage Map of Dhaka City	17
Fig. 4.1	Drawdown in a Pumped Artesian Aquifer	30
Fig. 4.2	Drawdown vs. Time Curve using the Jacob Method	32
Fig. 4.3	Time Drawdown and Residual Drawdown	34
Fig. 4.4	Family of Papadopulos-Cooper's Type Curves	38
Fig. 4.5	Graph of Corresponding Values of u_w and $u_w W(u_w)$	41
Fig. 4.6	Various Head Losses in a Pumped Well	44
Fig. 5.1	Transmissivity Map of Dhaka City	56
Fig. 5.2	Storativity Map of Dhaka City	59

ABBREVIATION

ADB	Asian Development Bank
BADC	Bangladesh Agriculture Development Corporation
BGS	British Geological Survey
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
DPHE	Department of Public Health Engineering
DWASA	Dhaka Water and Sewerage Authority
IMGD	Million Imperial Gallons Per Day
MODS	Maintenance, Operation, Distribution and Service
MPO	Master Plan Organization
PWL	Pumping Water Level
STW	Static Water Level
UNDP	United Nations Development Program

NOTATIONS

Δa	Aquifer Loss (L)
$B_1(r_w,t)$	Linear Aquifer Loss Co-efficient
B_2	Linear Well Loss Co-efficient
C	Non-linear Well Loss Co-efficient
D	Thickness of Aquifer (L)
E_w	Well Efficiency
g	Acceleration due to Gravity (L/T^2)
h	Piezometric Head (L)
K	Hydraulic Conductivity (L/T)
KD	Transmissivity (L^2/T)
n	Porosity
N_R	Reynold's Number
Q	Discharge (L^3/T)
r	Radial Distance from Well Axis (L)
r_{ew}	Effective Radius of Pumping Well (L)
r_w	Actual Radius of the Well (L)
S'	Storativity during Recovery
S	Storativity of the Aquifer
S_r	Specific Retention
S_s	Specific Storage (L^{-1})
s	Average Drawdown (L)
s'	Residual Drawdown (L)
S_y	Specific Yield
t'	Time since Pumping Stopped (T)
t_p	Total Pumping Time (T)
t_{sw}	Time when Aquifer Losses are Zero (T)
V	Gross Volume of Sample (L^3)
V_T	Total Volume of Sample (L^3)
V_v	Volume of Void (L^3)
V_w	Volume of Water (L^3)

W_r	Volume Occupied by Retained Water
W(u)	Well Function
W_y	Volume of Water Drained (L^3)
α and β	Compressibility of Aquifer and Compressibility of Water
dv_T	Total Volume Change of a Sample
$d\sigma_e$	The Change in the Effective Stress
d_p	Change in the Water Pressure
σ	Density of Fluid
μ	Viscosity of Fluid

Chapter 1
Introduction

1.1 General

With the increase of population, the demand for water is increasing throughout the world. Groundwater can be regarded as a reliable source of water supply for any climatic condition of a region. While, surface water is generally easy and economical, its availability is uncertain with season. Thus, the effective management of groundwater system is essential for a region to meet the increasing demand of water supply. Groundwater source provides clear water at almost constant temperature and is preferred compared to surface water for municipal water supply. As an assured supply of water, it can be obtained from the underground source even in the desert areas if the system is properly designed and maintained.

The city of Dhaka has an extensive water supply system dependent mainly on groundwater source. Dhaka WASA is supplying potable water to the metropolitan area by operating numerous deep tubewells at different places inside the city. The demand of potable water is increasing day by day and WASA shall have to depend mostly on tubewells for water supply for a number of years to come.

To keep pace with the expansion of the Dhaka city, water supply system has expanded through the development of numerous tubewells, and extension of the distribution system. At present 93 percent of Dhaka city water supply are met from exploitation of groundwater. Dhaka WASA is currently operating about 220 deep tubewells with a total production of water equal to 800 million liters/day while the existing water works at Chandnighat supplies about 50 million liters/day of treated surface water mainly to the old Dhaka city. Since the inception of the water supply system, about 360 wells have been drilled in Dhaka city out of which about 40 percent wells are not functioning at present.

The reasons for deterioration of yielding capacity of the operating wells have not been properly investigated. In most cases, the actual condition of the wells are not known. In general, no regular measurement of drawdown is carried out and deteriorated condition of the wells are observed only after the groundwater level has dropped below the level of the pump. Only recently, with the assistance of UNDP/World Bank under the Water and Sanitation project, DWASA has installed a computerized data base to facilitate the monitoring of performances of the wells.

There are many well commissioning test reports available with Dhaka WASA from long back. In the long span of period from early sixties to date, Dhaka WASA's tubewell commissioning test reports were not used to provide logical and systematic information about the hydraulic parameters of the aquifer system underneath. Historically, most of the installation of deep tubewells were based on thumb rules. Almost all the pumping tests conducted are without piezometers to mark water tables/heads at distances. The suites of tubewell commissioning reports are provided with specific drawdown data through step-drawdown tests under single-well principle. However, the single-well principle inhibits the identification of certain class of aquifer parameters; e.g., storage coefficient, specific yield etc.

The present research work deals with the evaluation of aquifer characteristics of the Dhaka city using the available pumping test of Dhaka WASA wells. Dhaka, the metropolitan and capital city of Bangladesh, is one of the fastest growing cities of the world withstanding the ever increasing population pressure through rapid transformation of its land use pattern. It has long been suspected that the annual abstraction of groundwater is much higher than its annual recharge. Several studies (Bhuiyan 1995; DWASA 1991; Serajuddin 1990 b; Dhar 1995 etc) indicated its annual static water level declination at the rate of 0.5 m to 1.5m, depending on the area considered. Hence, the aquifer system of the city exhibits its restricted capability to supply water to the existing wells. Due to progressive trend of abstraction the Dhaka city aquifer system is withstanding, the recharge-discharge regime may significantly be changed as a function of time. Clearly, the basin yield depends both on the manner in which the effects of withdrawals are transmitted through the aquifers and on the changes in rates of groundwater recharge and discharge induced by the withdrawals. As a result, the aquifer parameters may exhibit some changing trend with time also. An up to date knowledge of these parameters are essential to be incorporated in the saturated portion of a groundwater basin to analyse its transient hydrologic budget.

Very little work on the hydraulic properties of the Dhaka city aquifer system were performed. The study of saturated-unsaturated mathematical modeling by Bhuiyan (1995) has discussed these difficulties which arose due to the non-availability of the relevant parameters. However, the option for using some selected pumping test data already available with the Dhaka WASA may greatly relieve the pains in its modeling studies.

1.2 Objectives of the Study

There are many well commissioning test reports available in Dhaka WASA from long back. These reports were never used for any systematic study for unknown reason. The pumping tests conducted by DWASA have never used piezometers to determine its time drawdowns at distances. As such the proposed study will use those data as a single well pumping test to fulfil the following objectives:

(i) To determine the transmissivity of the Dhaka city aquifer system by some selected methods which are most suitable for the pumping test conducted by Dhaka WASA.

(ii) To compare the results obtained by different methods and thereby identify the most suitable method for the existing pumping tests conducted by the Dhaka WASA.

(iii) To determine the well and aquifer losses based on those single well pumping tests.

(iv) To determine the storativity of the aquifer.

(v) To prepare an iso-transmissivity map for the Dhaka city.

(vi) To prepare an iso-storativity map for the Dhaka city.

(vii) To determine the specific capacity, well efficiency, skin factor etc.

Chapter 2
LITERATURE REVIEW

2.1 Physical Properties and Principles

At present, a significant proportion of our water requirements are met from groundwater source. Adequate knowledge on its origin, occurrence, recharge and movement are essential. Therefore, hydraulic properties of the aquifers need to be evaluated at different places for the proper design, construction and maintenance of the wells. There are many physical properties related to water bearing formation that are in common use in the literature has been described in the following sub-sections for its ready references.

2.1.1 Physical Properties of Water Bearing Formation

The parameters that are generally used in groundwater flow analysis are as follows:

Porosity(n): Porosity is an index of how much groundwater can be stored in the saturated material. Mathematically it is expressed as

$$n = \frac{V_v}{V_T}$$

where, V_T = total volume of the sample; V_v = volume of void
Porosity is usually expressed as a decimal fraction or as a percentage.

Hydraulic Conductivity (K): The hydraulic conductivity is the constant of proportionality in Darcy's law. It is defined as the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Compressibility of Aquifer (α): Compressibility of aquifer is an important material property in the analysis of unsteady flow to wells. It describes the change in the volume or the strain induced in an aquifer (or aquitard) under a given stress, or

$$\alpha = \frac{-dV_T / V_T}{d\sigma_e}$$

here, dV_T = the total volume change of a given mass of material; $d\sigma_e$= the change in the effective stress.

Compressibility is expressed in m^2/N or Pa^{-1}. Its value for clay ranges from 10^{-6} m^2/N, to 10^{-8}, for sand from 10^{-7} to 10^{-9} m^2/N, for gravel and fractured rock from 10^{-8} to 10^{-10} m^2/N.

Similarly, the compressibility of water is defined as

$$\beta = \frac{-dV_w / V_w}{dp}$$

A change in the water pressure dp induces a change in the volume Vw of a given mass of water. The compressibility of groundwater under the range of temperature that is usually encountered can be taken constant as 4.4 x 10^{-10} m^2/N.

Transmissivity (KD or T): Transmissivity is the product of the average hydraulic conductivity (K) and the saturated thickness (D) of the aquifer. Consequently, transmissivity is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer. Transmissivity has the dimension of $length^2/time$.

Specific Storage (S_s): The specific storage of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. The release of water from storage under condition of decreasing head (h) stems from the compaction of the aquifer due to increasing effective stress and the expansion of the water due to decreasing pressure (p). Mathematically, specific storage is expressed as

$$Ss = \rho g(\alpha + n\beta)$$

where, ρ = mass density of water; g = acceleration due to gravity; n = porosity

The dimension of specific storage is $length^{-1}$.

Storativity (S): The storativity of a saturated confined aquifer of thickness D is the volume of water that is released from storage per unit surface area of the aquifer per unit decline in the component of hydraulic head normal to that surface. Mathematical, storativity is defined as,

$$S = \rho g D (\alpha + n\beta) = S_s D$$

Specific Retention (S_r): In the saturated zone, groundwater fills all the interestics of soil, hence porosity of the formation is the direct measure of the water contained per unit volume. The specific retention of a soil is the ratio expressed as a percentage of the volume of water it will retain after saturation against the force of gravity to its own volume. If S_r is the specific retention. then expressed as

$$S_r = 100\ W_r/V$$

where, W_r = volume occupied by retained water; V= gross volume of the soil

Specific Yield (S_y): The specific yield S_y may be defined as the ratio expressed as a percentage of the volume of water which after being saturated can be drained by gravity to its own volume. Thus

$$S_y = 100\ W_y/V$$

where, W_y = volume of water drained

As, Wr+Wy = W, it is apparent that n = Sy+Sr, thus, specific yield is a fraction of the porosity of the formation. Values of specific yield depend upon grain size, shape and distribution of pores and compaction of the stratum.

Diffusivity (KD/S): The hydraulic diffusivity is the ratio of the transmissivity and the storativity of a saturated aquifer. Diffusivity has the dimension of length/time.

2.1.2 Groundwater Movement/Darcy's Law

Groundwater in its natural state is invariably moving. The flow through aquifers can be expressed by Darcy's law which states that the flow rate Q through porous media is proportional to the head loss "dh" and inversely proportional to the length of flow path "dl", or

$$V = -K\frac{dh}{dl}$$

Experiment shows that Darcy's law is valid for Reynolds number, $N_R < 1$ and does not depart seriously up to $N_R = 10$ (Todd 1980) where,

$$N_R = \frac{\rho V d}{\mu}$$

where, V = specific discharge; d = representative length; ρ = density of fluid

μ = viscosity of fluid

2.2 Previous Studies

Very little work on the hydraulic properties of the Dhaka city aquifer system were performed. Aquifer test data are reported by Parsons (1980), BWDB (1984), the British Geological Survey (BGS) as reported by Barker et al. (1989) and MMI (1990). Parsons (1980) supervised a total of 32 tests on different wells; out of which only 17 tests conducted on WASA wells in Dhaka city and the remaining 15 tests on BADC and other organization wells in the adjoining areas of Tongi, Joydebpur, Savar and Narayangonj. But the methods of analysis were not indicated. BWDB (1984) have carried out 16 tests throughout greater Dhaka, but only 3 tests were in Dhaka city area. The tests were analysed by various methods including the leaky aquifer type methods. Barker et al. (1989) reported 14 detailed pumping tests in Dhamrai, Saturia and Manikgonj upazilas. The study also included laboratory hydraulic conductivity tests. MMI (1990) reported four aquifer tests from Kapasia upazila, analysed by leaky aquifer type curve and other methods.

A transmissivity map has been prepared by the Dhaka Region Groundwater and Subsidence Project (DWASA, 1991) from the pumping tests data reported earlier (Parsons

1980; BWDB 1984; Barker et al. 1989 and MMI 1990) for the greater Dhaka district. The map contains very few data points within the city area. There are about 360 deep tubewells installed over a period from 1960 to 1997 within Dhaka city which contain only the construction and development data of the wells. Almost all the wells are under partial penetration, tapping a complex layering system of confined-unconfined-leaky conditions. Although correction for partial penetration exists, the influence of layering is such that the effective aquifer thickness is only slightly more than the screen length. A considerable thickness of these fine sand layers, not screenable with standard well screens available in Bangladesh, are yet to be tested. Also, there may be difficulties in interpreting these tests, in particular failing to take proper account of vertical leakage may lead to serious over estimation of the transmissivities. This effect is, however, in the opposite direction to that of partial penetration.

A common and greater cause of error results from misinterpretation of piezometer data in layered aquifers, especially where low conductivity horizons are not clearly defined. This is one of the constant dilemmas of practical pumping test interpretation. Piezometers are essential if storage coefficients and leakages are to be analysed, and yet may lead to a larger error than using only the pumping well as the indicator of the water level. So far in Dhaka WASA wells, almost no piezometer has been used for pumping tests. Under the single well pumping test, if well losses are significant, the drawdown due to laminar flow in the aquifer will be exaggerated and hence the transmissivity may be underestimated. Thus, a proper estimation of well losses is a precondition of applying any time variant method of transmissivity determination. Transmissivity may be estimated from specific drawdown data using Logan approximation method (Kruseman and de Ridder 1990); which is the method appropriate to commissioning test data. The method is liable to produce over estimated results under vertical leakage and transient aquifer responses.

Transmissivity may also be estimated from lithological data. Considerable work on correlating grain size, color and conductivity was done on the IDA I, IDA II and ADB deep tubewell projects (MMP 1984). Their purpose was to establish a system for predicting well yields, and indirectly therefore optimising well design from drilling data alone. Hydraulic conductivities were assigned on the basis of a back analysis of existing wells. Their system has been successful in producing two cusec deep tubewells over a wide area of Bangladesh. A comparison of the transmissivities calculated from aquifer tests and estimated either by the Logan method or on the basis of lithology shows a considerable deviation from the expected 1:1 relationship. Welsh (1977) also determined transmissivity close to Dhaka city by analysing the attenuation of river stage fluctuations in adjacent piezometers. Welsh (1977) concluded that the magnitude of the groundwater fluctuation proves that there is a good hydraulic continuity between the rivers and the aquifer. Unfortunately, Welsh (1977) did not report the storage values used, however, the transmissivity values were approximately half the average values derived from aquifer tests in Dhaka city (DWASA, 1991).

Since most tubewells in Bangladesh are partially penetrating, horizontal conductivity was estimated from both aquifer test and Logan method by taking the screen length as the effective aquifer thickness. However, only the BGS finite element method (Barker et al. 1989) calculated horizontal conductivities directly. An empirical relationship has been derived by DWASA (1991) study between the conductivities determined from the Logan transmissivity and those estimated from lithology as follows:

$$K = 1.39K_{litho} - 16.8$$

The relationship fits a good straight line such that a lithological data may provide the hydraulic conductivity directly. The lithological grouping based on MMP (1984) classification coincide with the physiographic units, as well as the underlying geological units (DWASA, 1991). The study concluded that the typical brown fine to medium grained sand (available in upper alluvium) has an average conductivity of 15-20 m/day, ranging up to about 30 m/day where significant coarse sand is present. Grey medium to coarse sands, which are characteristic of the lower alluvial sequence, are typically in the range of 55-75 m/day. Although the conclusion neither contradicts nor confirms the effects of weathering of feldspars, it does explain why the color effect should be so marked. Except in the BGS study there are practically no data available for the upper aquifer, which is generally too fine to screen, conductivity was therefore based on lithology. The results of the BGS study showed that the lower aquifer is three times more permeable than the upper.

For the areas around Dhaka city, Davies and Herbert (1990) have published the results of 150 laboratory hydraulic conductivities carried on good quality drive samples (all grey sands) of the upper and lower alluvial sequences in a falling head permeameter. The finer grained sediments tested by Davies and Herbert (1990) are the only direct measurements of conductivity for the non-screenable aquifers.

Aquifer tests may also provide an estimate of the vertical conductivity of the overlying aquitard. A range of values (2.2×10^{-4} to 7.1×10^{-1} m/d) obtained from analytical solutions of DWASA (1991) and BGS finite element model (Barker et al. 1989) have provided an aggregate parameter that does not explicitly recognize the effects of layering. However, more data are available from geotechnical investigations as vertical conductivity can be calculated from the time rate of consolidation, although sample disturbance may lead to underestimation of the conductivity of over consolidated Dhaka clays. Various attempts were made to correlate these conductivities with index properties. Although it can be argued that the conductivity of a clayey soil is related to some combination of grain size (such as clay content or Atterberg limits) and an in situ parameter (such as void ratio, bulk density or liquidity index), no statistically valid relationship could be found. It has been shown (DWASA 1991) that the low-land alluvium (around 10^{-4} m/d) is more permeable than the Madhupur clay (around 10^{-5} m/day). In so far as anisotropy influences the conductivity of clays, BUET (1977) reported six determinations for Madhupur clay and low-land alluvium from the Dhaka-Narayanganj-Demra scheme. The ratio of horizontal to vertical conductivities fell into the narrow range of 1.4 to 2.4. Five determinations of the vertical conductivities of Madhupur clay at depths of 3-4 m in Dhaka city reported by Welsh (1977) in the range of 1.1×10^{-3} to 2.1×10^{-2} m/day. His method and the explanation of this difference are not known. The differences in aquitard conductivity derived from pumping test and laboratory measurement may not simply be due to analytical problems, it is quite likely that they reflect the heterogeneity of the upper aquitard. Laboratory determination of the vertical conductivity of sand is not normally done because of the difficulty of taking undisturbed samples below the water table. In general, therefore vertical conductivity of saturated sand must be assumed with the horizontal conductivity taken as a limiting value. Anisotropy in sand is usually considered to be between 1 and 10 (DWASA 1991), although high anistrophy probably reflects layering rather than an intrinsic property. An indirect determination of the vertical conductivities of the Dihing upper and lower alluvial sequences was reported from the BGS model (Barker et al. 1989).

The groundwater model requires the specific storage of each layer (storage coefficient divided by thickness) as an input parameter. Frequency distribution conducted by DWASA (1991) for the three main aquifers shows that the Dupi Tila has the least confinement and also the smallest range of values (7.5×10^{-5} to 2.5×10^{-6} per m) and therefore indicates the greatest elastic compressibility. The frequency distribution for the lower alluvial unit is smaller, but lower. The upper unit shows wide range of specific storage, which probably represents the variable degree of confinement. Although the specific yield may be defined in simple terms as "the ratio of the volume of water that, after saturation, can be drained by gravity to its own volume" (Todd 1980). In practice it is more complicated, because, the piezometric surface and geological layering make specific yield a time and depth dependent parameter, respectively.

It is possible to calculate specific yield from pumping tests; however, such tests are rarely long enough, and their interpretation is usually complicated by natural groundwater fluctuations. One such determination, of 0.21, is reported by Welsh (1977) for the Gymkhana site in Dhaka, where he observed the gradual transition from leaky to unconfined conditions over a period of months. But, even this can only be valid for a particular water table depth. Specific yield of the top aquitard was also calculated in the Barker et al. (1989) finite element model. The results range between 0.02 and 0.27, with an average of 0.084. The BGS values are constant with depth, and derived from a short term test. For modeling purpose the approach adopted by MPO (1987) may be used, in which specific yield is related to lithology and can, therefore, be made depth dependent. The specific yield values for the top 40 m, but in one meter intervals, were reported by DWASA (1991) for about 100 profiles for different parts of greater Dhaka.

Chapter 3
Study Area

3.1 Physical Setup of Dhaka City

The study area is the Dhaka city which is metropolis as well as the capital of Bangladesh. The study area lies between latitude $23^0 40'$N to $23^0 54'$N and longitudes between $90^0 20'$E to $90^0 31'$E. It is bounded by the Tongi khal in the north, the Buriganga river in the south and south-east, the Balu river in the east and the Turag river in the west, covering an area of about 415 km^2 (180 sq.miles). A Number of N-S, E-W, NE-SW and NW-SE trending faults and lineaments traverse through the city. The faults control stream courses and characterized by vertical and lateral movements. The following sub-sections describe the general features of Dhaka city in terms of its geology, topography, land form and recharge and discharge systems as a whole.

3.1.1 Geology of the Dhaka City

Geologically, Dhaka city is an integral part in the southern tip of the Madhupur tract, an uplifted block in the Bengal Basin, with many depressions of recent origin in it.

The city is compacted by Madhupur clay occupying the major northern part. Flood plain deposits laid down by the Brahmaputra river and its distributaries. The Madhupur clay formation is overlained and underlained by the alluvium and Dupi Tila formations respectively. A stratigraphic succession of Madhupur tract in Dhaka city has been given by Salahuddin (1991), Alam (1988), Alam et al. (1990), Monsur (1990), and DWASA (1991). The thickness of the Madhupur clay formation varies from 6 to 25 m with an average thickness of about 10 m. From base to top, this formation can be divided into two units (Rizvi 1970; Islam 1976). The lower clay unit is grey with molting of red brown, yellow and orange colours. The clay is sticky, plastic and compact containing calcareous modules. The upper clay unit is highly weathered. It is generally brownish, red to brick red, massive steady, plastic and compact in dry condition and soft when wet. It contains some calcareous modules, plant roots and manganese spot (Monsur 1991).

The alluvium formation unconformably overlies the Madhupur clay formation. The thickness varies from 0 to 25 m. It is divided into two units depending on the mode of occurrence. The high land alluvium lies above the present flood plain (mainly silt and clay) whereas the low land alluvium laid down by the main drainage system. It is divided into three sub-unit: the back swamps and depression deposits; natural levee and interstream deposits and the river bed deposits.

The Dupi Tila formation is mainly comprises two distinct units - a lower sand stone and an upper clay stone (Khan 1978). The sand stone is yellow, medium to coarse grained, massive, poorly consolidated, contains quartz granules and pebbles with sub ordinate clay stone. The maximum thickness is about 600 m. The sand forming the main aquifer at Dhaka city beneath the Madhupur tract are assigned to Dupi Tila (Alam et al. 1990).

3.1.2 Relief and Topography

The city is characterized by low relief with many low depressions. The average elevation of the city is about 6 m above M.S.L. The maximum and minimum elevation occur in the Mirpur zoo and the peripheral area of the city respectively (Fig. 3.1). The ground surface slopes towards both east and west but general slope is from the north towards the south and southeast (Chowdhury 1993).

3.1.3 Land Form

Three distinct land forms can be recognized in the city. These are high lands, low lands and abandoned channels and depressions. The high land areas have greater N-S extent and constitute about 40 percent of the land areas. The extreme north western and middle western parts of the city area are highly eroded and the ground surface elevation (about 5 to 8 m) does not represent the actual elevation. This unit remain unaffected during flooding. The peripheral part of the city is low and constitute about 35 percent of the study area. It is affected by flood during monsoon season. The north western, central eastern and south eastern part of the city are marked by abandoned channels and depressions which constitute 25 percent of the study area (Fig. 3.2). The general elevation is 1.5 to 2.5 m and sometimes with elevations below sea level (Chowdhury 1993).

3.1.4 Drainage System

The city is demarcated by three main rivers and one khal. The rivers are the Turag in the west, the Balu river in the east and the Buriganga in the south and south-east. The Tongi-khal is situated in the north of the city (Fig. 3.3).

The Turag river comes from the north and joins the Buriganga river near Mirpur. The Balu river also comes from the north and joins the Lakha river near Demra. The Tongi khal takes water from the Turag river and discharges it into the Balu river. The Buriganga is a tidal river which issues from the north-west and flows towards the southeast. The city is traversed by numerous khals, entrenched streams and lakes. The rivers commonly show dendritic pattern except the western part which shows trellise pattern together with dendritic drainage system.

3.2 Recharge and Discharge

In Dhaka city recharge to the aquifer system occurs primarily from the rivers that enters as horizontal flow and secondarily from the vertical inflow from the rainfall and flooding. Recharge is also reported to take place through leakage from the water supply and sewer systems. Vertical recharge takes place very slowly as the aquifer system consists of thick clay layer (on average about 10 m) above it. Recharge from horizontal as well as vertical inflow from the flood water of the low lying areas in and around the city is thought to be occurred only during the period from July to September. The recharge to the aquifer system of the city has been reduced gradually as the rechargeable areas are being reduced due to urbanization. In general groundwater moves toward maximum hydraulic gradient, i.e., from recharge areas of high water level to pumping areas of depressed water level.

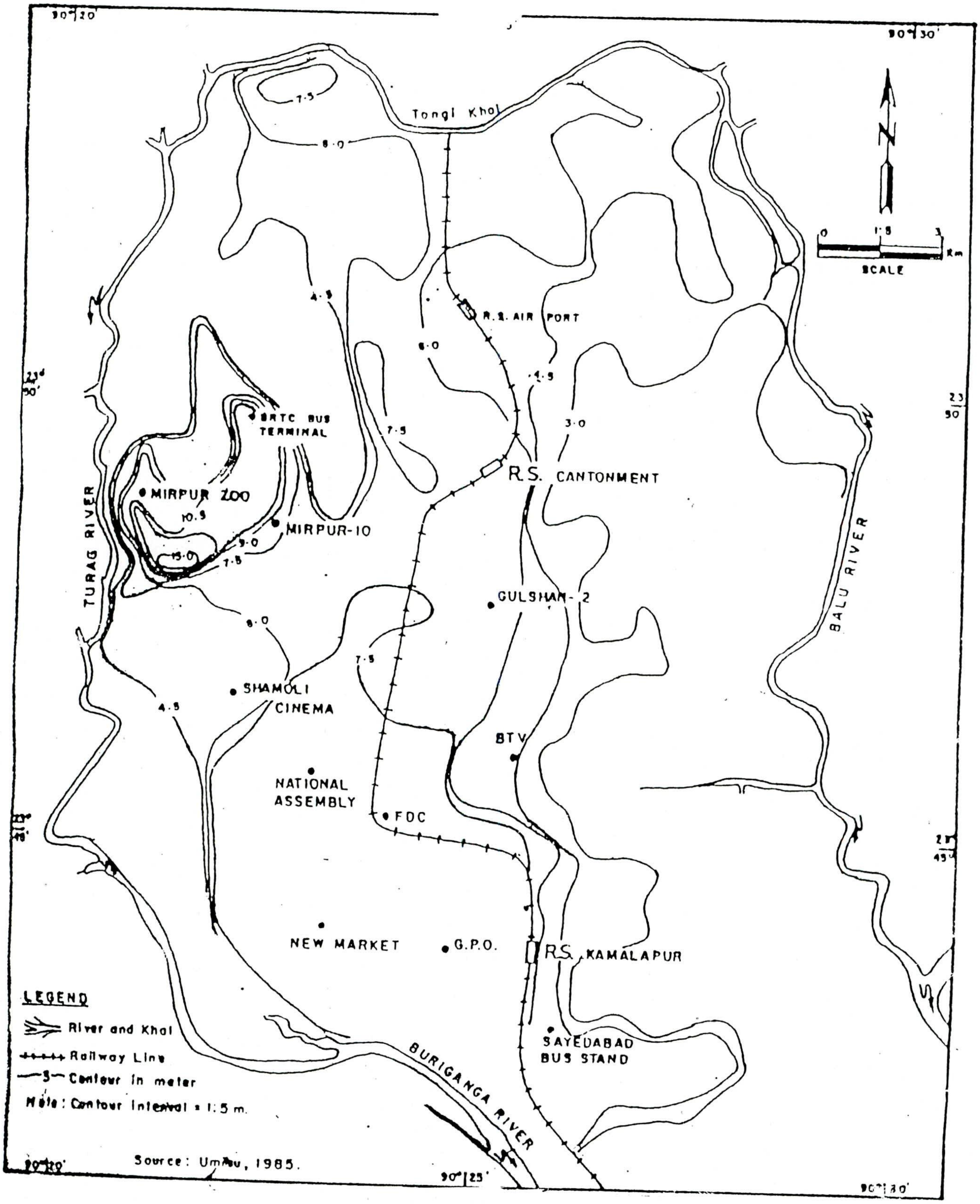

FIG. 3.1 TOPOGRAPHY OF DHAKA CITY

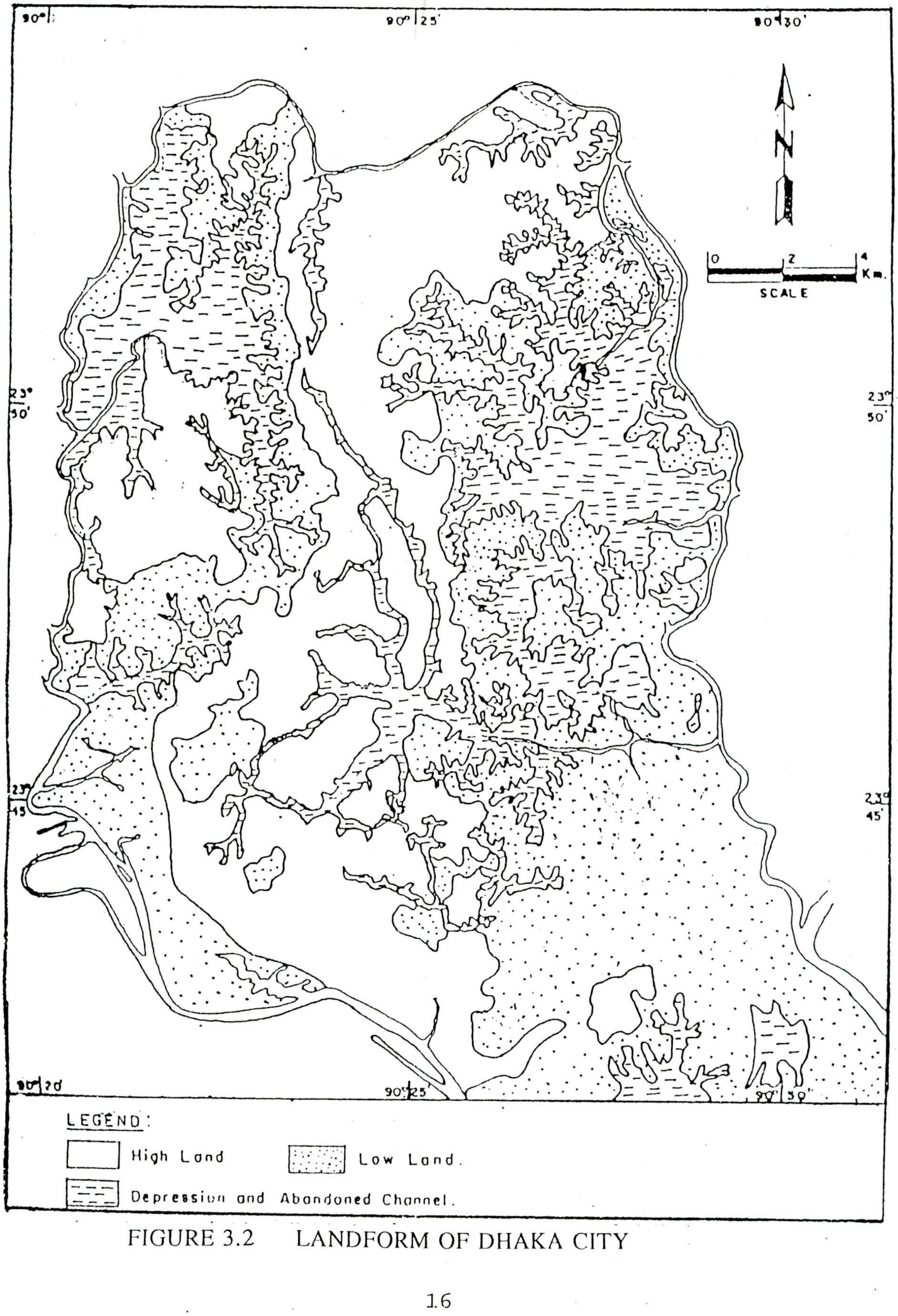

FIGURE 3.2 LANDFORM OF DHAKA CITY

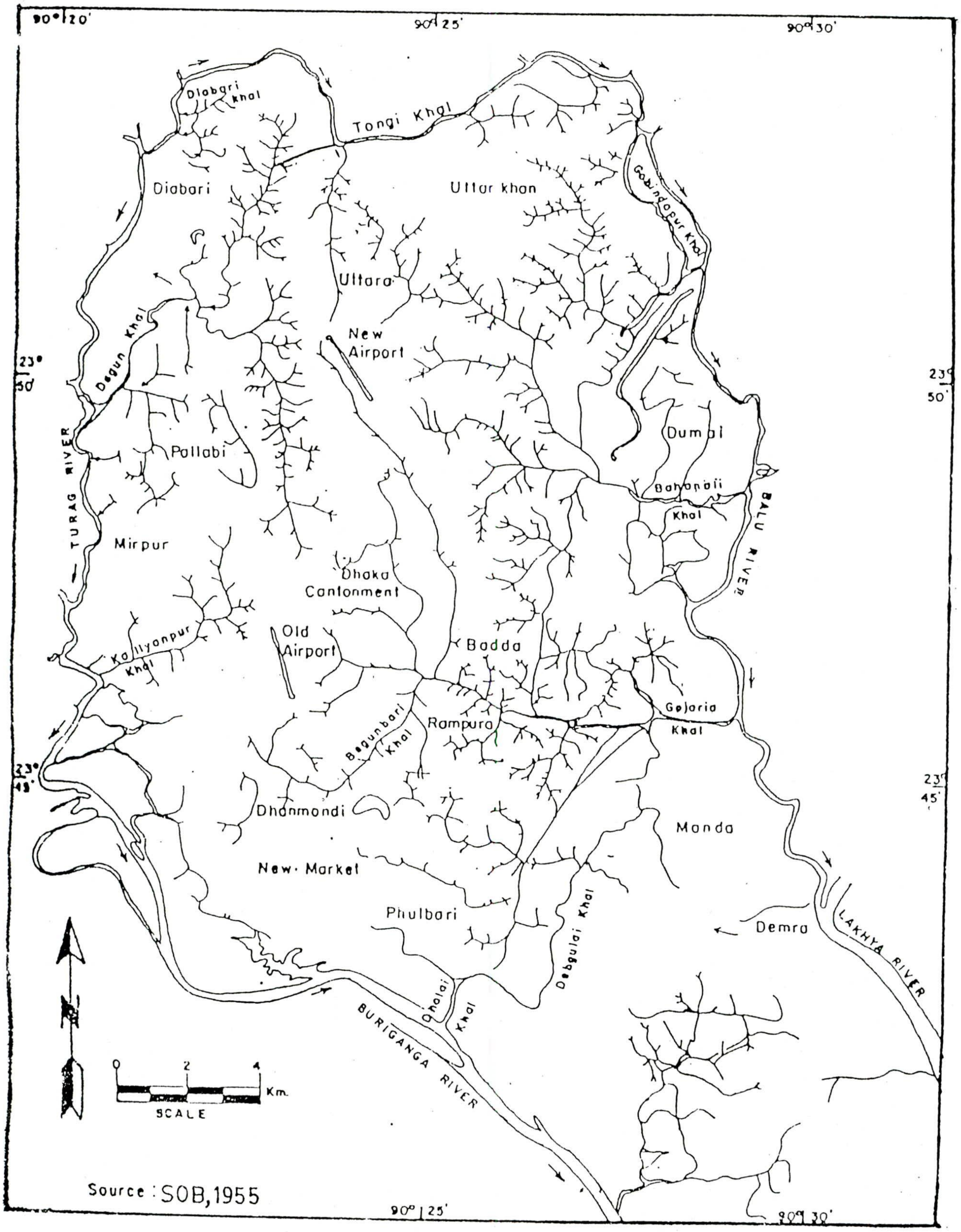

FIG. 3.3 DRAINAGE MAP OF DHAKA CITY

3.3 Climate

The Dhaka district lies within the humid subtropical zone with moderately warm temperature, high humidity and high annual rainfall (Chowdhury 1993). The dry winter season from November through March, is characterized by moderate temperature and scanty rainfall. The monsoon season experiences with almost daily rainfall and high temperature which prevails from June through September. The lowest temperature records in January varies from 45^0-60^0F and highest temperature recorded in April or May varies from 100-105°F (Chowdhury 1991).

The area receives concentrated rainfall from June to September (areal average is 2130 mm). The annual evaporation of Dhaka region ranges from 840 to 1020 mm.

3.4 Sub-Surface Geology and Aquifer System

Detailed information about the sub-surface geology are available with the BWDB and DWASA bore log data. The aquifer system beneath Dhaka is complex in nature and functioning as a leaky, semiconfined aquifer. The thickness of different formation layers as well as the aquifer properties are found to vary between places. A simplified configuration of this aquifer system (which is a closer approximation of the actual lithology) have been visualized (DWASA 1991).

Upper Aquitard

Top most layer of top soil composed of finer plastic concentration of impervious clay and low permeable silt. It ranges from 6 to 10 m on average up to a 15 m thick at different places.

Upper Aquifer

Below upper aquitard, the media composed of fine to medium fine sand to a depth of 30-45 m. Shallow and hand-pump tubewells extract water from this aquifer.

Lower Aquitard

Bottom to upper aquifer, the material composed of silt and clay with variable thickness.

Lower Aquifer

Below lower aquitard, the media composed of medium to coarse sand with a thickness of ranging from 90 to 120 m depth. This is the main source of municipal and irrigation water supply for Dhaka city. It is found that in majority of the places the main aquifer can be classified as semi-confining in nature.

3.5 Groundwater Hydrographs

The position and fluctuation of groundwater table or potentiometric surface may be available from routinely monitored BWDB and BADC piezometers located in the study area. From the available data a marked difference on seasonal fluctuation of groundwater hydrograph in and outside the Dhaka city have been observed. The fluctuation of groundwater table in BWDB piezometers outside Dhaka show a good response with seasonal change. Besides, piezometric hydrographs show gradual declination with time. A highest depressed groundwater level in Dhaka city than its adjoining area can easily be noticed. The possible cause of this situation is the excessive abstraction of groundwater. The deepest groundwater level was found in the central Dhaka (Motijheel, Ramna and its adjoining areas). The rate of water level fall is increasing gradually which may create an alarming situation in future.

The annual rainfall in Dhaka city is about 2130 mm and the most part of which occurs through the months of June through September. The low lying areas inside and outside the Dhaka get flooded from July to September. This water may recharge the aquifer in the study area by vertical percolation. However, the following factors may retard the process of vertical percolation in the study area:

- Gradual reduction of rechargeable surface areas due to construction of buildings, roads and concrete pavements.

- The top most fine material consists of plastic clay (about 7 to 15 m in thickness) which retards greatly the percolation rate.

- The percolation through the unsaturated materials reduces the inter connected pore spaces by the deposition of finer materials.

- Lowering of groundwater level increases the length of flow paths which in turn develops the time constraints of recharge.

- Most of the beels and low lying areas surrounding the Dhaka city are covered by the thick impervious clay which is not favourable for vertical recharge.

The contribution of water from the adjoining rivers into the aquifer system are seemed to be limited although it is indicated that there are great differences between the river stages and the groundwater levels. The rivers are being silted and reducing the permeabilities of their beds.

The groundwater gradient and the flow path towards Dhaka city (Fig. 3.3) indicates that there is no outflow even at full recharge time. Besides, the higher depth of bottom aquifer and its static water level indicate that the components of evapotranspiration from groundwater is negligible.

3.6 Different Features of DWASA Wells

To meet the increasing water demand in Dhaka city, priority was given to the abstraction of groundwater than surface water due to its excellent potable quality. DPHE first installed water wells in Dhaka city in 1949. Since 1949, DPHE and later on DWASA after its establishment has been installing wells at an average rate of about 3 to 4 wells per year. During the period 1949-

1959, wells were drilled and constructed at depths between 75-110 m using 20-30 m length of slotted brass screen. The pump chambers were 25-40 cm in diameter and about 20 m depth. Between 1959-1969, the well depths were increased to 110-140 m using 30-45 m of slotted brass screen. Depth of pump chambers during this period were increased to 27-34 m and its diameter to 36 cm. From 1969, DWAṢA wells have been drilled progressively deeper ranging from 110-190 m and have been using a standard more or less fixed design parameters and construction procedures for tubewells inside Dhaka city.

Since the first deep tubewell in 1949, WASA has installed about 360 wells, most of them during the last 15 years. In June 1997, 220 deep tubewells were in operation and they produced in all 800 million liters/day.

3.6.1 Well Design

Since 1969, DWASA has been installing (Serajuddin 1984) gravel packed wells drilled by reverse rotary drilling method. The tubewells are designed with a minimum yield of 4896 m^3/day (1 IMGD).

The tubewells are drilled with a diameter of 560 mm (22 inch) to a depth of about 200 m. Typically they have an upper pump housing section made of mild steel, usually 460 mm in diameter, to a depth of about 60 m which generally specified by the engineers during drilling operation. The length and diameter of upper pump housing depend on pumping water level (PWL) when well is in operating condition and size of the pump installed.

Immediately after upper housing, a reducer is attached of different shape which connects the lower blind pipe and strainer of the well. The diameter of the blind pipe and strainer is 200 mm. After the boring operation, the concerned engineers check the log of material along with the respective sample (sieve analysis is done from sample taken in every 1.5 m). Depending upon their engineering practice they select the most potential stratum of the aquifer and the strainer is placed accordingly in that region of the aquifer. The strainer length depends on aquifer configuration. The blind pipe is placed in the remaining portion of the well. A bail plug about 1.5 m long of same diameter having its bottom securely sealed is installed at the bottom of the well. Centralizers (minimum 9.5 mm dia steel bar) are generally attached with the 200 mm blind pipe and screen at an interval not exceeding 10 m which provide a well clearance.

Previously Dhaka WASA used 50 slot screen. As a consequence of wide spread sand yielding problem, around in 1989, DWASA started to use 30 slot screen.

In Dhaka, a proper commercial graded gravel pack material is difficult to purchase. Instead, a gravel pack material is collected from local source and graded at site as per design. The following design criteria is followed in selecting gravel size for the pack material shown in Table 3.1.

Gravels are placed immediately after installation of well fixtures with an average thickness of 175 mm. The gravels are poured around the tubewell up to a level 15 m below the ground surface. Prior the completion of graveling, two G.I. pipes each of 8 cm nominal diameter with sufficient length are installed to reach from 30 cm above the pump house floor to 60 cm below the top of the gravel pack.

Table 3.1. Gravel Size Used in DWASA Wells as Pack Material

Screen size	Percent by weight retained by the screen sizes specified
3/8"	0
4	20-30
8	40-60
16	20-40
Pan	0-5

As a sanitary protection of annular space between the housing pipe and the hole above the gravel pack are back-filled with paddled clay upto a level 6 m below the ground surface. The remaining space is filled with cement grout (1:1:2) as per direction of site engineer.

The pumps used in DWASA wells may either be a submersible or turbine pump. When a new well is constructed, a pump with a capacity of 200 m^3/hr is installed. It has the ability to produce a 70 meter pressure head and are mainly essential to lift water on overhead water reservoirs, otherwise, a 40 m head is enough.

3.6.2 Construction of Deep Tubewells

Reverse rotary drilling method is applied to drill wells in Dhaka city. The drilling fluid flows down the borehole outside the drill pipe from a mud pit. The drilling fluid is air lifted by drilling pipe to the surface entering through the bit and the cuttings are allowed to settle in the pit. To prevent the borehole caving, the fluid level is kept at ground level at all times. No stabilizer is used with the drilling fluid. After every 1.5 m drilling, samples are collected for sieve analysis to prepare bore log data which afterwards used for placement of screens.

Placement of gravel pack around a well is carried out carefully to avoid segregation or bridging. From ground level, gravel is poured into the annular space of well. A circulation of water is established downward in the annular space which force the gravel to pass downward.

Previously the well development was practiced by DWASA consisted of step pumping and back washing only. This method was considered to be inefficient. Therefore, recently water jetting has been added to well development. The equipment used for water jetting include a jetting tool which is a piece of pipe with fittings. It has a diameter of less than that of the screen and four nozzles placed at 90^0 angle. Beginning at the lowest screen, jetting tool is gradually drawn upward, slowly rotated by turning a clamp at the top. The high velocity jet, forces water through the screen openings. Fine sand, silt and clay are washed out of the aquifer and the turbulence created by the jet, brings these fine materials into the well through screen openings above and below the point of operation. While jetting, abstraction is continued to ensure a negative head to remove the fines as they are washed into the well. Dhaka WASA use a pressure between 3,000 kPa to 4,000 kPa for water jetting. Each screen is jetted at least 5 minutes or until the discharge water is clear.

To carry out step pumping with back washing, water is lifted to the surface by a pump. The pump is then stopped and the water in the column pipe falls back into the well thus creating a surging effect through the screen opening. Step pumping starts at an initial rate of 75 percent of the design discharge. The rate is then gradually increased to 150 percent of the design discharge. Development pumping is continued for at least 6 hours or until water is clear and contains less than 100 ppm of sand. Pumping is carried out with intermittent backwashing at 30 minutes intervals.

The principle aim of a pumping test is to determine the performance characteristics of the well and the hydraulic properties of the aquifer. Dhaka WASA starts test pumping after the development is completed and the static water level has recovered within 30 mm of the static water level before development.

The pumping is generally conducted as follows:

Pumping at	75 percent of	design	capacity	for	6 hours
"	100	"	"	"	6 hours
"	125	"	"	"	6 hours
"	150	"		"	6 hours

Water level records are taken during the test pumping as follows:

every second minute for 10 minutes

every fifth minute for 20 minutes

every tenth minute for 30 minutes

every twentieth minute for 3 minutes

every half hour for 2 minutes.

6 hourly recovery records are taken immediately after pumping stopped. Recovery records are taken in specified time intervals.

Chapter 4
Methodology

4.1 General

General flow equation of groundwater movement are derived from Darcy's law and the equation of continuity. Well flow equations derived from these flow formula are the effective tools to understand the flow of water towards a well. The subsurface geology may have the different types of configuration and none of the two geological systems are very identical. For practical purpose, some simplified definitions have been developed to mathematically interpret their behaviour on groundwater flow. Through such simplications, a number of flow formula have been developed depending on different flow conditions, geological variations and different boundary conditions. Even though the original concept of flow formula are almost same, their final representation vary depending on followings:

- steady or unsteady flow
- constant or variable discharge
- fully or partially penetrating well
- isotropic or anisotropic aquifer
- aquifer types such as confined, unconfined or leaky aquifer
- special boundary conditions of geologic section

The DWASA deep tubewells have the construction and development test data. The measured drawdowns are available in a well itself. Thus the aquifer properties are obtained with the help of single well principle. Theoretical concepts of single well pumping test are demonstrated in section 4.4. The brief description on the selection of tubewells and the types of data collected for the present study are provided in sections 4.3 and 4.2, respectively.

4.2 Collection of Data

This study involves an analysis related to deep tubewell construction and development data. The data generated from DWASA wells for the design, construction and development are preserved for each well in DWASA office. The lithology/ bore log data obtained for the well location at the time of drilling are also available along with their description of well fixtures. The tests that are carried out for DWASA wells can be delineated as follows:

i) six hourly well development test at 3 to 4 different discharges;
ii) a recovery test;
iii) six hourly step drawdown test at 3 to 4 different discharges;
iv) another recovery test.

In the present study, the step drawdown test data and its subsequent recovery test data are used. The first step (for six hours at a discharge of 3674 m^3/day in most cases) of the step drawdown data are analysed considering it as a single well test. The data of these pumping tests are provided in Appendix-G.

4.3 Selection of Tube Wells

The tubewells that are selected for the present study meet the following criteria:

i) both the data related to construction (bore-log, well fixtures etc. of the wells) and the performance tests (step drawdown with recovery test) are available for the well concerned;

ii) the number of selected wells in a zone should be representative for that zone.

According to Dhaka WASA, there are 6 MODS zones in the city area. The number of selected wells for analysis from each zone are shown in Table 4.1.

Table 4.1 Number of Selected Tubewells at Different Zones

MODS Zone	.I	II	III	IV	V	VI	Total
Number of Wells Selected	8	7	7	9	6	7	44

4.4 Single Well Pumping Tests

A single well test is in which no piezometers are used. Water level changes during pumping or recovery are measured only in the well itself. The drawdown in a pumped well, however, is influenced by well losses and well-bore storage. In the hydraulics of well flow, the well is generally regarded as a line source or line sink, i.e., the well is assumed to have an infinitesimal radius, so that the well bore storage can be neglected. In reality, any well has a finite radius and thus a certain storage capacity. Well-bore storage is large when compared with the storage in an equal volume of aquifer material. In a single well test, well-bore storage must be considered when analyzing the drawdown data.

To determine whether the early time drawdown data are dominated by well-bore storage, a log-log plot of drawdown versus pumping time should be made. If the early time drawdowns plot as a unit slope straight line, we can conclude that well-bore storage effects exists. Here, the methods presented are derived from single well constant discharge test. The methods applied in the present study are:

i) Jacob's straight line method
ii) Theis recovery method
iii) Papadopulos-Cooper curve fitting method
iv) Hurr-Worthington method.

4.4.1 Jacob's Straight Line Method

In order to develop and solve the well flow equations, it becomes necessary to make the following assumptions:

i) The aquifer has an infinite areal extent.

ii) The aquifer is homogenous, isotropic and of uniform thickness over the area that will be influenced by the test.

iii) Prior to pumping the piezometric surface is horizontal (or nearly so) over the area that will be influenced by the test.

iv) The aquifer is pumped at a constant discharge rate.

v) The well penetrates to the entire thickness of the aquifer and thus receives water by horizontal flow.

vi) The flow to the well is in unsteady state.

vii) The water removed from storage is discharged instantaneously with decline of head.

viii) The time condition that are to be met

$$\frac{25\, r_c^2}{KD} < t < \frac{cS}{20} \; \left(= \frac{L^2 S}{20\, KD} \right)$$

where, r_c = radius of the unscreened part of the well where the water level is changing; t = time since the start of pumping; S = storativity;
if the above conditions are satisfied, the effect of well-bore storage and leakage can be neglected.

When water is pumped from a production well, the water level in the well and also in the vicinity of the well lowers. The distance-drawdown curve around a well forms a cone of depression, the outer boundary (meeting point of cone of depression and original piezometric level of water level) of which depicts the area of influence of well.

The approximate partial differential equation representing the unsteady radial flow in a homogenous, isotropic and compressible confined aquifer of uniform thickness with transmissivity KD and storativity S is,

$$\frac{\partial^2 h}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial h}{\partial r} = \frac{S}{KD} \frac{\partial h}{\partial t} \tag{4.1}$$

where, h = piezometric head; r = the radial distance from the well axis;
t = the pumping time; S = dimensionless storativity; KD = transmissivity, m^2/day;

Theis (1935) obtained a solution for the unsteady radial flow to a well in a non-leaky confined aquifer based on the analogy between groundwater flow and heat conduction. In the analysis, the well is replaced by a mathematical sink of constant strength and is assumed to have an infinitesimal diameter.

The boundary conditions are

$h = h_0$ as r = infinity for $t \geq 0.0$, and

$$\lim_{r \to 0} \left(r \frac{\partial h}{\partial r} \right) = \frac{Q}{2\pi KD} \qquad (4.2)$$

and the initial condition,

$h(r,0) = h_0$ for $t < 0.0$,

The solution to the problem (Fig. 4.1) given by Eq^n. 4.1 is as follows:

$$s = h_0 - h = \frac{Q}{4\pi KD} \int_u^\infty \frac{e^{-u}}{u} du \qquad (4.3)$$

where, h_0 = piezometric head 'before pumping starts as in Fig. 4.1
Q = operating discharge of the well; $u = r^2S/4KDt$

$$S = \frac{4KD\ t\ u}{r^2} \qquad (4.4)$$

The exponential integral expressed symbolically as W(u), that is,

$$W(u) = \int_u^\infty \frac{e^{-u}}{du} \qquad (4.5)$$

Where W(u) is read as the "Well Function" for non-leaky isotropic confined aquifers for fully penetrated wells and at constant discharge condition.

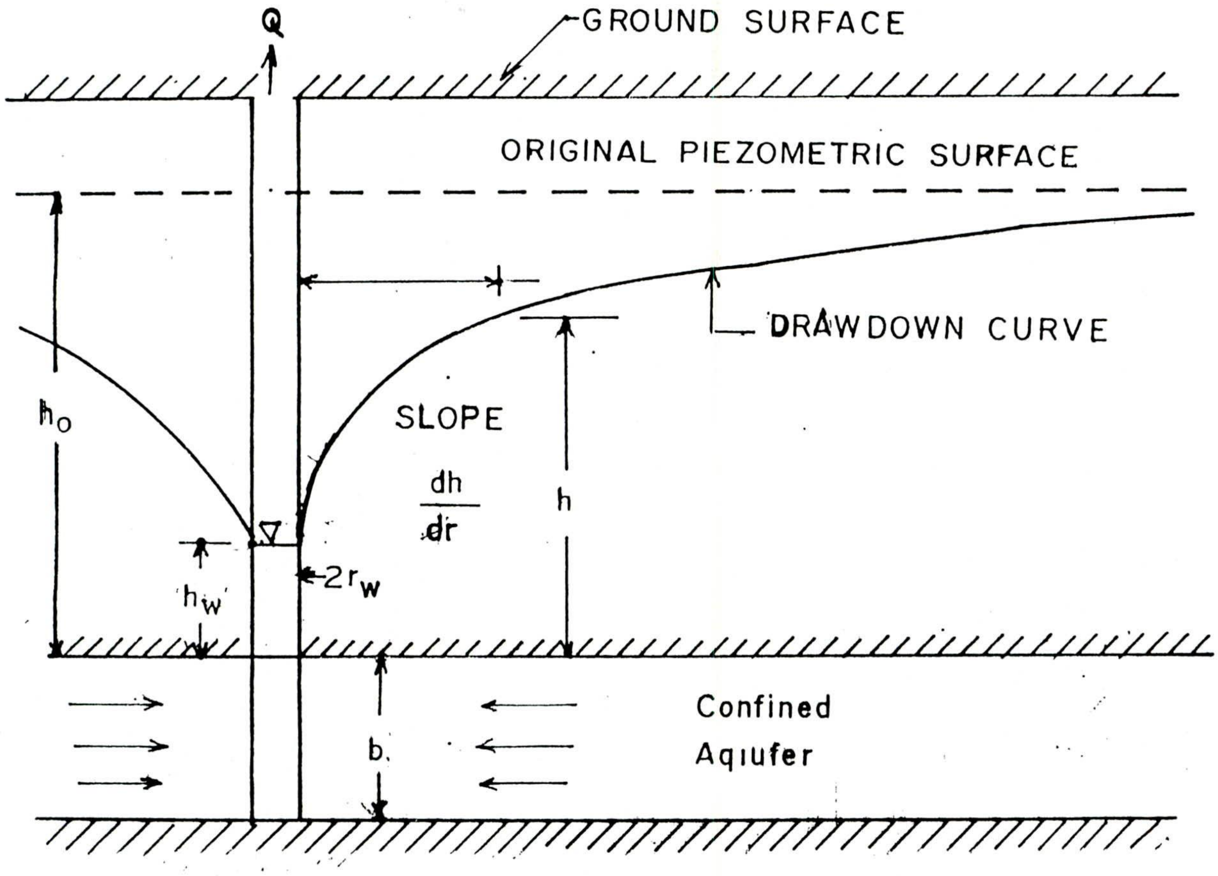

Fig.4.1 Drawdown in a Pumped Artesian Aquifer

Based on Theis formula, Jacob developed a method (Cooper and Jacob 1946) to calculate the aquifer parameters or the drawdown at any distance from the well when the aquifer parameters are known.

The Theis equation can be written as

$$s = \frac{Q}{4\pi KD} W(u) = \frac{Q}{4\pi KD}\left[-0.5772 - \ln u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - ..\right] \tag{4.6}$$

The value of u decreases when,

i) the time (t) increases and

ii) the distance from the well (r) decreases.

Evidently, the terms beyond ln u in the series become so small that they can be neglected, i.e.,

- after a sufficiently long pumping time and
- drawdown observations are made in the near vicinity of the well.

In that case for small values of u (for u <0.01) the drawdown can be approximated by,

$$s=\frac{Q}{4\pi KD}\left(-0.5772-\ln\frac{r^2S}{4KDt}\right) \qquad (4.7)$$

with an error less than	1%	2%	5%	10%
for u smaller than	0.03	0.05	0.1	0.15

After being rewritten and changed into decimal logarithms, the equation reduces to,

$$s=\frac{2.3Q}{4\pi KD}\log\frac{2.25KDt}{r^2S} \qquad (4.8)$$

Because Q, KD and S are constant, a plot of drawdown s versus the logarithm of t forms a straight line (Fig. 4.2). If this line is extended until it intercepts the time-axis where s=0, the interception point has the coordinates, s = 0 and t = t_o, substituting these values into Eq^n. (4.10) gives

$$0=\frac{2.3Q}{4\pi KD}\log\frac{2.25KDt_0}{r^2S}$$

and because $\frac{2.3Q}{4\pi KD}\neq 0$

it follows that, $$\frac{2.25KDt_0}{r^2S}=1 \qquad (4.9)$$

The slope of the straight line, i,e., the drawdown difference Δs per log cycle of time log t/t_o = 1 is equal to 2.3 Q/4πKD, Hence,

$$KD=\frac{2.3Q}{4\pi\Delta S} \qquad (4.10)$$

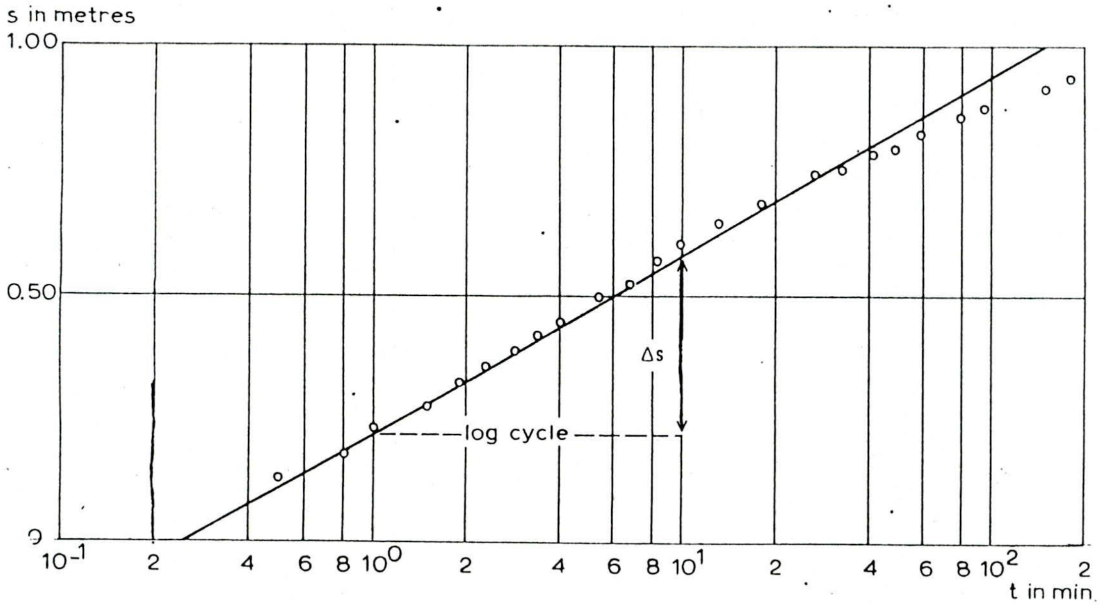

Fig. 4.2 Drawdown versus Time Curve using the Jacob Straight Line Method

Similarly, it can be shown that, for a fixed time t, a plot of s versus r on semi-log paper forms a straight line and the following equations can be derived as follows:

$$S = \frac{2.25\,KD\,t}{r_0^2} \qquad (4.11)$$

and

$$KD = \frac{2.3Q}{4\pi\Delta S} \qquad (4.12)$$

Again, If all the drawdown data of all piezometers are used, the values of s versus t/r^2 can be plotted on semi-log paper. Subsequently, a straight line can be drawn through the plotted points. Continuing with the same line of reasoning as above, it will derive the following formulas

$$S = \frac{2.25\,KD\,t}{r_0^2} \qquad (4.13)$$

and

$$KD = \frac{2.3Q}{4\pi\Delta S}$$

This method can also be applied to single well constant discharge tests to estimate the aquifer transmissivity.

For single well test, in confined aquifer, the time condition should be met is $t > 25r_c^2/KD$

If this time condition is met, the effect of well-bore storage can be neglected. For single well tests in leaky aquifers

$$\frac{25\, r_c^2}{KD} < t < \frac{cS}{20}\left(= \frac{L^2 S}{20\, KD}\right)$$

As long as $t < \frac{cS}{20}$, the influence of leakage is negligible.

Jacob's method can also be applied if the well is partially penetrating provided that late time $\left(t > \frac{D^2S}{2KD}\right)$ data are used. According to Hantush (1964) the additional drawdown due to partial penetration will be constant for $t > D^2S/2KD$ and hence will not influence the value of Δs as used in Jacob's method.

Procedure

- On semi-log paper, plot the observed values of s versus the corresponding time t (t on a logarithmic scale) and draw a straight line through the plotted points.
- Determine the slope of the straight line, i.e., the drawdown difference Δs per log cycle of time.
- Substitute the values of Q and Δs into $KD = 2.30Q/4\pi\Delta s$ and calculate KD.

4.4.2 Theis Recovery Method

When the pump is shut down after a pumping test, the water levels in the well and the piezometers will start to rise. This rise in water levels is known as residual drawdown s'. It is expressed as the difference between the original water level before the start of pumping and the water level measured at a time t' after the cessation of pumping (Fig. 4.3).

It is always good practice to measure the residual drawdowns during the recovery period. Recovery test measurements allow the transmissivity of the aquifer to be calculated, thereby providing an independent check on the results of the pumping tests, although costing very little in comparison with the pumping test.

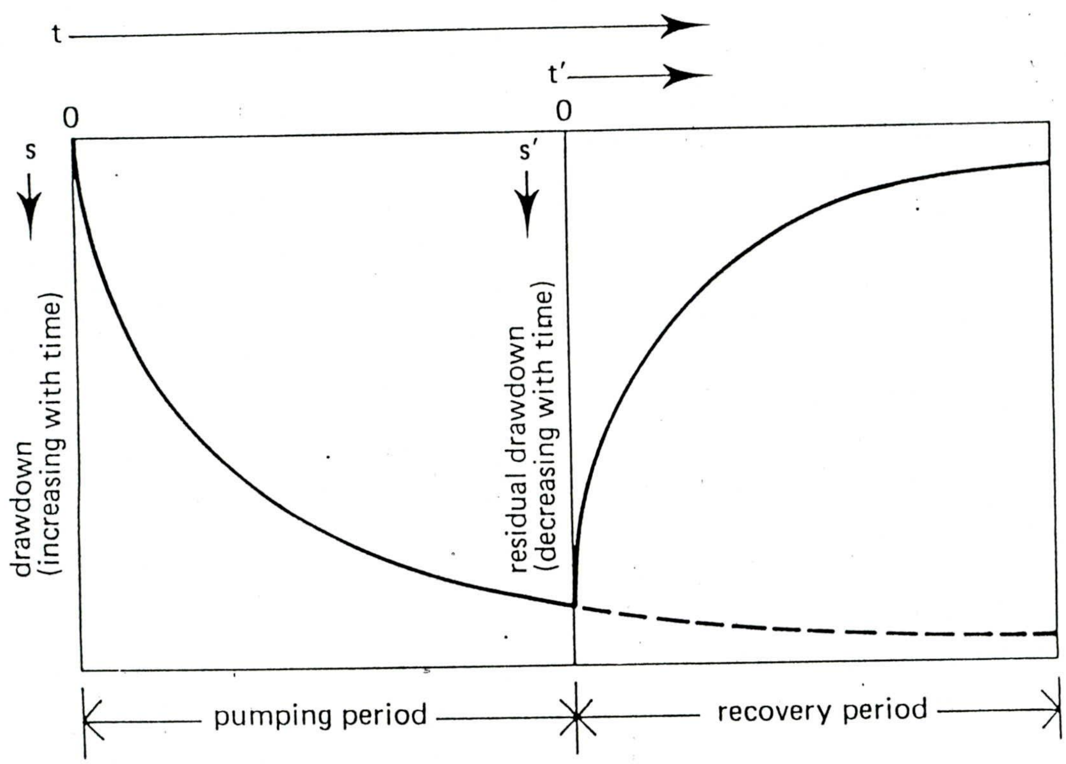

Fig. 4.3 Time Drawdown and Residual Drawdown

Residual drawdown data are more reliable than pumping test data because recovery occurs at a constant rate, whereas a constant discharge during pumping is often difficult to achieve in the field.

Assumptions

i) The aquifer is confined leaky or unconfined

ii) The aquifer has an infinite areal extent.

iii) The aquifer is homogenous, isotropic and of uniform thickness over the area influenced by the test.

iv) Prior to pumping the piezometric surface is horizontal (on nearby so) over the area that will be influenced by the test.

v) The aquifer is pumped at a constant discharge rate.

vi) The well penetrates the entire thickness of the aquifer and thus receives water by horizontal flow.

vii) The water removed from storage is discharged instantaneously with decline of head.

viii) The flow to the well is in unsteady state.

ix) $t_p > 25r_c^2/KD$

$t' > 25r_c^2/KD$

where, t_p = pumping time; t' = recovery time; r_c = radius of the unscreened part of the well where the water level is.changing.

The analysis of a recovery test is based on the principle of superposition. Applying this principle, we assume that after the pump has been shut down, the well continues to be pumped at the same discharge as before, and that an imaginary recharge equal to the discharge is injected into the well. The recharge and the discharge thus cancel each other, resulting in an idle well as is required for the recovery period.

According to Theis (1935), the residual drawdown after pumping test with a constant discharge is

$$s' = \frac{Q}{4\pi KD}\{W(u) - W(u')\} \tag{4.14}$$

where,

$$u = \frac{r^2 S}{4\pi KD\, t} \quad and \quad u' = \frac{r^2 S'}{4\pi KD\, t'}$$

when u and u' are sufficiently small (for u <0.01) - Eq^n. (4.14) can be approximated by

$$s' = \frac{Q}{4\pi KD}\left(\ln \frac{4KD\,t}{r^2 S} - \ln \frac{4KD\,t'}{r^2 S'}\right) \qquad (4.15)$$

where, s' = residual drawdown in m; S' = storativity during recovery, dimensionless; S = storativity during pumping, dimensionless; t = time in days since the start of pumping; t' = time in days since the cessation of pumping; Q = rate of recharge = rate of discharge in m^3/d.

when S and S' are constant and equal and KD is constant, Eq^n. (4.15) can be written as

$$s' = \frac{2.30\,Q}{4\pi KD}\log \frac{t}{t'} \qquad (4.16)$$

A plot of s' versus t/t' on semi-log paper (t/t' on log) will yield a straight line. The slope of the line is

$$\Delta s' = \frac{2.30\,Q}{4\pi KD} \qquad (4.17)$$

where, $\Delta s'$ is the residual drawdown difference per log cycle of t/t'.

The Theis recovery method is also applicable to data from single well pumping test conducted in confined, leaky or unconfined aquifers.

Procedure

- For each observed value of s', calculate the corresponding value of t/t'
- Plot s' versus t/t' on semi-log paper (t/t' on the logarithmic scale)
- Fit a straight line through the plotted points
- Determine the slope of the straight line, i.e., the residual drawdown difference $\Delta s'$ per log cycle of t/t'
- Substitute the known values of Q and $\Delta s'$ into Eq^n. (4.17) $\Delta s' = 2.30\, Q/4\pi KD$ and calculate KD.

4.4.3 Papadopulos-Cooper's Method

The assumptions and conditions underlying the Papadopulos-Cooper method are:

i) The aquifer is confined.

ii) The aquifer has an infinite areal extent.

iii) The aquifer is homogenous, isotropic and of uniform thickness over the area influenced by the test.

iv) Prior to pumping the piezometric surface is horizontal (or nearly so) over the area that will be influenced by the test.

v) The aquifer is pumped at a constant discharge rate.

vi) The well penetrates the entire thickness of the aquifer and thus receives water by horizontal flow.

vii) The water removed from storage is discharged instantaneously with decline of head.

viii) The well diameter can not be considered infinitesimal; hence, storage in the well can not be neglected.

ix) The flow of the well is in an unsteady state.

x) The non-linear well losses are negligible.

Papadopulos and Cooper (1967) observed that the influence of well-bore storage on the drawdown in a well decreases with time and becomes negligible at $t > 25r_c^2/KD$, where r_c is the radius of the unscreened part of the well, where the water level is changing.

For a constant discharge test in a well that fully penetrates a confined aquifer, Papadopulos and Cooper (1967) devised a curve fitting method that takes the storage capacity of the well into account. The method is based on the following drawdown equation

$$s_w = \frac{Q}{4\pi KD} F(u_w, \alpha) \qquad (4.18)$$

where, $u_w = \dfrac{r_{ew}^2 S}{4KD\,t}$ so, $S = \dfrac{4KD\,t\,u_w}{r_{ew}^2}$ (4.19)

$$\alpha = \frac{r_{ew}^2 S}{r_e^2}$$

r_{ew} = effective radius of the screened (or otherwise open) part of the well,

$r_{ew} = r_w . e^{-skin}$; r_w= radius of unscreened part of the well where the water level is changing.

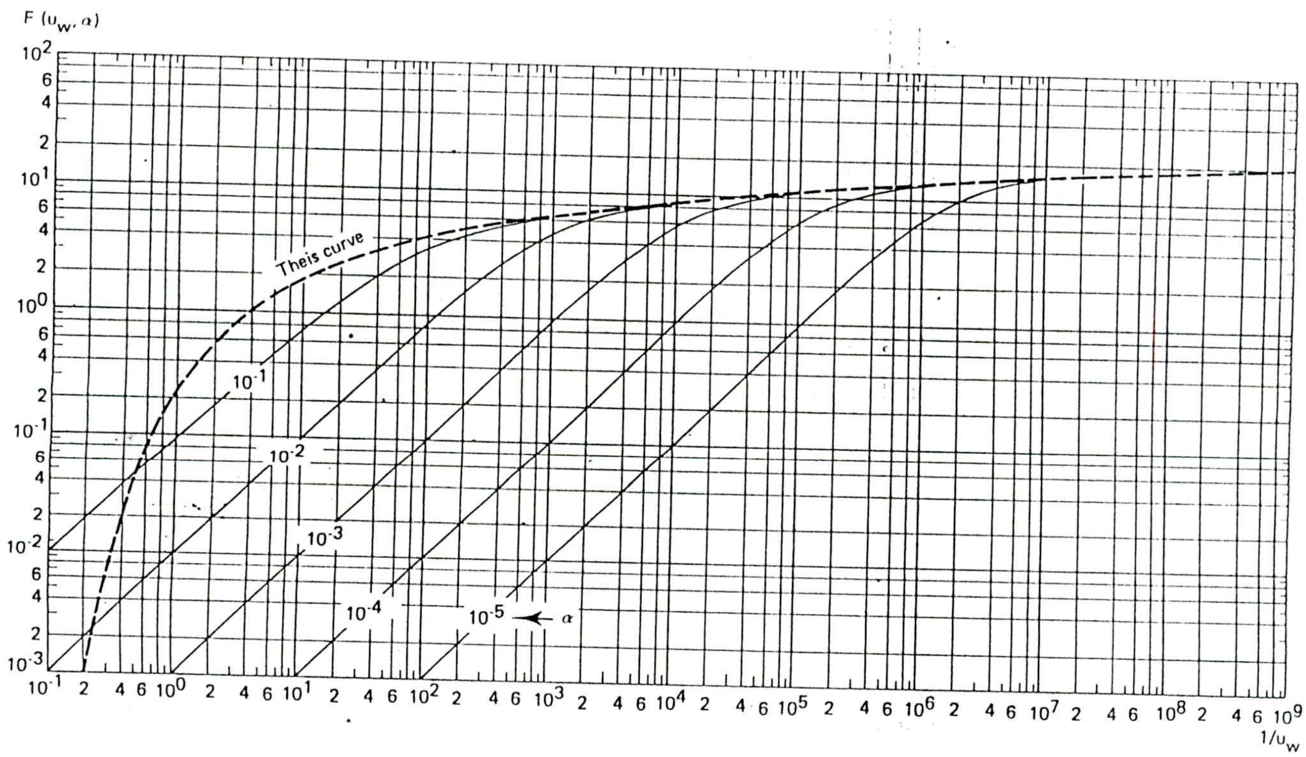

Fig. 4.4 Family of Papadopulos-Cooper's Type Curves: $F(u_w,\alpha)$ versus $1/u_w$ for Different Values of α

Procedure

- On log-log paper, the family of type curves $F(u_w, \alpha)$ versus $1/u_w$ for different values of α are plotted and shown in Fig. 4.4.
- On another sheet of log-log paper of the same scale, plot the data curve s_w versus t.
- Match the data curve with one of the type curves.
- Choose an arbitrary point on the superimposed sheets and note for that point the values of $F(u_w, \alpha)$, $1/u_w$, s_w and t note also the value of α on the matching type curve.
- Substitute the values of $F(u_w,\alpha)$ and s_w, together with the known value of Q, into Eq^n. (4.18) and calculate KD and then calculate the value of S using the Eq^n. (4.19).

4.4.4 Hurr-Worthington's Method

Hurr-Worthington's method is based on the following assumptions and conditions.

i) The aquifer is confined or leaky.

ii) The aquifer has an infinite areal extent.

iii) The aquifer is homogenous, isotropic and of uniform thickness over the area influenced by the test.

iv) Prior to pumping the piezometric surface is horizontal (or nearly so) over the area that will be influenced by the test.

v) The aquifer is pumped at a constant discharge rate.

vi) The well penetrates the entire thickness of the aquifer and thus receives water by horizontal flow.

vii) The water removed from storage is discharged instantaneously with decline of head.

viii) The storage in the well can not be neglected.

ix) The flow to the well is in unsteady state.

x) The storativity is known or can be estimated with reasonable accuracy.

xi) The non-linear well losses are negligible.

The unsteady state flow to a small diameter well pumping a confined aquifer can be described by a modified Theis equation, provided that the non-linear well losses are negligible. The equation is written as

$$s_w = \frac{Q}{4\pi KD} W(u_w) \qquad (4.20)$$

$$\text{where, } u_w = \frac{r_{ew}^2 S}{4KD\,t} \qquad (4.21)$$

Rearranging Eq^n. (4.20) gives

$$W(u_w) = \frac{4\pi KD\, s_w}{Q} \qquad (4.22)$$

Hurr (1966) demonstrated that multiplying both sides of Eq^n. (4.22) by u_w eliminates KD from the right hand side of the equation

$$u_w W(u_w) = \frac{4\pi KD\, s_w}{Q} * \frac{r_{ew}^2 S}{4KD\,t} = \frac{\pi\, r_{ew}^2 S}{t} * \frac{s_w}{Q} \qquad (4.23)$$

The Fig. 4.5 is plotted to illustrate the given values of u_w and $u_w W(u_w)$.

Hurr (1966) outlined a procedure for estimating the transmissivity of a confined aquifer from a single drawdown observation in the pumped well. In 1981, Worthington incorporated Hurr's procedure in a method for estimating the transmissivity of (thin) leaky aquifers from single well drawdown data.

In leaky aquifers the drawdown data can be affected by well losses, by well-bore storage phenomena during early pumping times, and by leakage during late pumping times.

According to Worthington (1981), after the drawdown data have been corrected for non-linear well losses, one can calculate "pseudo-transmissivities by applying Hurr's procedure to a sequence of the corrected data. Both well-bore storage effects and leakage effects reduce the drawdown in the well and will therefore lead to calculate pseudo-transmissivities for each time and each corrected drawdown. An average of these pseudo-transmissivity values is the best estimated transmissivity in the location concerned.

The unsteady state drawdown data from confined aquifers can also be used to construct a semi-log plot of pseudo-transmissivities versus time to account for the early time well-bore storage effects.

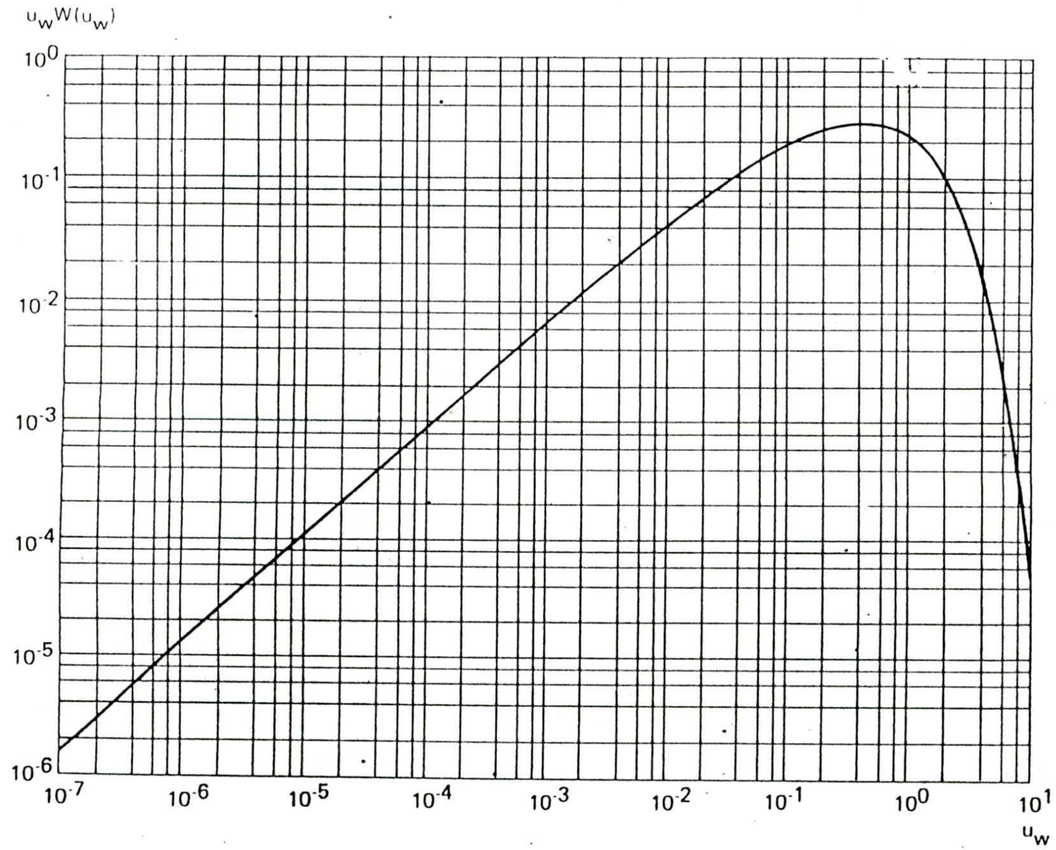

Fig. 4.5 Graph of Corresponding Values of u_w and $u_w W(u_w)$

Procedure

- For a single drawdown observation calculate $u_wW(u_w)$ from Eq^n. (4.23) for known values of S and r_{ew} and the corresponding values of t, s_w, and Q.
- From Fig. 4.5 determine the corresponding value of u_w by knowing $u_wW(u_w)$.
- Calculate pseudo-transmissivity value by substituting the values of u_w, r_{ew}, t and s_w into Eq^n. (4.21).
- An average of all the pseudo-transmissivities will provide the best estimate of transmissivities in the location concern.

4.5 Logan Approximation Method

If a well in a confined aquifer has been pumped for such a long period that the flow is in steady-state, the Logan method can be applied to calculate the transmissivity.

Logan (1964) derived his formula from the Theim's formula for a confined aquifer which can be written as

$$KD = \frac{2.3\ Q \log r_{max}/r_w}{2\pi s_{mw}} \tag{4.24}$$

where, r_w = radius of the pumped well; r_{max} = radius of influence (= radius of depression cone); s_{mw} = maximum drawdown in the pumped well.

The accuracy of the calculation depends only on the accuracy of the measurement of s_{mw} (on which well losses may have a substantial influence) and on the accuracy of the ratio r_{max}/r_w. The ratio of r_{max}/r_w can not be accurately determined without the use of piezometers. However, the variations in the ratio r_{max} and r_w may be substantial, the variations in the logarithms of their ratios are much smaller.

Therefore, assuming an average condition of the radius of influence, a value of 3.33 for the logarithm of the ratio may be accepted as a rough approximation and the Eq^n. (4.24) yields

$$KD = \frac{1.22\,Q}{s_{mw}} \tag{4.25}$$

Substituting the values of Q and s_{mw} in the Eq^n. (4.25) and the value of KD can be determined.

4.6 Well Performance Test

The drawdown in a pumped well consists of two components, the aquifer loss and the well loss. A well-performance test is conducted to determine these losses (Fig. 4.6).

Aquifer losses are the head losses that occur in the aquifer where the flow is laminar. They are time-dependent and vary linearly with the well discharge. In practice, the extra head loss induced, for instance, by partial penetration of a well is also included in the aquifer losses.

Well losses are divided into linear and non-linear head losses. Linear well losses are caused by damaging of the aquifer during drilling and completion of the well. These losses comprise, head losses due to compaction of the aquifer material during drilling, head losses due to plugging of the aquifer with drilling mud which reduces the permeability near the bore-hole, head losses in the gravel pack and head losses in the screen. Amongst the non-linear well losses are the friction losses that occur inside the well screen and in the suction pipe where the flow is turbulent, and the head losses that occur in the zone adjacent to the well where the flow is usually also turbulent. All these well losses are responsible for the drawdown inside the well being much greater than one would expect on theoretical grounds.

The well performances tests are mainly two types: step drawdown test and recovery test. However, the main objective of any well performance test is to split the total drawdown into different loss components. Here, the step drawdown test is used for the analysis.

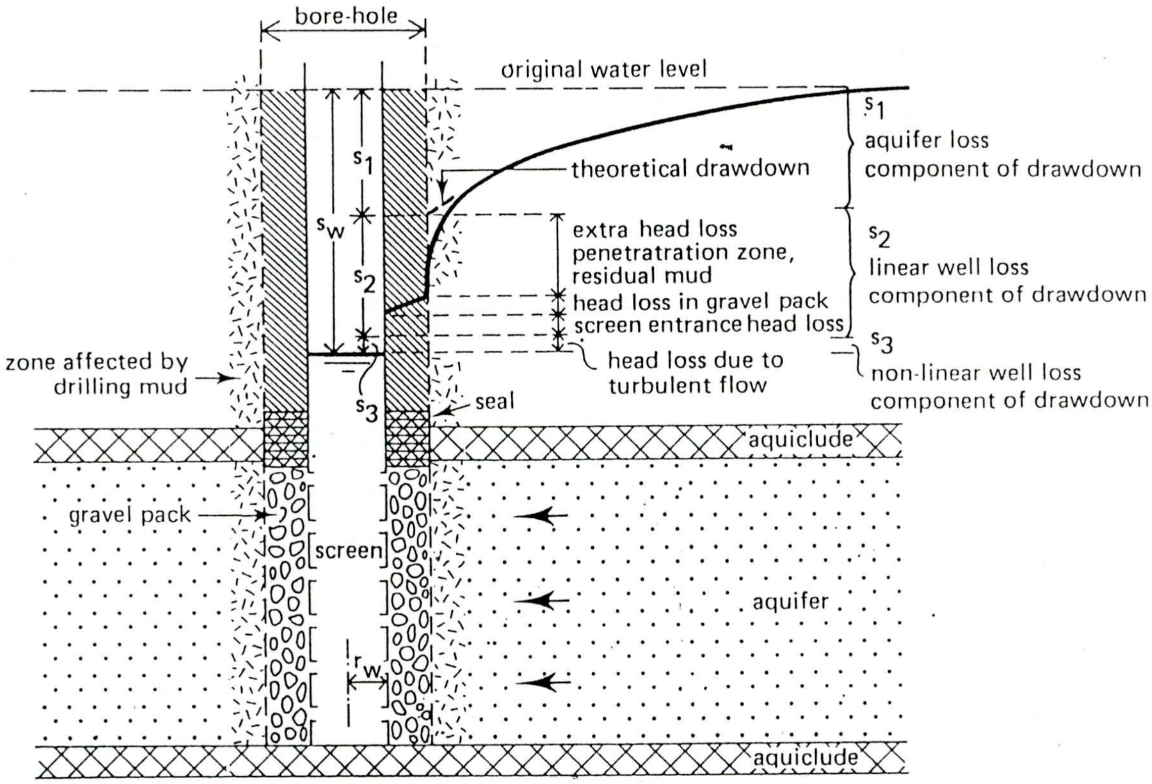

Fig. 4.6 Various Head Losses in a Pumped Well

4.6.1 Step Drawdown Test

It is a single well test (first performed by Jacob in 1947) in which the well is pumped at a low constant discharge rate until the drawdown within the well stabilizes. The pumping rate is then increased to a higher constant discharge rate and the well is pumped until the drawdown stabilizes once more. This process is repeated through at least three steps, which should all be of equal duration say, from 30 minutes to 2 hours each.

For the drawdown in a pumped well, Jacob gave the following equation:

$$s_w = B(r_{ew}, t)Q + CQ^2 \tag{4.26}$$

where, $B(r_{ew},t) = B_1(r_{ew},t)+B_2$ (4.27)

$B_1(r_{ew},t)$ and B_2 = linear aquifer and well loss coefficients respectively;
C = non-linear well loss coefficient; r_{ew} = effective radius of the well;
r_w = actual radius of the well; Q = discharge; t = pumping time.

Like, Jacob, different researchers have also found considerable variations in water level in and outside of the wells and tried to explain it mathematically in more exact form. Rorabaugh (1953) therefore suggested that Jacob's equation should be:

$$s_w = BQ + CQ^p \tag{4.28}$$

where, p have the values of 1.5 to 3.5, depending on the value of Q. But the value of p = 2, as proposed by Jacob is still accepted (Ramey 1982; Skinner 1988).

Various methods are available to analyze the step drawdown test. The methods based on Jacob's equation are:

i) The Hantush-Bierschenk method determines B and C which can be applied in confined, leaky or unconfined aquifers;
ii) The Eden-Hazel method can be applied in confined aquifers which gives the value of well loss coefficients as well as estimates of the transmissivity of the aquifer.

In this study, Hantush-Bierschenk method is used to determine the losses.

4.6.2 Hantush-Bierschenk's Method:

The procedure suggested by Hantush (1964) and Bierschenk (1963) is applicable if the following assumptions and conditions are satisfied:

i) The aquifer is confined or leaky.

ii) The aquifer has an infinite areal extent.

iii) The aquifer is homogenous, isotropic and of uniform thickness over the area influenced by the test.

iv) Prior to pumping the piezometric surface is horizontal (or nearly so) over the area that will be influenced by the test.

v) The aquifer is pumped step-wise at increased discharge rate.

vi) The well penetrates the entire thickness of the aquifer and thus receives water by horizontal flow.

vii) The water removed from storage is discharged instantaneously with decline of head

viii) The diameter of the well is small, i.e,. the storage in the well can be neglected

ix) The flow to the well is in an unsteady state

x) The non-linear well losses are appreciable and vary according to the expression CQ^2

Applying the principle of superposition to Jacob's equation, Hantush (1964) expressed the drawdown $s_{w(n)}$ in a well during the n-th step of a step-drawdown test as:

$$S_{w(n)} = \sum_{i=1}^{n} \Delta Q_i B(r_{ew}, t - t_i) + CQ_n^2 \qquad (4.29)$$

where, $s_{w(n)}$ = total drawdown in the well during the n-th step at time t;

r_{ew} = effective radius of the well; Q_n = constant discharge during the n-th step;

t_i = time at which the i-th step begins ($t_1 = 0$); $\Delta Q_i = Q_i - Q_{i-1}$ = discharge increment beginning at time t_i; Q_i = constant discharge during the i-th step of that preceding the n-th step.

The sum of increments of drawdown taken at a fixed interval of time from the beginning of each step ($t-t_i = \Delta t$) can be obtained from Eq^n. (4.29).

$$\sum_{i=1}^{n} \Delta s_w(i) = s_{w(n)} = B(r_{ew}, \Delta t)\, Q_n + CQ_n^2 \qquad (4.30)$$

where, $\Delta s_{w(i)}$ = drawdown increment between the i-th step and that preceding it, taken at time $(t_i+\Delta t)$ from the beginning of the i-th step. Eq^n. (4.30) can also be written as,

$$\frac{s_w(n)}{Q_n} = B(r_{ew}, \Delta t) + CQ_n \qquad (4.31)$$

A plot of $s_{w(n)}/Q$ versus Q_n on arithmetic paper will yield a straight line whose slope is equal to C. The ordinate of this straight line at zero discharge gives the value of B.

4.7 Determination of Different Types of Losses

Referring from the Jacob's formula, the drawdown in a fully penetrated well (neglecting the well loss components) can be expressed as

$$s = \frac{2.3Q}{4\pi KD}\log\frac{2.25KDt}{r_{ew}^2 S} \qquad (4.32)$$

$= B_1(r_{ew},t)Q$ = Aquifer Loss

Again, from Eq^n. (4.27)

$B(r_{ew},t) = B_1(r_{ew},t)+B_2$

multiply both side by Q

$B(r_{ew},t)Q = B_1(r_{ew},t)Q+B_2Q$

Where, $B(r_{ew},t)Q$ = Laminar Loss, $B_1(r_{ew},t)Q$ = Aquifer Loss, B_2Q = Linear Well Loss

$B_2Q = B(r_{ew},t)Q - B_1(r_{ew},t)Q$

Turbulent loss (non-linear well loss) = CQ^2

Total well loss = Linear well loss + Non-linear well loss = $B_2Q + CQ^2$

4.8 Specific Capacity of the Well

If the operating discharge is divided by the average drawdown (ADD) of a production well, the specific capacity is obtained. Specific capacity is a measure of the productivity of a well. From step drawdown test, the drawdown of a well is

$s = (B_1 + B_2)\ Q + CQ^2$

Therefore, the specifc capacity is

$$\frac{Q}{s}=\frac{1}{(B_1+B_2)\,Q+CQ^2} \tag{4.33}$$

Any significant decline in the specific capacity of well can be attributed either to a reduction in the transmissivity due to a lowering of the ground water level in an unconfined aquifer or to an increase in well losses associated with various type clogging or the deterioration of well screen.

4.9 Well Efficiency

The theoretical well efficiency or simple the well efficiency Ew can be expressed as

$$E_w=\frac{B_1 Q}{(B_1+B_2)\,Q+CQ^2}*100\ \% \tag{4.34}$$

A well is said to be 100 percent efficient, if it exhibit no well losses, that is the ($B_2Q + CQ^2$) term becomes zero. A well efficiency of 70 to 80 percent is usually obtainable if an appropriate and efficient design construction and development practice are followed.

4.10 Determination of Skin Factor

In groundwater hydraulics, the skin effect is defined as the difference between the total drawdown observed in a well and the aquifer loss component, assuming that the non-linear well losses are negligible. Adding skin effect to Jacob's Eq^n. (4.8) and assuming that the non-linear well losses are so small that they can be neglected, we get

$$S_w=\frac{Q}{4\pi KD}\ln\frac{2.25\,KD\,t}{r_w^2 S}+(skin)\cdot\frac{Q}{2\pi KL}$$

$$=\frac{Q}{4\pi KD}\left[\ln\frac{2.25\,KD\,t}{r_w^2 S}+2(skin)\right] \tag{4.35}$$

Where, skin($Q/2\pi KD$) = skin effect in m, skin = skin factor dimensionless

r_w = actual radius of the well in m.

After the pump has been shut down, the residual drawdown s'_w in the well for $t' > 25r_w^2S/KD$ is

$$S'_w = \frac{Q}{4\pi KD}\left[\ln\frac{2.25\,KD\,t}{r_w^2 S} + 2(skin)\right] - \frac{Q}{4\pi KD}\left[\ln\frac{2.25\,KD\,t'}{r_w^2 S} + 2(skin)\right]$$

$$= \frac{2.3Q}{4\pi KD}\log\frac{t}{t'}$$

For $t' > 25r_w^2S/KD$, a semi log plot of s'_w versus t/t' will yield a straight line.

For time $t = t_p$ = total pumping time, Eq^n. (4.35) becomes,

$$S_w(t_p) = \frac{Q}{4\pi KD}\ln\frac{2.25\,KD\,t_p}{r_w^2 S} + (skin)\frac{Q}{2\pi KL}$$

The difference between $s_w(t_p)$ and the residual drawdown s'_w at any time t' is

$$S_w(t_p) - S'_w = \frac{Q}{4\pi KD}\ln\frac{2.25\,KD\,t_p}{r_w^2 S} + (skin)\frac{Q}{2\pi KD} - \frac{Q}{4\pi KD}\ln\frac{t_p + t'_i}{t'_i} \qquad (4.36)$$

For, $$\frac{t_p + t'_i}{t'_i} = \frac{2.25\,KD\,t_p}{r_w^2 S} \qquad (4.37)$$

Eq^n. (4.36) reduces to

$$s_w(t_p) - s'_{wi} = skin\left(\frac{Q}{2\pi KD}\right)$$

$$skin = \frac{2\pi KD}{Q}\{s_w(t_p) - s'_w\} \qquad (4.38)$$

Chapter 5
Results and Discussions

5.1 Transmissivity

The construction and development tests on the DWASA deep tubewells were performed without installation of piezometers. So, the pumping tests conducted by DWASA can be treated as a single well test. Determination of transmissivity and storativity are therefore encountered some constraints in utilizing the well-known methods which are based on piezometric readings. To utilize the single well tests, some 5 suitable methods are selected from literature to overcome these constraints. The methods are Jacob straight line method, Theis recovery method, Papadopulos-Cooper method (curve-fitting method), Hurr-Worthington method and Logan (approximation) method. The selected 44 wells are analysed by these methods and their zone-wise transmissivity and storativity results are presented in Tables 5.1 - 5.6. Calculations on each of these methods are explained in Appendix-A. Few graphical representations of the time-drawdown curves based on Jacob method are shown in Appendix-B, Papadopulos-Cooper method in Appendix-C, Theis recovery method in Appendix-D, Hurr-Worthington method in Appendix-E.

It is seen from Tables 5.1 - 5.6 that the Jacob straight line method gives consistently higher values than the other 4 methods. Transmissivity values calculated from these other 4 methods vary more or less closely. Actually, Jacob's method is a well known method to determine the transmissivity using the drawdowns observed by piezometers at certain distances apart from the pumped well. In this regard, although the Jacob's method under single well principle does not require piezometric readings, it becomes very sensitive with respect to drawdown for minor variations in the discharge rate. A constant discharge is essential for this method which is very difficult to achieve in practice. Again, Jacob's straight-line method is applicable to data from single well tests in leaky aquifers, provided that $25r_c^2/KD < t < cS/20$. Under single well test, it is not possible to determine the value of c for Dhaka city wells. If we take very high value of c and a minimum value of S, the time we obtain indicates that the method is not applicable for late time data points.

The Hurr-Worthington's method is applicable for corrected time-drawdown data. To do the correction, the turbulent losses calculated are subtracted from the observed drawdown data. On the otherhand, the Logan approximation method is an empirical method, dependent only on the maximum drawdown observed in the well.

Table. 5.1 Transmissivity and Storativity Values for Zone 1

Location	Jacob St. Line Method (m^2/d)	Theis Recovery Method (m^2/d)	Papadopu.-Cooper Method (m^2/d)	Hurr-Worth. Method (m^2/d)	Logan Method (m^2/d)	Storativity by Papa.-Cooper Method
Jurain	1733	494	508	465	459	$1.0x10^{-5}$
Mughdapara	1149	730	584	450	484	$1.8x10^{-5}$
Gopibagh	736	657	636	501	512	$1.2x10^{-5}$
Jatrabari	1636	403	532	227	372	$3.2x10^{-5}$
Bangababan	1013	482	487	342	339	$2.4x10^{-5}$
Sayedabad	925	395	493	371	475	$1.3x10^{-5}$
Paterbagh	1321	738	493	408	450	$4.7x10^{-5}$
Laxmibazar	1325	686	633	526	544	$1.3x10^{-5}$

Table. 5.2 Transmissivity and Storativity Values for Zone 2

Location	Jacob St. Line Method (m^2/d)	Theis Recovery Method (m^2/d)	Papadopu.-Cooper Method (m^2/d)	Hurr-Worth. Method (m^2/d)	Logan Method (m^2/d)	Storativity by Papa.-Cooper Method
B.D.R. Pil.	3057	820	756	582	676	$1.9x10^{-5}$
Azimpur	1784	643	1170	1026	1075	$2.9x10^{-5}$
Hazaribag	3887	1219	1026	927	959	$4.6x10^{-5}$
Islambag	2056	1187	975	840	959	$9.5x10^{-5}$
Jagonnath. C.	1285	-	685	465	832	$1.5x10^{-5}$
Rajnra. D.R.	2121	1291	1349	1385	1096	$2.2x10^{-5}$
Mitford H.	4638	1276	923	524	791	$1.9x10^{-5}$

Table. 5.3 Transmissivity and Storativity Values for Zone 3

Location	Jacob St. Line Method (m^2/d)	Theis Recovery Method (m^2/d)	Papadopu.-Cooper Method (m^2/d)	Hurr-Worth. Method (m^2/d)	Logan Method (m^2/d)	Storativity by Papa.-Cooper Method
Central Road	1896	747	840	651	699	$1.6x10^{-5}$
Dhanmondi R7	2257	1216	878	856	857	$8.3x10^{-5}$
Pisci.M.pur	1822	642	585	452	498	$1.2x10^{-5}$
Dhaka Lab.S.	1188	400	824	694	738	$3.1x10^{-5}$
Barabo,S..moli	892	519	468	331	365	$2.7x10^{-5}$
Monipuripara	2509	754	975	798	777	$1.7x10^{-5}$
Bangla Motor	2013	1019	866	672	709	$1.7x10^{-5}$

Table. 5.4 Transmissivity and Storativity Values for Zone 4

Location	Jacob St. Line Method (m^2/d)	Theis Recovery Method (m^2/d)	Papadopu.-Cooper Method (m^2/d)	Hurr-Worth. Method (m^2/d)	Logan Method (m^2/d)	Storativity by Papa.-Cooper Method
Mirpur-2	1690	544	452	484	570	$1.6x0^{-6}$
Mirpur-7	1320	873	715	722	587	$2.3x10^{-5}$
Mirpur-10	1620	831	797	684	725	$2.6x10^{-5}$
Mirpur-12 B.D	1288	386	439	318	350	$4.7x10^{-5}$
Mirpur B. C.	612	462	487	405	445	$3.7x10^{-5}$
Kallyanpur	457	328	355	246	266	$1.2x10^{-5}$
Pallabi	1387	399	452	556	366	$3.3x10^{-5}$
Kafrul	1725	366	546	387	420	$3.9x10^{-6}$
Gudaraghat	2196	239	300	208	214	$1.5x10^{-6}$

Table. 5.5 Transmissivity and Storativity Values for Zone 5

Location	Jacob St. Line Method (m^2/d)	Theis Recovery Method (m^2/d)	Papadopu.-Cooper Method (m^2/d)	Hurr-Worth. Method (m^2/d)	Logan Method (m^2/d)	Storativity by Papa.-Cooper Method
Nakhalpara	1672	500	508	427	457	$1.0x10^{-5}$
Banani	3396	630	755	531	611	$1.1x10^{-5}$
Uttara	2481	1096	1125	994	975	$1.4x10^{-5}$
Shahajadpur	1644	781	548	441	493	$1.1x10^{-5}$
Kuratoli	2016	920	910	857	901	$1.5x10^{-5}$
Ashkona	1532	720	738	691	665	$2.5x10^{-5}$

Table. 5.6 Transmissivity and Storativity Values for Zone 6

Location	Jacob St. Line Method (m^2/d)	Theis Recovery Method (m^2/d)	Papadopu.-Cooper Method (m^2/d)	Hurr-Worth. Method (m^2/d)	Logan Method (m^2/d)	Storativity by Papa.-Cooper Method
Circuit House	1752	525	582	511	558	$1.9x10^{-5}$
Rajarbagh	826	517	451	359	388	$1.6x10^{-5}$
Ulon,Rampura	1546	775	873	648	712	$1.0x10^{-5}$
Goran	1889	630	650	584	598	$2.3x10^{-5}$
Shahajanpur	2095	545	508	410	462	$8.4x10^{-6}$
Eskaton Gar.	1241	384	609	453	487	$3.0x10^{-5}$
Khilgaon	1321	720	499	383	412	$1.1x10^{-5}$

The Papadopulos-Cooper's method is a curve-fitting method devised to match data curves with the type curves by taking the storage capacity of the well into account. The early-time portion of the type curves corresponds to the period when most of the water is derived from storage within the well. But the data points observed for Dhaka city wells are taken after exhausting the storage in the wells. Thus the observed data on the logarithmic plots exhibit a flat curvature. Apparently several good matching positions depending on personal judgement are obtainable. In such case, Papadopulos-Cooper method becomes practically indeterminate. Again, the method is only applicable for confined aquifers which is very difficult to ascertain in Dhaka city aquifer systems.

In the Theis recovery method, the transmissivity depends on the slope of the residual drawdown versus time (log) curves. It is known that the storage in the well have an influence on the residual drawdown at the beginning of a recovery test. If the conditions $t_p > 25r_c^2/KD$ and $t' > 25r_c^2/KD$ are met, a semi-log plot of s'_w versus t/t' yields a straight-line and Theis recovery method is applicable. As the observed recovery data should be plotted as a straight-line for at least one log cycle of t/t', according to Uffink (1982) both t_p and t' should be at least $500r_c^2/KD$. While the above conditions for t_p and t' are met for all the wells in Dhaka city, it has been pointed out that the tests conducted are for 4 different discharges of 4 time steps. Thus the discharge value that is used in the Theis equation is the weighted average of the 4 discharges applied in the test. But the water level that is observed recovers at a rate may not in conformation to this weighted average discharge. Although it is known that the recovery test is more reliable than pumping test, the above testing procedure left some doubt in its subsequent analysis by Theis method.

Therefore, it reveals from the above discussion that the Hurr-Worthington's method provides a better result than the other 4 methods. In the Hurr-Worthington's method there are provisions for correcting the observed drawdowns due to turbulence losses occurred in the wells. As a result, Hurr-Worthington method is selected as an appropriate method for the already available pumping tests of DWASA wells. Subsequently on the basis of the Hurr-Worthington's method, an iso-transmissivity map, using the selected 44 wells data, is drawn to get an idea of its spatial variations in the aquifer system of the Dhaka city. The map as presented in Fig. 5.1 shows that the south-west region and north-east corner of the city have higher transmissivity values in the range of 700 to 1000m^2/day, while rest of the region have lower transmissivity values in the range of 400 to 500 m^2/day. Tables 5.7 to 5.12 are provided here to isolate the point transmissivity values obtain by Hurr-Worthington method along with the range of transmissivity values (maximum and minimum) obtained by those other 4 methods, i.e., Papadopulos-Cooper, Hurr-Worthington, Theis recovery and Logan methods. It is observed from

Table 5.7 Range of Transmissivity Values for Zone 1 by the Selected 4 Methods

Location	Hurr-Worthingtong (m^2/d)	Max^m (m^2/d)	Min^n (m^2/d)
Jurain	465	508	459
Mughdapara	450	730	450
Gopibagh	501	657	501
Jatrabari	227	532	227
Bangababan	342	487	339
Sayedabad	371	493	371
Paterbagh	408	738	408
Laxmibazar	526	686	526

Table 5.8 Range of Transmissivity Values for Zone 2 by the Selected 4 Methods

Location	Hurr-Worthingtong (m^2/d)	Max^m (m^2/d)	Min^n (m^2/d)
B.D.R. Pilkhana	582	820	507
Azimpur	1026	1170	943
Hazaribag	927	1219	927
Islambag	840	1187	840
Jagonnath. College	465	832	465
Rajnarayan Dhar Road	1385	1385	1096
Mitford Hospital	524	1276	524

Table 5.9 Range of Transmissivity Values for Zone 3 by the Selected 4 Methods

Location	Hurr-Worthingtong (m^2/d)	Max^m (m^2/d)	Min^n (m^2/d)
Central Road	651	840	651
Dhanmondi Road 7	856	1216	856
Pisciculture,M.pur	452	642	452
Dhaka Lab. School	694	824	491
Barabo,Shamoli	331	519	331
Monipuripara	798	975	777
Bangla Motor	672	1019	672

Table 5.10 Range of Transmissivity Values for Zone 4 by the Selected 4 Methods

Location	Hurr-Worthingtong (m^2/d)	Max^m (m^2/d)	Min^n (m^2/d)
Mirpur-2	484	570	452
Mirpur-7	722	873	580
Mirpur-10	684	831	684
Mirpur-12 B.D	318	439	318
Mirpur B. C.	405	487	405
Kallyanpur	146	355	246
Pallabi	556	556	366
Kafrul	387	546	387
Gudaraghat	208	300	208

Table 5.11 Range of Transmissivity Values for Zone 5 by the Selected 4 Methods

Location	Hurr-Worthingtong (m^2/d)	Max^m (m^2/d)	Min^n (m^2/d)
Nakhalpara	427	508	427
Banani	531	755	531
Uttara	994	1125	975
Shahajadpu	441	781	441
Kuratoli	857	920	857
Ashkona	691	738	665

Table 5.12 Range of Transmissivity Values for Zone 6 by the Selected 4 Methods

Location	Hurr-Worthingtong (m^2/d)	Max^m (m^2/d)	Min^n (m^2/d)
Circuit House	511	558	512
Rajarbagh	359	517	359
Ulon,Rampura	648	873	648
Goran	584	650	584
Shahajanpur	410	545	410
Eskaton Gar.	453	609	453
Khilgaon	383	720	383

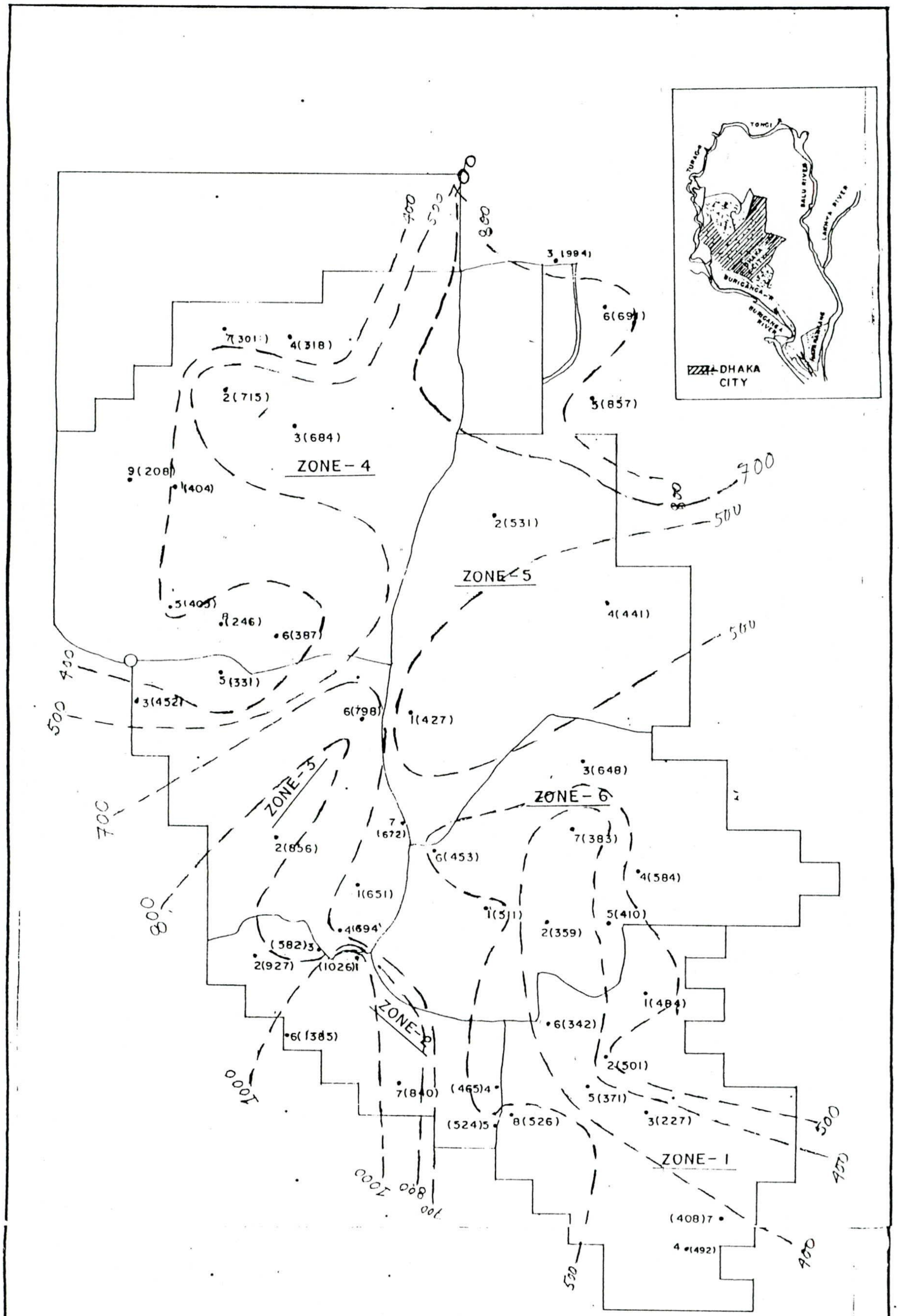

FIG: 5-1. TRANSMISSIVITY MAP OF DHAKA CITY

ZONE : 1	ZONE : 2	ZONE : 3	ZONE : 4	ZONE : 6	ZONE : 5
1. MUGDAPARA	1. AZIMPUR	1. CENTRAL ROAD	1. MIRPUR – 2	1. NAKHALPARA	1. CIRCUIT HOUSE
2. GOPIBAGE	2. HAZARIBAGH	2. DANMONDI ROAD – 7	2. MIRPUR – 7	2. BANANI	2. RAJARBAGH
3. JATRABARI	3. B.D.R. PILKHANA	3. PISCICULTURE, MOHAMMADPUR	3. MIRPUR – 10	3. UTTRA	3. ULON RAMPURA
4. JURRAIN	4. JAGANATH COLLEGE	4. DHAKA LABORATORY SCHOOL	4. MIRPUR-12, BLOCK-D	4. SHAHAJADPUR	4. GORAN
5. SAYEDABAGH	5. MITFORD HOSPITAL	5. BARABO, SHAMOLI	5. MIRPUR BANGLA COLLEGE	5. KURATOLI	5. SHAJAHANPUR
6. RANGA BABAN	6. RAJNARAYAN DHAR ROAD	6. MONIPURIPARA	6. KAFRUL	6. ASHKONA	6. ESKATON GARDEN
7. PATERBAGH	7. ISLAMBAGH	7. BANGLA MOTOR	7. PALLBI		7. KHILGAON
8. LAXMIBAZAR			8. KALLYANPUR		
			9. GUDARAGHAT		

these tables that the highest point transmissivity obtained at Uttara (Zone 5) by Theis recovery method which is about 1517 m^2/day and the lowest point transmissivity obtained at Gudaraghat (Zone 4) by Hurr-Worthington method which is about 208 m^2/day. It is worthy to mention here that the highest point transmissivity value obtained by Hurr-Worthington method is at Rajnarayan Dhar Road of Zone 2 which is about 1385 m^2/day.

Transmissivity values obtained by the present study are compared with the previous studies conducted for the same wells or nearby wells and are presented in Table 5.13. It is observed that the values are in close proximity. The methods applied for the previous studies are not mentioned in their report. Despite of very scantly transmissivity values are available from previous studies, the closeness of the values with present study builds some confidence to the values obtained for a large number of points, and off course will be more beneficial for detail characterization of the aquifer concern.

Table 5.13 Comparison of Transmissivity Values with Previous Studies

Location	Transmissivity from present study		Transmissivity from previous studies	
	Hurr-Worth. Method (m^2/day)	Theis Recovery Method (m^2/day)	Values (m^2/day)	References
Dhanmondi 7	856	1042	794	Parsons, 1980
Azimpur	1025	943	1048	Parsons, 1980
Uttara	994	1317	1001	BWDB
Mirpur	405	462	422	BWDB
Gymkhana/B.D.R.Pil.	582	507	435	Welsh, 1977
Tajgaon/Monipuripara	798	1114	1184	Parsons, 1980
Khilgaon	383	705	901	Parsons, 1980
Rampura	648	-	884	Sajal, 1995

5.2 Storativity

The storativity values of different places of Dhaka city are calculated only by Papadopulos-Cooper's methods and zone-wise storativity values are presented in Tables 5.1-5.6. It is observed that the highest storativity value is found in Islambagh (9.5×10^{-5}) tubewell of Zone 2 and lowest storativity value is found in Gudaraghat (1.5×10^{-6}) of Zone 4. A storativity contour map is drawn in Fig. 5.2 which shows the storativity values of different places of Dhaka city. It is seen from the map that the majority of the city area representating storativity values around 2×10^{-5}. It is also seen that the south-western part of the Dhaka city gives the highest storativity values which is about 4×10^{-5}.The north-west corner and the south-east corner of Dhaka city represent the storativity values of 3×10^{-5}.

Table 5.14 Comparison of Storativitiy Values with Previous Studies

Location	Storativity from present study	Storativity from previous studies	
	Papadopulos-Cooper Method	Storativity Value	Reference
Mirpur	3.7×10^{-5}	3.5×10^{-4}	BWDB
Gymkhana/B.D.R.Pil.	1.9×10^{-5}	1.6×10^{-3}	Welsh, 1977
Uttara	1.4×10^{-5}	9.0×10^{-4}	BWDB
Dhanmondi	8.3×10^{-5}	4.7×10^{-4}	Parsons, 1980

Storativity values obtained by the present study are compared with the previous studies conducted for the same wells or nearby wells and are presented in Table 5.14. The values compared vary more than one order of magnitude for two wells and the rest two wells are within one order at magnitude. There is no method mentioned for the previous studies obtained from the literature. For the present study, only Papadopulos-Cooper method is found suitable for S determination. Again, the method is applicable under confined aquifer system which is in doubt for the situation prevailing in Dhaka city.

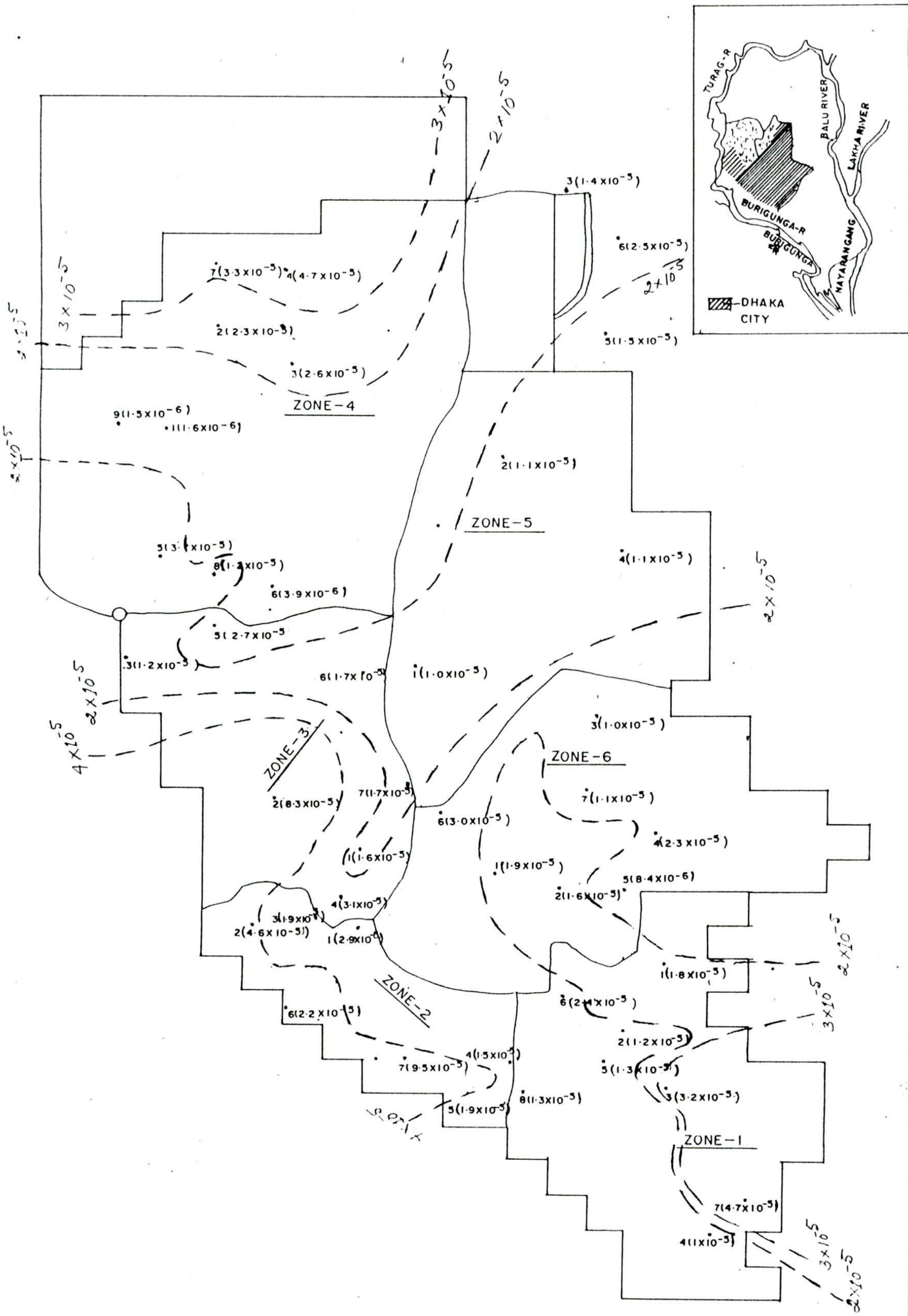

FIG. 5·2 – STORATIVITY MAP OF DHAKA CITY

ZONE : 1	ZONE : 2	ZONE : 3	ZONE – 4	ZONE–6	ZONE – 5
1. MUGDAPARA	1. AZIMPUR	1. CENTRAL ROAD	1. MIRPUR – 2	1. NAKHAL PARA	1. CIRCUIT HOUSE
2. GOPIBAGE	2. HAZARIBAGH	2. DANMONDI ROAD – 7	2. MIRPUR – 7	2. BANANI	2. RAJARBAGH
3. JATRABARI	3. B.D.R PILKHANA	3. PISCICULTURE MOHAMMADPURE	3. MIRPUR – 10	3. UTTRA	3. ULON RAMPURA
4. JURRAIN	4. JAGANATH COLLEGE	4. DHAKA LABORATORY SCHOOL	4. MIRPUR – 12, BLOCK – D	4. SHAHAJADPUR	4. GORAN
5. SAYEDABAGH	5. MITFORD HOSPITAL	5. BARABO, SHAMOLI	5. MIRPUR BANGLA COLLEGE	5. KURATOLI	5. SHAJAHANPUR
6. BANGA BABAN	6. RAJNARAYAN DHAR ROAD	6. MONIPURIPARA	6. KAFRUL	6. ASKONA	6. ESKATON GARDEN
7. PATERBAGH	7. ISLAMBAGH	7. BANGLA MOTOR	7. PALLBI		7. KHILGAON
8. LAXMIBAZAR			8. KALLYAN PUR		
			9. GUDARA GHAT		

5.3 Different Types of Losses

The well performance test (step drawdown test) data are used to determine the different types of losses which are presented in Tables 5.15 - 5.20. Co-efficients of B and C are calculated from the s/Q versus Q curves (Appendix-F). The zone-wise values of B and C are presented in Tables 5.21 - 5.26. These values can then be used to obtain the relationship between drawdown and discharge to choose, empirically, an optimum yield for the well, or to obtain information on the condition or efficiency of the well.

(a) Aquifer Losses

Aquifer losses are the head losses that occur in the aquifer where the flow is laminar. They are time dependent and vary linearly with the well discharge. Aquifer losses are independent of the well itself and depend on various aquifer characteristics. The highest aquifer loss found in Kallyanpur well (20.91 m) of Zone 4 and the lowest aquifer loss is found in Rajnarayan Dhar Road well (8.21 m) of Zone 2. It is interesting to note that the Zone-wise aquifer losses shown in the tables are comparable with the areas where transmissivity values are higher have less aquifer losses and areas where transmissivity values are lower have high aquifer losses.

(b) Total Well Losses

Total well losses are divided into linear and non-linear well losses. Linear well losses are caused by damaging of the aquifer during drilling and completion of the well, i.e., head losses due to plugging of the aquifer with drilling mud which reduces the permeability near the bore-hole, head losses in the gravel pack and head losses in the screen. The non-linear well losses are the friction losses that occur inside the well screen and in the suction pipe where the flow is turbulent and the head losses that occur in the zone adjacent to the well where the flow is also turbulent. All these well losses are responsible for the drawdown inside the well being much greater than one would expect on theoretical ground. The total well losses are found to vary in Dhaka city between 2.14 m and 14.73 m.

(c) Laminar Losses

Laminar losses are the sum of the aquifer losses and the linear well losses of the well. In this study the laminar well losses are found to vary between 10.4 m and 25.7 m.

(d) Turbulent Losses

These losses are also called non-linear well losses which occur due to turbulent flows inside the well and just outside in the vicinity of the well. Turbulent losses that are found for all the wells tested vary between 0.59 m and 7.83 m.

All these types of losses at an operating discharge of 4897 m^3/day (2 cusec) are obtained and shown in Table 5.26 to 5.31.

5.4 Specific Capacity and Well Efficiency

Both the specific capacity and the well efficiency are important to measure the performance of a well. The specific capacity (discharge/drawdown) represents the productivity of the aquifer also. In Dhaka city, the specific capacity varies from 550.82 m^2/day to 219.00 m^2/day and zone-wise specific capacity values of the wells are given in Tables 5.21 - 5.26.

The well efficiency (aquifer loss/total loss) represents the productivity of the well only and its evaluation requires the distinction of total drawdown into its aquifer and well loss component. The highest efficiency is found in Mirpur-10 well (86 percent) of Zone 4 and the lowest efficiency found in Khilgaon well (45 percent) of Zone 6. The well efficiency of different tubewells are presented in Tables 5.15 - 5.20. Low efficiency as low as 70 percent indicates its inadequate and poor well development.

5.5 Skin Factor

Skin effect is to account for the head losses in the vicinity of a well. The theory behind this concept is that the aquifer is assumed to be homogeneous up to the wall of the borehole, while all head losses are assumed to be concentrated in a thin, resistant, 'skin' against the wall of the borehole. The skin factors of the wells of Dhaka city varies from 0.32 to 8.06. The high values of skin factors indicate that the wells are poorly developed.

Table. 5.15 Different Types of Losses in Zone 1 at an Operating Discharge 7348 m^3/day

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)	Efficiency (%)
Jurain	18.52	4.85	16.12	7.25	69
Mughdapara	18.54	2.08	13.37	7.25	65
Gopibagh	17.38	3.12	14.59	5.90	71
Jatrabari	23.48	1.22	19.66	5.04	79
Bangababan	25.72	7.83	18.81	14.73	56
Sayedabad	19.77	2.57	16.82	5.52	75
Paterbagh	19.47	1.76	16.96	4.27	79
Laxmibazar	16.42	3.38	14.8	5.00	75

Table. 5.16 Different Types of Losses in Zone 2 at an Operating Discharge 7348 m^3 /day

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)	Efficiency (%)
B.D.R. Pil.	15.36	0.94	13.21	3.10	81
Azimpur	14.03	0.59	9.39	5.23	64
Hazaribag	13.74	1.49	9.04	6.19	59
Islambag	13.52	2.21	10.49	5.24	66
Jagonnath College	17.33	4.05	15.59	5.78	73
Rajnarayan D.R.	10.43	4.19	8.21	6.41	56
Mitford Hospital	14.18	1.49	11.94	3.73	76

Table. 5.17 Different Types of Losses inZone 3 at an Operating Discharge 7348 m^3/day

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)	Efficiency (%)
Central Road	14.11	1.99	12.58	3.52	78
Dhanmondi R7	12.05	1.89	10.59	3.55	76
Pisci.M.pur	17.86	2.57	15.63	4.8	76
Dhaka Lab.S.	14.92	2.03	13.09	3.86	77
Barabo,S..moli	18.36	3.92	14.16	8.12	64
Monipuripara	11.39	2.69	9.85	4.23	70
Bangla Motor	12.64	1.43	11.52	2.55	81

Table. 5.18 **Different Types of Losses in Zone 4 at an Operating Discharge 7348 m^3/day**

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)	Efficiency (%)
Mirpur-2	22.71	2.96	18.56	7.11	72
Mirpur-7	16.17	3.78	14.84	5.11	74
Mirpur-10	14.55	1.11	13.52	2.14	86
Mirpur- 12 B.-D	22.06	3.78	18.74	7.00	72
Mirpur B. C.	19.39	1.35	17.05	3.69	82
Kallyanpur	23.49	3.19	20.91	5.77	78
Pallabi	24.69	3.24	18.99	8.93	68
Kafrul	21.6	4.86	18.67	7.79	71
Gudaraghat	-	-	-	-	-

Table. 5.19 **Different Types of Losses in Zone 5 at an Operating Discharge 7348 m^3/day**

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)	Efficiency (%)
Nakhalpara	19.46	2.92	17.25	5.12	77
Banani	16.09	0.69	13.16	3.62	81
Uttara	11.31	2.03	8.4	4.94	63
Shahajadpur	18.11	1.49	11.11	8.49	57
Kuratoli	12.71	1.84	8.88	5.67	61
Ashkona	16.68	3.81	14.54	5.95	71

Table. 5.20 **Different Types of Losses in Zone 6 at an Operating Discharge 7348 m^3/day**

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)	Efficiency (%)
Circuit House	15.91	2.51	13.52	4.81	73
Rajarbagh	21.75	5.27	18.08	8.94	67
Ulon,Rampura	15.79	1.22	12.05	4.96	71
Goran	15.58	3.29	13.95	4.92	74
Shahajanpur	19.24	1.35	14.29	6.29	69
Eskaton Gar.	19.10	2.11	17.43	3.78	82
Khilgaon	21.53	2.43	10.86	13.1	45

Table. 5.21 Different Well and Aquifer Parameters for Zone 1

Location	Sp. Capacity (m^2/day)	B (day/m^2)	C (day^2 /m^5)	Skin Factor
Jurain	314.40	$2.52x10^{-3}$	$9x10^{-8}$	1.1
Mughdapara	356.35	$2.523x10^{-3}$	$3.85x10^{-8}$	3.75
Gopibagh	358.60	$2.365x10^{-3}$	$5.75x10^{-8}$	1.63
Jatrabari	297.49	$3.195x10^{-3}$	$2.25x10^{-8}$	0.93
Bangababan	219.00	$3.5x10^{-3}$	$1.45x10^{-8}$	3.38
Peterbagh	328.92	$2.65x10^{-3}$	$3.25x10^{-8}$	4.64
Sayedabad	346.11	$2.69x10^{-3}$	$4.75x10^{-8}$	0.52
Laxmibazar	371.00	$2.235x10^{-3}$	$6.25x10^{-8}$	1.75

Table. 5.22 Different Well and Aquifer Parameters for Zone 2

Location	Sp. Capacity (m^2/day)	B (day/m^2)	C (day^2 /m^5)	Skin Factor
B.D.R. Pil.	450.73	$2.09x10^{-3}$	$1.75x10^{-8}$	2.86
Azimpur	502.6	$1.91x10^{-3}$	$1x10^{-8}$	7.89
Hazaribag	482.47	$1.87x10^{-3}$	$2.75x10^{-8}$	4.89
Islambag	465	$1.84x10^{-3}$	$4.1x10^{-8}$	6.38
Jagonnath College	343.69	$2.158x10^{-3}$	$5.5x10^{-8}$	1.01
Rajnarayan D.R.	502.59	$1.42x10^{-3}$	$7.75x10^{-8}$	3.59
Mitford Hospital	468.9	$1.93x10^{-3}$	$1.25x10^{-8}$	7.42

Table. 5.23 Different Well and Aquifer Parameters for Zone 3

Location	Sp. Capacity (m^2/day)	B (day/m^2)	C (day^2 /m^5)	Skin Factor
Central Road	456.39	$1.92x10^{-3}$	$3.7x10^{-8}$	0.98
Dhanmondi R7	527	$1.64x10^{-3}$	$3.5x10^{-8}$	5.22
Pisci.M.pur	359.67	$2.43x10^{-3}$	$4.75x10^{-8}$	1.72
Dhaka Lab.S.	433	$2.03x10^{-3}$	$3.75x10^{-8}$	0.32
Barabo,S..moli	329	$2.498x10^{-3}$	$3.75x10^{-8}$	0.91
Monipuripara	521.88	$1.55x10^{-3}$	$5.00x10^{-8}$	1.02
Bangla Motor	522.25	$1.72x10^{-3}$	$2.65x10^{-8}$	3.08

Table. 5.24 **Different Well and Aquifer Parameters for Zone 4**

Location	Sp. Capacity (m^2/day)	B (day/m^2)	C (day^2 /m^5)	Skin Factor
Mirpur-2	286.25	$3.09x10^{-3}$	$5.5x10^{-8}$	2.54
Mirpur-7	368	$2.2x10^{-3}$	$7x10^{-8}$	5.03
Mirpur-10	469	$1.98x10^{-3}$	$2.05x10^{-8}$	3.37
Mirpur- 12 B.-D	284.36	$3.41x10^{-3}$	$7.0x10^{-8}$	0.42
Mirpur B. C.	354.29	$2.64x10^{-3}$	$2.5x10^{-8}$	4.19
Kallyanpur	275.4	$3.197x10^{-3}$	$5.90x10^{-8}$	4.16
Pallabi	263.09	$3.36x10^{-3}$	$6.00x10^{-8}$	2.05
Kafrul	277.7	$2.94x10^{-3}$	$9.00x10^{-8}$	0.81
Gudaraghat	-	-	-	-

Table. 5.25 **Different Well and Aquifer Parameters for Zone 5**

Location	Sp. Capacity (m^2/day)	B (day/m^2)	C (day^2 /m^5)	Skin Factor
Nakhalpara	328.33	$2.648x10^{-3}$	$5.40x10^{-8}$	0.56
Banani	437.9	$2.19x10^{-3}$	$1.275x10^{-8}$	0.75
Uttara	550.82	$1.54x10^{-3}$	$3.75x10^{-8}$	2.84
Shahajadpur	374.89	$2.465x10^{-3}$	$2.75x10^{-8}$	8.06
Kuratoli	505.00	$1.73x10^{-3}$	$3.40x10^{-8}$	4.07
Ashkona	358.6	$2.27x10^{-3}$	$7.05x10^{-8}$	2.81

Table. 5.26 **Different Well and Aquifer Parameters for Zone 6**

Location	Sp. Capacity (m^2/day)	B (day/m^2)	C (day^2 /m^5)	Skin Factor
Circuit House	398.91	$2.165x10^{-3}$	$4.65x10^{-8}$	0.72
Rajarbagh	271.95	$3.098x10^{-3}$	$6.7x10^{-8}$	2.30
Ulon,Rampura	431.98	$2.15x10^{-3}$	$2.25x10^{-8}$	2.56
Goran	389.40	$2.12x10^{-3}$	$6.1x10^{-8}$	0.91
Shahajanpur	356.87	$2.618x10^{-3}$	$2.5x10^{-8}$	1.08
Eskaton Gar.	346.44	$2.60x10^{-3}$	$3.9x10^{-8}$	0.59
Khilgaon	306.68	$2.93x10^{-3}$	$4.5x10^{-8}$	5.37

5.6 Limitations of the Study

Methods for evaluating the pumping test data based on the ideal assumptions have been described in Chapter 4. In practice, such ideal conditions are rarely encounter in the field. Deviations that occur from the idealized situation can be noted as follows:

From the bore log data, it can be observed that the assumptions of homogeneous and isotropic with uniform thickness of aquifer system are not valid for Dhaka city. The thickness of the aquifer and aquitard layers are found to vary from place to place, while experts differ on describing its configuration. It has been found that the system behaves as a semi-confined composite aquifer with two layers separated by a thin layer of aquitard. In the study area, a large number of wells are competing with each other for the ever decreasing underground water in a close space, therefore, interferences of its zone of influences are obvious. Pumping tests conducted by DWASA are believed to be influenced by other nearby running wells and at this stage it is not possible to separate its influence on the drawdowns obtained for the wells under investigation.

Table. 5.27 Different Types of Losses in Zone 1 at an Operating Discharge 4897 m^3/day (2 cusec)

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)
Jurain	12.34	2.16	12.01	2.49
Mughdapara	12.36	0.92	10.39	2.89
Gopibagh	11.58	1.38	11.03	1.93
Jatrabari	15.65	0.54	13.61	2.39
Bangababan	17.14	0.35	15.03	2.46
Sayedabad	12.98	0.78	12.34	1.42
Paterbagh	13.17	1.14	9.78	4.53
Laxmibazar	10.94	1.49	10.21	2.22

Table. 5.28 Different Types of Losses in Zone 2 at an Operating Discharge 4897 m^3 /day (2 cusec)

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)
B.D.R. Pil.	10.23	0.42	9.28	1.37
Azimpur	9.35	0.24	6.48	3.11
Hazaribag	9.16	0.66	6.09	3.73
Islambag	9.01	0.98	6.01	3.98
Jagonnath College	10.57	1.32	9.14	2.75
Rajnarayan D.R.	6.95	1.86	5.6	3.21
Mitford Hospital	9.45	0.29	6.1	3.64

Table. 5.29 Different Types of Losses inZone 3 at an Operating Discharge 4897 m^3 /day (2 cusec)

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)
Central Road	9.4	0.89	8.05	2.24
Dhanmondi R7	8.03	0.84	5.91	2.96
Pisci.M.pur	11.89	1.14	10.22	2.81
Dhaka Lab.S.	9.94	0.89	9.01	1.82
Barabo,S..moli	12.23	0.92	11.06	2.09
Monipuripara	7.59	1.19	6.32	2.46
Bangla Motor	8.42	0.64	7.59	1.47

Table. 5.30 **Different Types of Losses in Zone 4 at an Operating Discharge 4897 m^3 /day (2 cusec)**

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)
Mirpur-2	15.13	1.32	12.84	3.61
Mirpur-7	10.77	1.68	8.66	3.79
Mirpur-10	9.69	0.49	8.02	3.35
Mirpur- 12 B.-D	16.69	1.73	15.98	2.44
Mirpur B. C.	12.93	0.59	11.08	2.44
Kallyanpur	15.66	1.42	14.33	2.85
Pallabi	16.45	1.44	14.03	3.86
Kafrul	14.39	2.16	13.14	3.41
Gudaraghat	-	-	-	-

Table. 5.31 **Different Types of Losses in Zone 5 at an Operating Discharge 4897 m^3 /day (2 cusec)**

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)
Nakhalpara	12.97	1.29	11.11	3.15
Banani	10.72	0.31	9.32	1.71
Uttara	7.54	0.89	5.98	2.45
Shahajadpur	12.07	0.66	9.91	2.82
Kuratoli	8.47	0.82	8.02	1.27
Ashkona	11.12	1.69	10.38	2.43

Table. 5.32 **Different Types of Losses in Zone 6 at an Operating Discharge 4897 m^3 /day (2 cusec)**

Location	Laminar Loss (m)	Turbulent Loss (m)	Aquifer Loss (m)	Total Well Loss (m)
Circuit House	10.6	1.12	9.85	1.87
Rajarbagh	15.17	1.61	14.51	2.27
Ulon,Rampura	10.53	0.54	9.03	2.04
Goran	10.38	1.46	9.96	1.88
Shahajanpur	12.82	0.59	12.26	1.15
Eskaton Gar.	12.73	0.94	12.02	1.65
Khilgaon	14.35	1.08	10.79	4.64

Chapter 6
Conclusions and Recommendations

6.1 Conclusions

A detailed analysis on the collected data from DWASA wells have been done. From the obtained results, the conclusions are made as follows:

1. As all the wells in Dhaka city exhibit non-linear well losses above 0.5 m, Hurr-Worthington's method under the single-well principle is selected as the appropriate method to calculate transmissivity for Dhaka WASA wells.

2. The majority of the city area representating transmissivity values ranging from 400 to 500 m^2/day. The south-western part and north-eastern corner of Dhaka city have higher transmissivity value, i.e., 700-1000 m^2/d.

3. Under the single-well principle, Papadopulos-Cooper method applicable for confined aquifer is the only option to calculate storativity for the pumping tests conducted in Dhaka WASA wells. The storativity variations are within of the order of one for most of the wells in the Dhaka city. The majority of the city area representating the storativity values which is around 2×10^{-5}. The south-western part of the Dhaka city gives the highest storativity values which is about 4×10^{-5}. The north-west corner and the south-east corner of Dhaka city represent the storativity values of 3×10^{-5}.

4. Zones 1, 4 and 6 show aquifer losses higher compared to other zones. Productivity (specific capacity) of most of the wells of zones 2, 3 and 5 are better than the other three zones. Most of the well's skin factor, except few wells, fall in the range between 0.7 and 3.0.

5. The total well losses of Dhaka WASA wells are much higher because of poor construction and development operations.

6.2 Recommendations for Further Study

As an extension of present investigation, the following studies may be recommended:

(i) In this study program, methods based on single well principle are used due to lack of piezometric readings. Pumping tests with the installation of piezometers can be conducted at few points of Dhaka city to get the aquifer parameters reliably.

(ii) In the study area, a large number of DWASA and private tubewells are extracting water. So, well interference is obvious. In this study, well interference can not be distinguished from each other. So, further studies can be done by distinguishing these well interferences.

(iii) Based on the transmissivity values obtained in this study, statistical analysis by stochastic methods may be done to obtain optimal range of transmissivities at different points of Dhaka city.

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APPENDIX-A

Sample Calculations

Appendix-A

A. Determination of Transmissivity and Storativity

i. By Jacob Straight Line Method

From Fig. B-1 (Appendix B) $\Delta s = 8.96 - 8.418 = 0.542$ m
(Eskaton Garden Well) $Q = 3674$ m^3/day

$$KD = \frac{2.3Q}{4\pi\Delta S} = 2.30 \times 3674/(4\pi \times 0.542) = 1240.75 \text{ m}^2/\text{day}$$

ii. By Theis Recovery Method

From Fig. D-1 (Appendix D) $\Delta s' = 1.68 - 0.83 = 0.85$ m
(Islambagh Well)

For Theis Recovery Method,

$$Q_{avg.} = (3674+4898+6120+7348)/4 = 5510 \text{ m}^3/\text{day}$$

$$KD = \frac{2.3Q}{4\pi\Delta S} = 2.30 \times 5510/(4\pi \times 0.85) = 1187 \text{ m}^2/\text{day}$$

iii. By Papadopulos-Cooper Method

From Fig. C-1, matching with type curve (Appendix C)
(Central Road, Dhanmondi Well)

match point, A

$F(u_w,\alpha)$	= 3
s_w	= 1.04 m
t	= 11 minutes
$1/u_w$	= 2×10^7
Q	= 3657 m^3/day
r_{ew}	= 0.2794 m

$$KD = \frac{Q}{4\pi s_w} F(u_w, \alpha)$$

or, KD = $3657 \times 3/(4\pi \times 1.04)$

or, KD = 839.61 m^2/day

From Eq^n. (4.19)

$$S = \frac{4KD\, t\, u_w}{r_{ew}^2}$$

$$= 4 \times 840 \times 11/(0.2795^2 \times 2 \times 10^7 \times 24 \times 60)$$

$$= 1.6\times10^{-5}$$

(iv). By Hurr-Worthington Method

From Appendix E-1 (B.D.R. Pilkhana)

At Time 5 Minute, $s_w = 5.945$ m

$r_{ew} = 0.2794$ m

$Q = 3680$ m^3/day

From Eq^n. (4.23),

$$u_w W(u_w) = \frac{\pi r_{ew}^2 S}{t} \times \frac{s_w}{Q}$$

$= (3.14 \text{ x } .2794^2 \text{ x } 9 \text{ x } 10^{-4} \text{ x } 5.945 \text{ x } 24 \text{ x } 60)/(1 \text{ x } 3680)$

$= 0.00049$

From Fig. 4.5, $u_w = 5.09 \text{ x } 10^{-5}$

From Eq^n. (4.21),

$$KD = \frac{r_{ew}^2 \times S}{4 \pi u_w t}$$

$= (.2794^2 \text{ x } 9.0 \text{ x } 10^{-4} \text{ x } 24 \text{ x } 60)/(4 \text{ x } 3.14 \text{ x } 5.09 \text{ x } 10^{-5})$

$= 496.66$

Psuedo $KD_1 = 496.66$

Similarly, KD_2, KD_3..........in Table 5.E.1

$KD = $ Pseudo $(KD_1 + \ldots + KD_3 \ldots . + KD_{35})/35$

$= 581.76$

(v) By Logan Method

From Appendix G-1, Maximum Drawdown, $s_{max} = 11.496$ m

$Q = 3657$ m^3/day

$$KD = \frac{1.22\,Q}{S_{mw}} = 1.22 \text{ x } 3657/11.496 = 388 \text{ m}^2\text{/day}$$

B. Calculation of Different Types of Losses

From Fig. F-1 (Appendix F)
(Dhanmondi Road 7)

$B = 1.64 \text{x} 10^{-3}$

$C = 3.5 \text{x} 10^{-8}$

At an operating discharge $Q = 7348$ m^3/day

$KD = 1042$ m^2/day

Laminar loss (BQ) = 12.05 m

Turbulent loss (CQ^2) = 1.89 m

Aquifer loss $s = \frac{2.3Q}{4\pi KD} \log \frac{2.25KDt}{r_w^2 S}$

= (2.3 x 7348)/(4π x 1042) log (2.25 x 1042 x 0.25)/ (0.2794^2 x 8.3 x 10^{-5})

= 10.59 m = B_1Q

Linear well loss (B_2Q) = laminar loss (BQ) - aquifer loss (B_1Q)
= 12.05 - 10.59 = 1.46 m

Total well loss = linear well loss + turbulent well loss
= 1.46 + 1.89 = 3.35 m

C. Calculation of Specific Capacity and Well Efficiency

Total drawdown s = laminar loss + turbulent loss
= 12.05 + 1.89
= 13.94

Specific Capacity = $\frac{Q}{s} = \frac{1}{(B_1+B_2)+CQ}$

= 7348/13.94 = 527 m^2/day

Well Efficiency = $E_w = \frac{B_1Q}{(B_1+B_2)Q+CQ^2} * 100\ \%$

= (10.59/13.94) x 100% = 76%

D. Calculation of Skin Factor

From Eq^n. (4.37)

$$\frac{t_p+t_i'}{t_i'} = \frac{2.25KDt_p}{r_w^2 S}$$

For Uttara well, = (2.25 x 1096 x 1)/(.2794^2 x 1.4 x 10^{-5})
= 2.25 x 10^9

From Graph. D-2, s'_w = 8.28
$s_w(t_p)$ = 11.31

From Eq^n. (4.37)

$$skin = \frac{2\pi KD}{Q}\{s_w(t_p) - s_w'\}$$

= (2 x 3.14 x 1096(11.31-8.28))/7348
= 2.84

APPENDIX-B

Time-Drawdown Curves for Jacob Straight Line Method

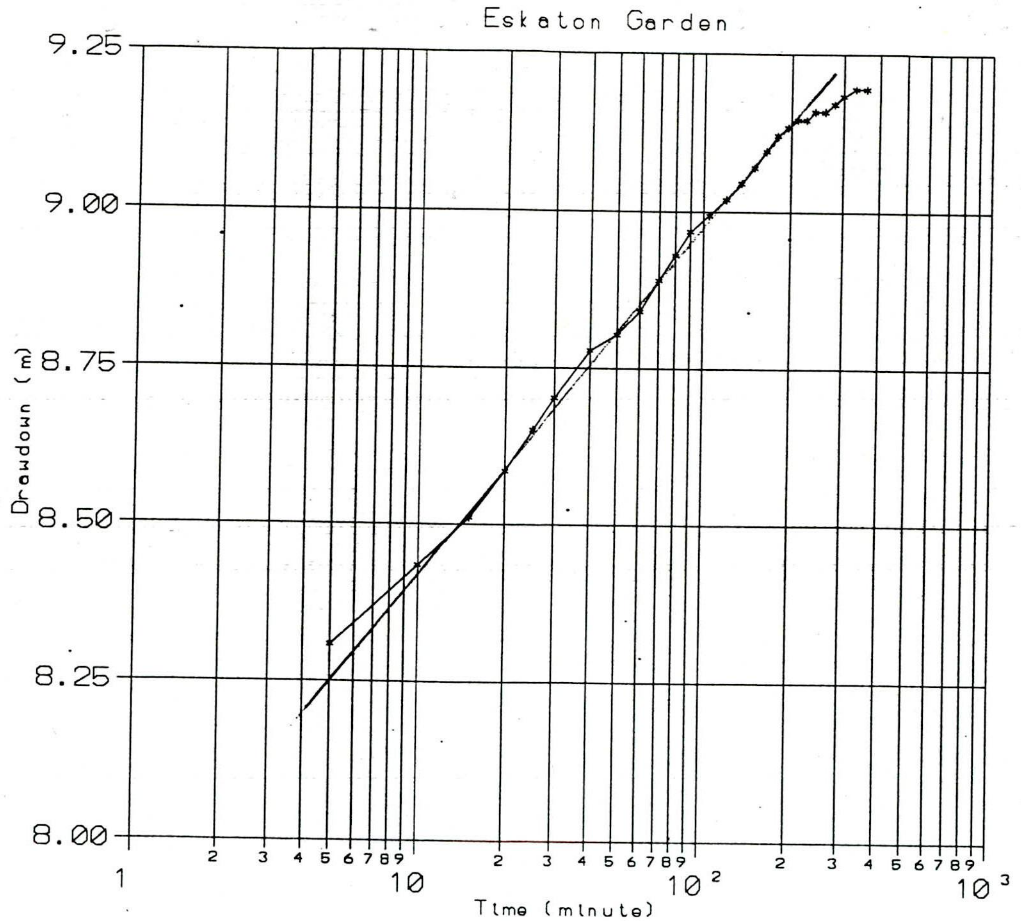


Fig.B-1. Analysis of Pumping Test Data by Jacob Straight Line Method

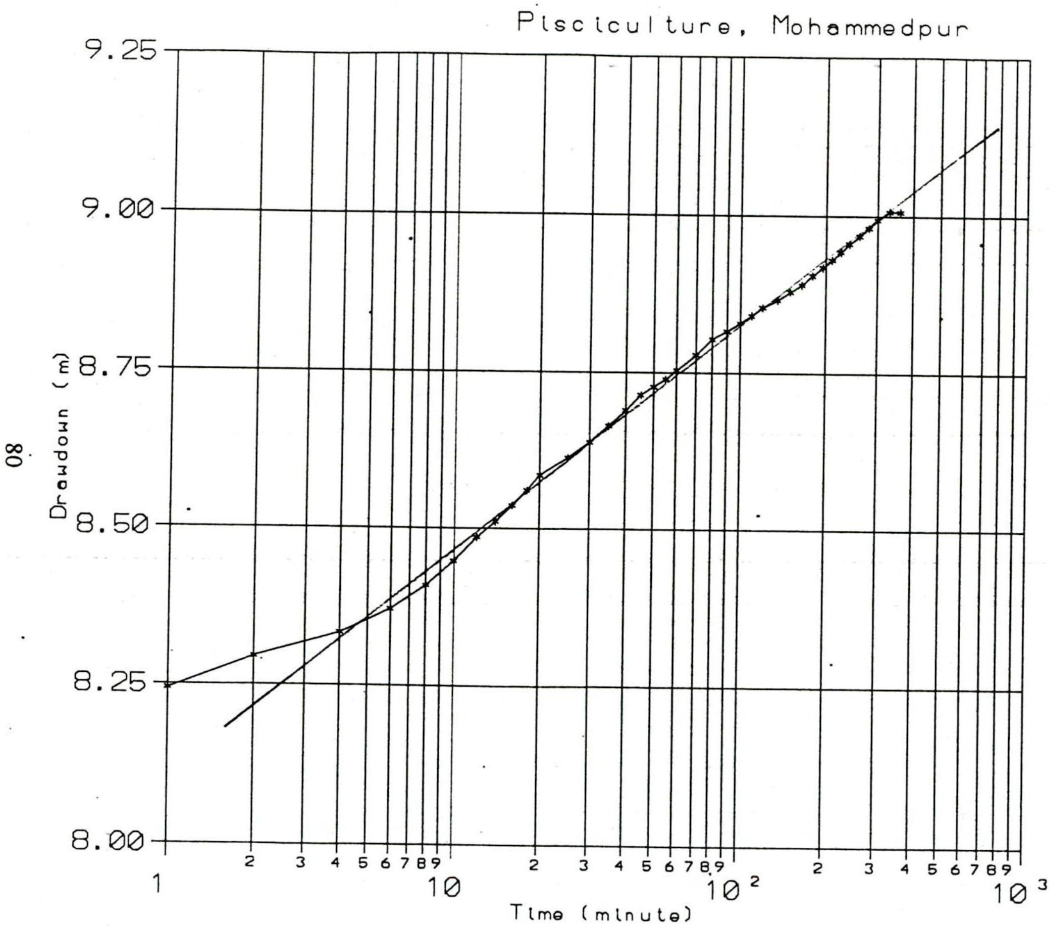


FIG. B-2 Analysis of Pumping Test Data by Jacob Straight Line Method

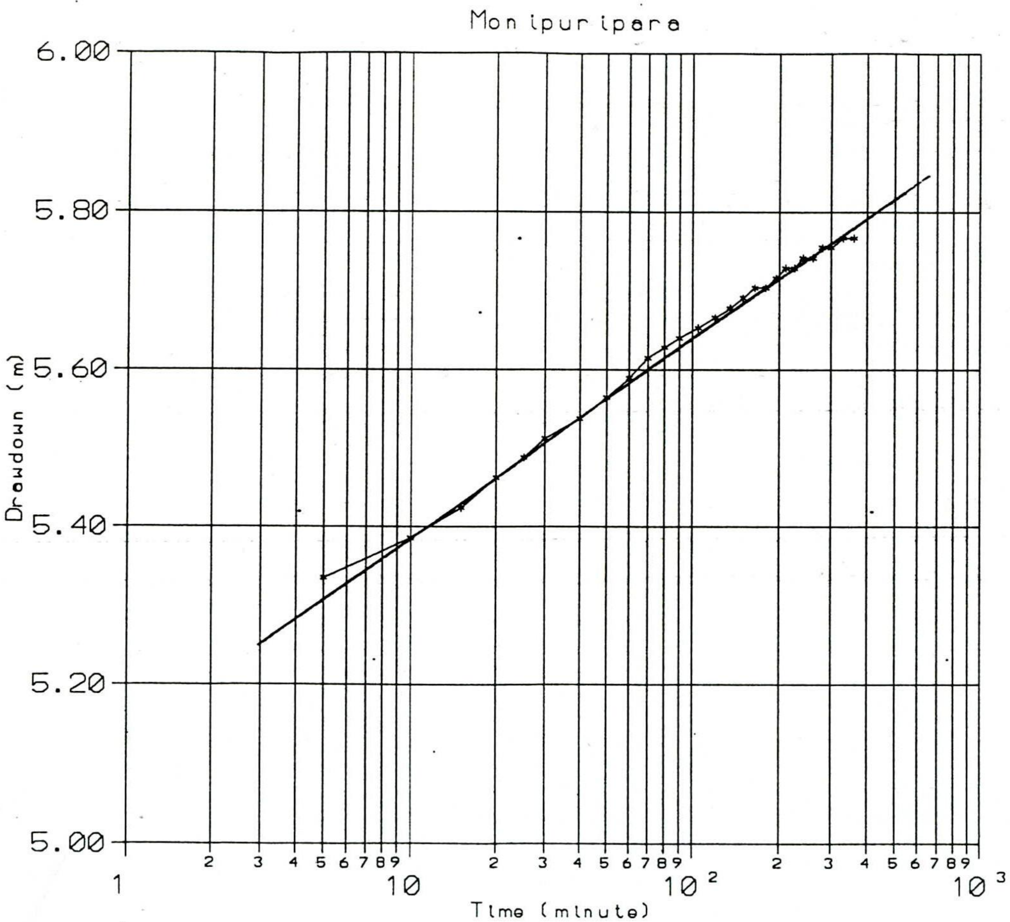


Fig. B-3 Analysis of Pumping Test data by Jacob Straight Line Method

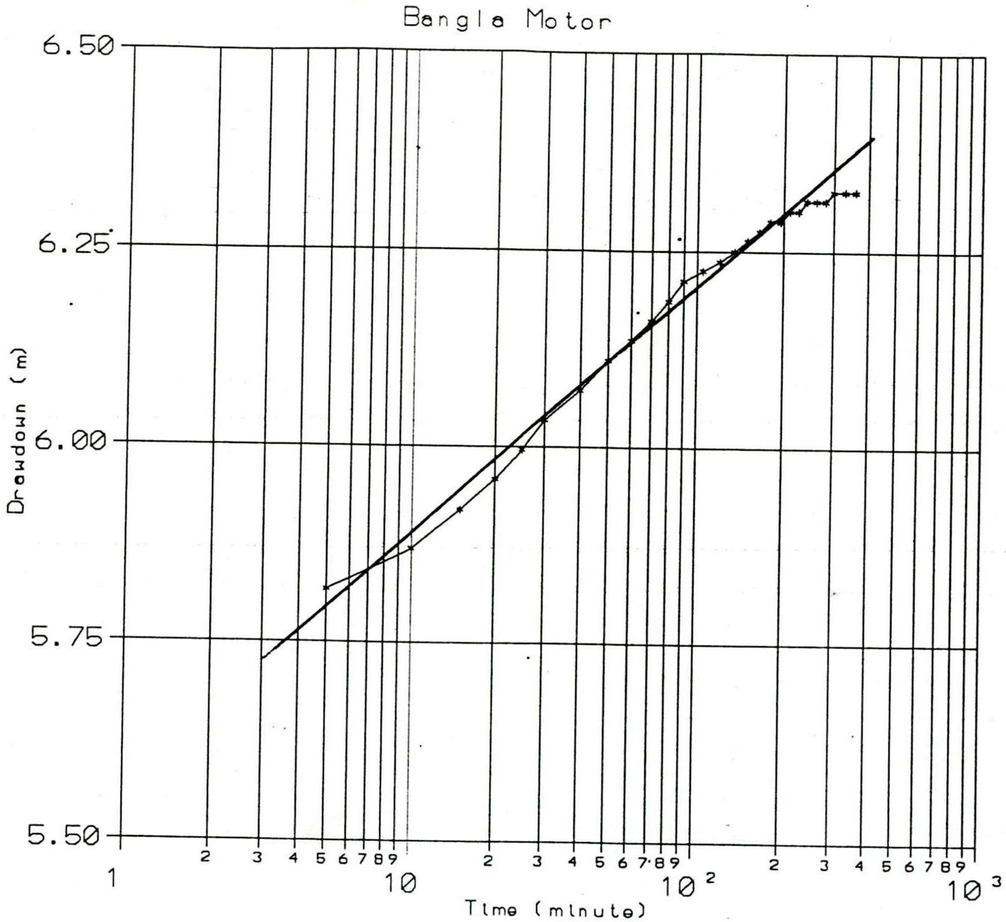


Fig. B-4. Analysis of Pumping Test Data by Jacob Straight Line Method

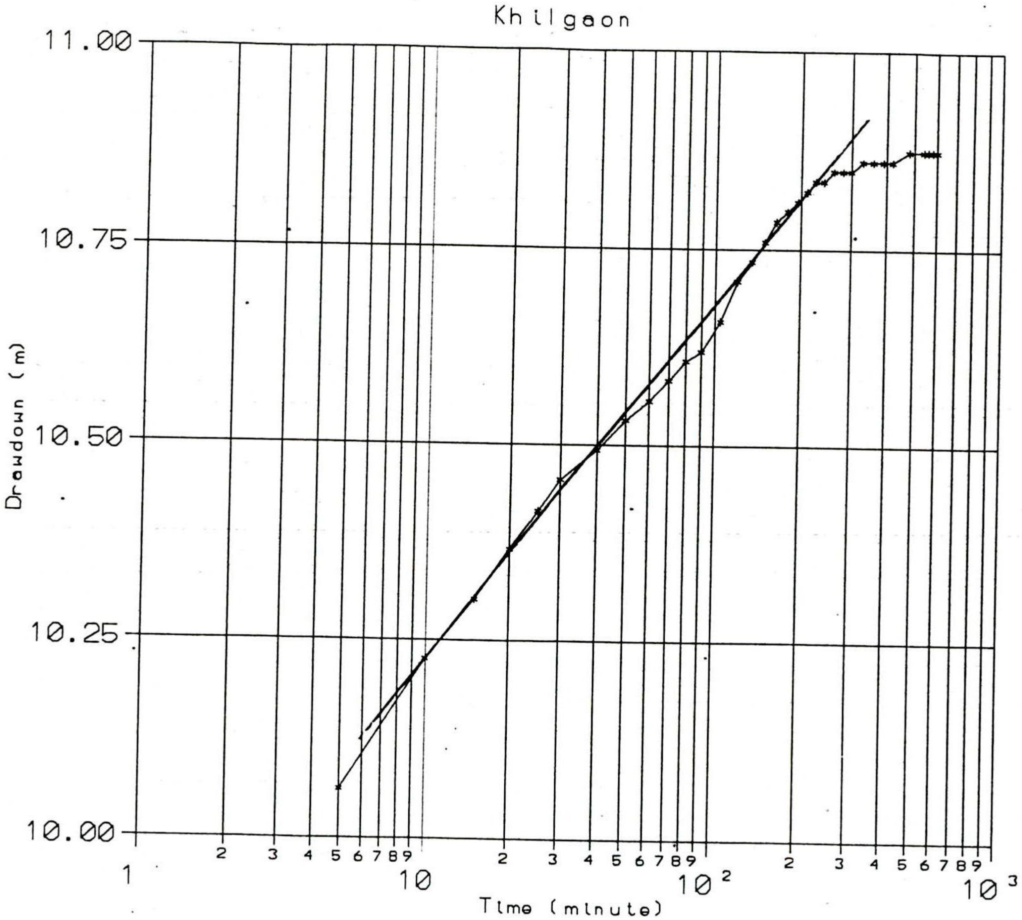
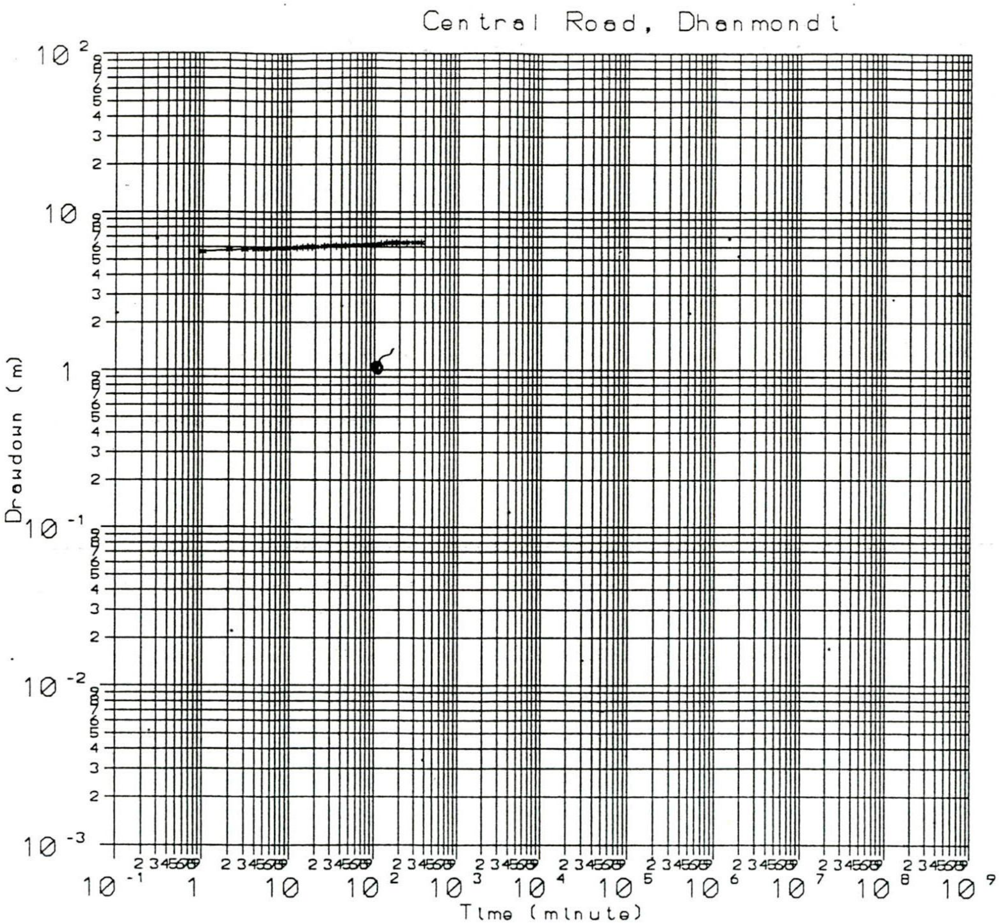


Fig. B-5. Analysis of Pumping Test Data by Jacob Straight Line Method

APPENDIX-C

Time-Drawdown Curves for Papadopulos-Cooper Method



match point, A

$F(u_w,\alpha)$ = 3
s_w = 1.04 m
t = 11 minutes
$1/u_w$ = 2×10^7

Fig. C-1. Analysis of Pumping Test Data by Papadopulos-Cooper Method

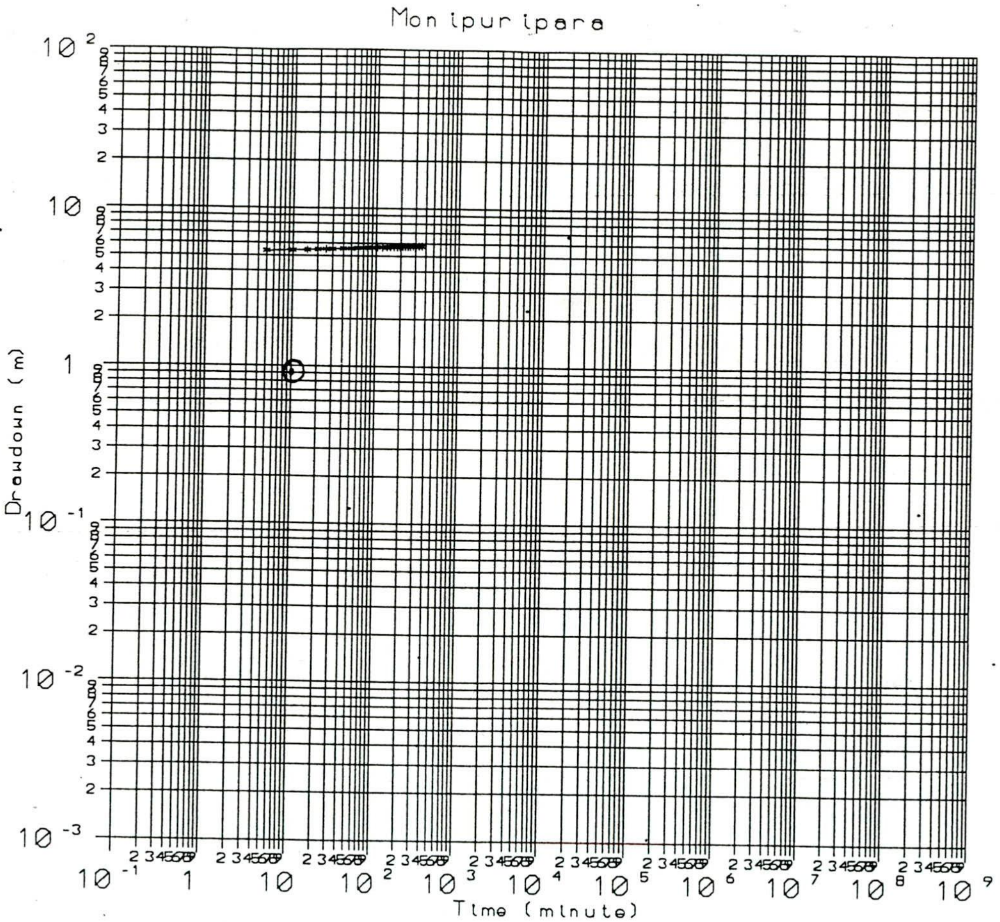


Fig. C-2. Analysis of Pumping Test Data by Papadopulos-Cooper Method

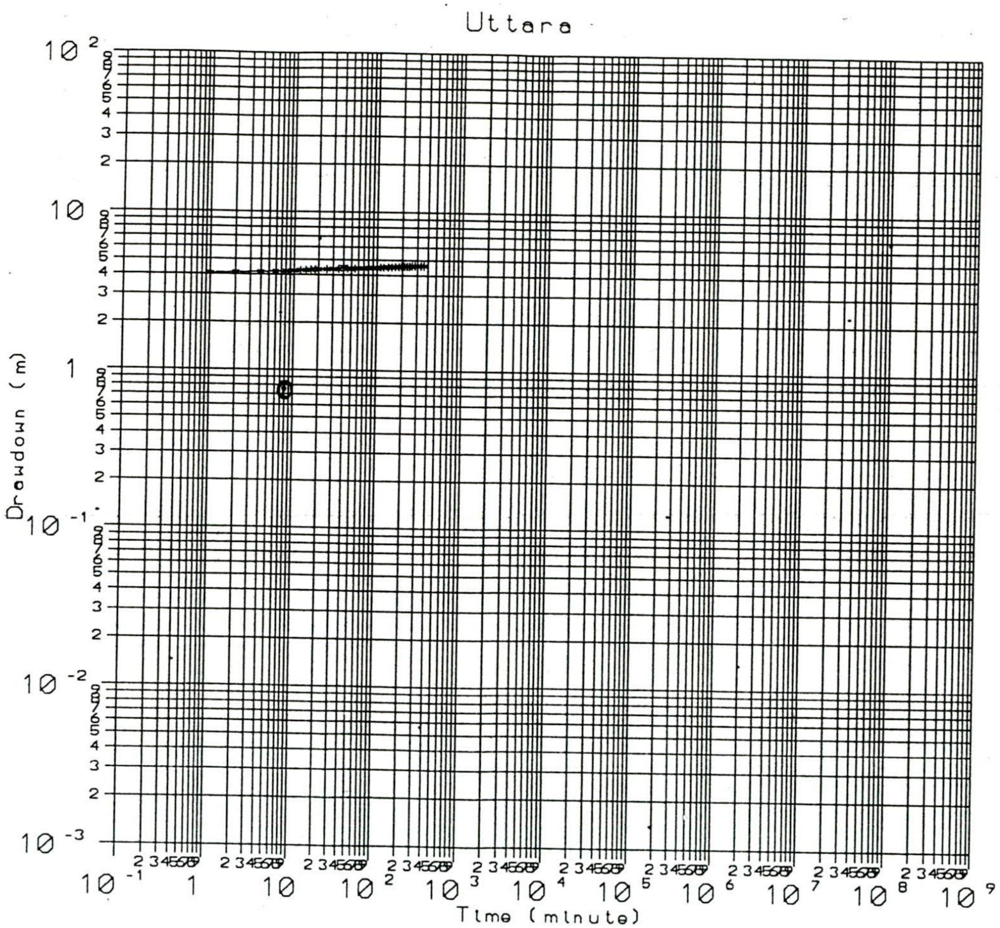


Fig. C-3. Analysis of Pumping Test Data by Papadopulos-Cooper Method

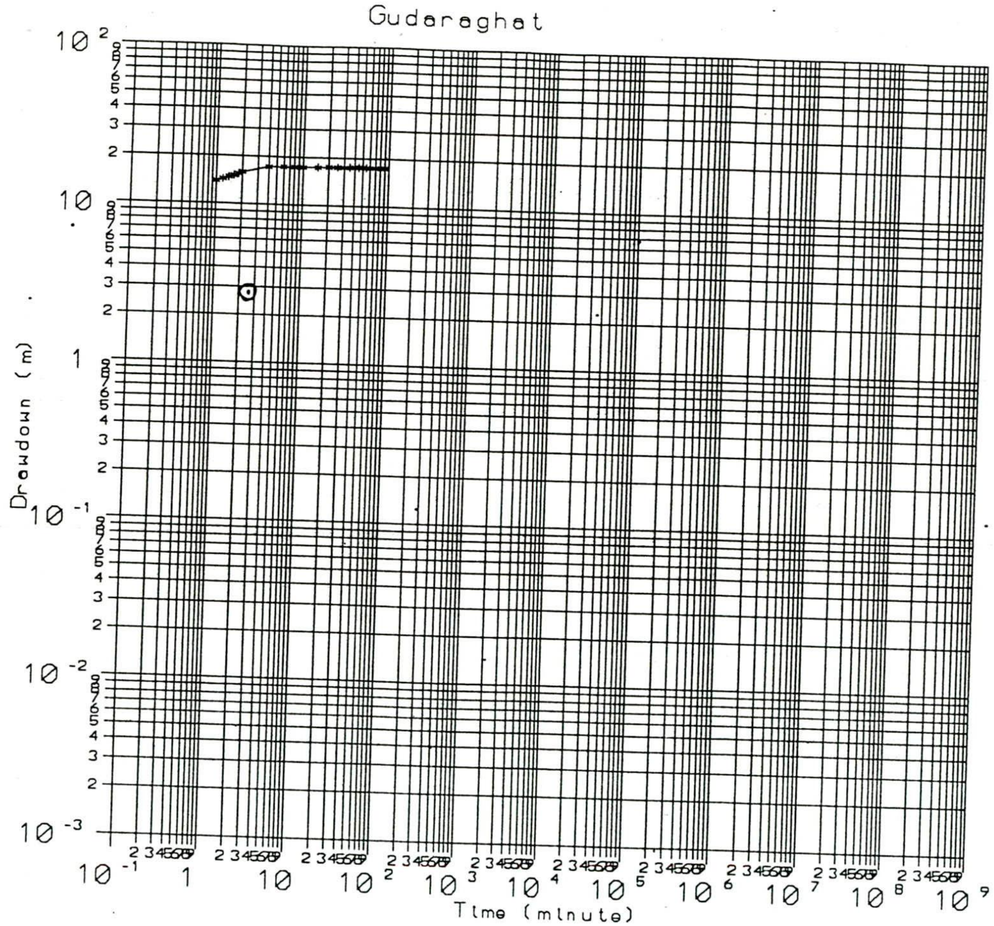


Fig. C-4. Analysis of Pumping Test Data by Papadopulos-Cooper Method

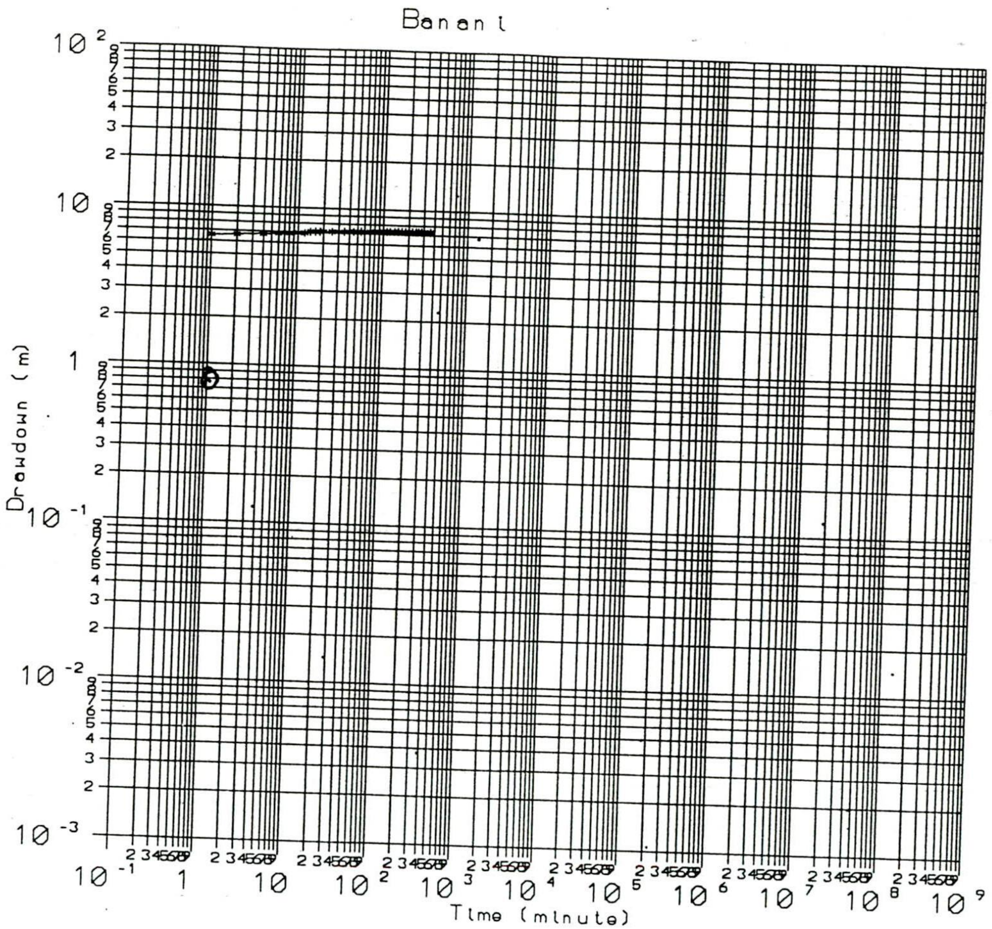


Fig. C-5. Analysis of Pumping Test Data by Papadopulos-Cooper Method

APPENDIX-D

Time-Drawdown Curves for Theis Recovery Method

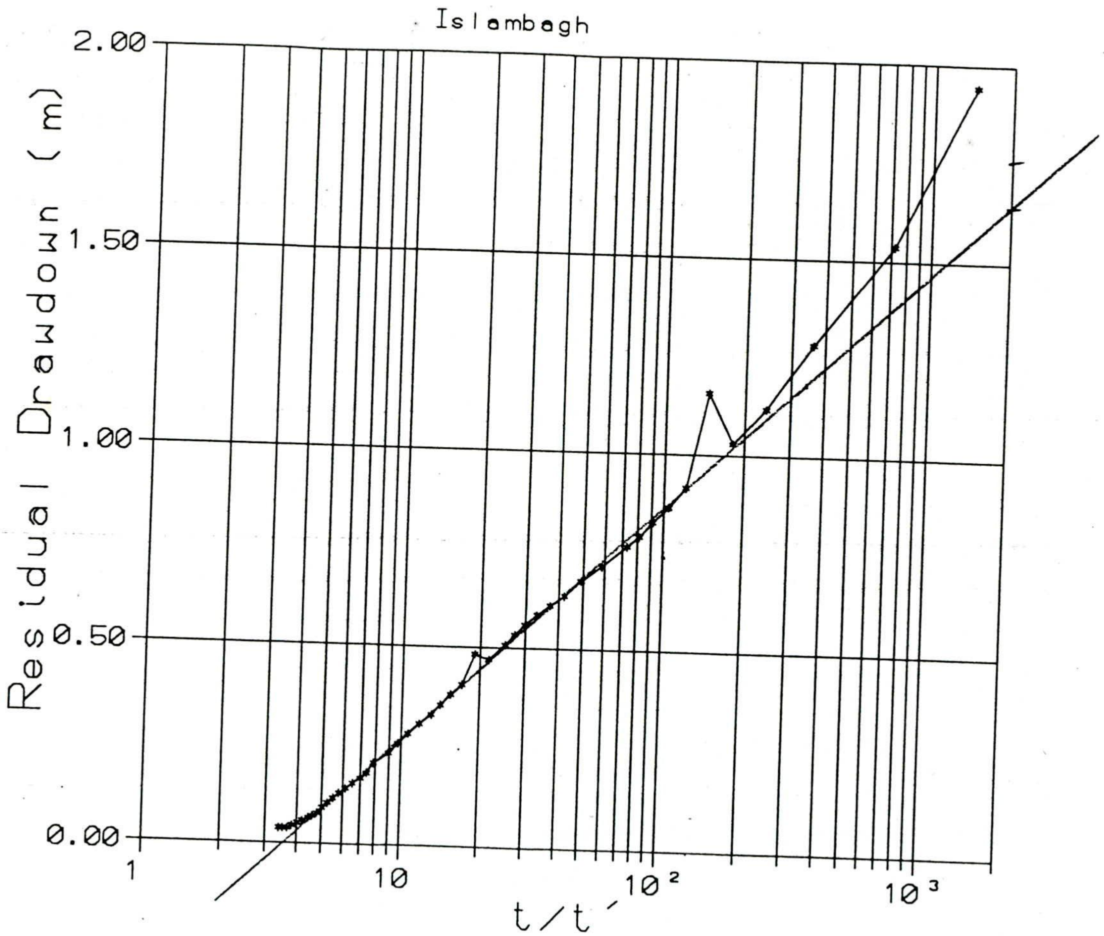


Fig. D-1. Analysis of Recovery Test Data by Theis Recovery Method

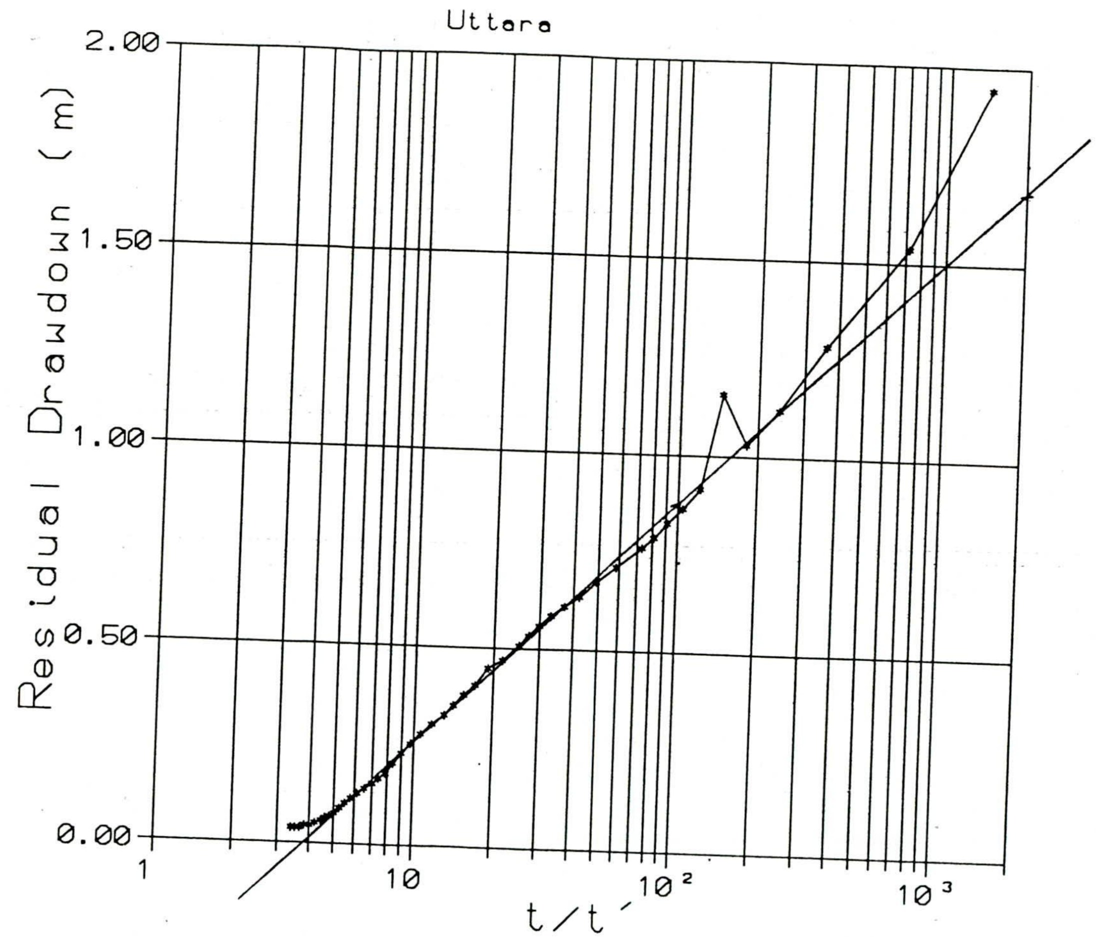


Fig. D-2. Analysis of Recovery Test Data by Theis Recovery Method

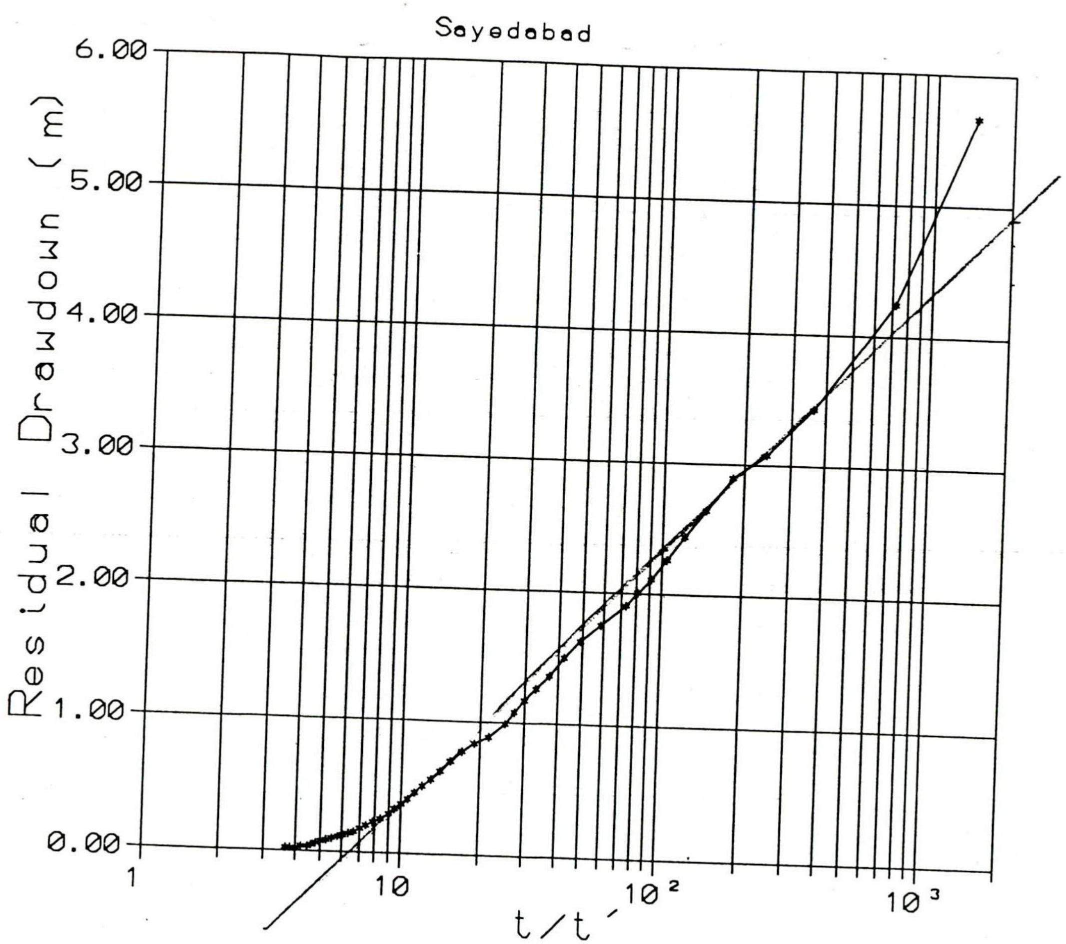


Fig. D-3. Analysis of Recovery Test Data by Theis Recovery Method

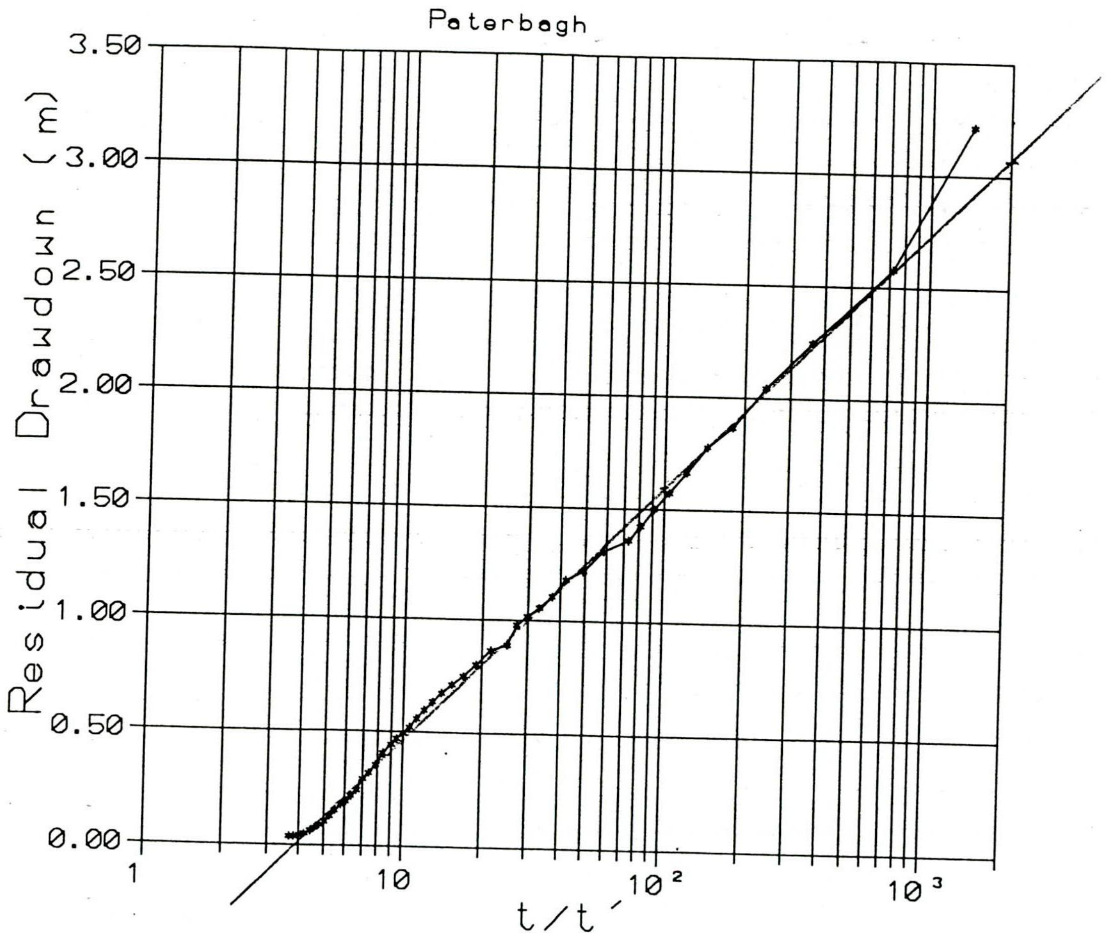


Fig. D-4. Analysis of Recovery Test Data by Theis Recovery Method

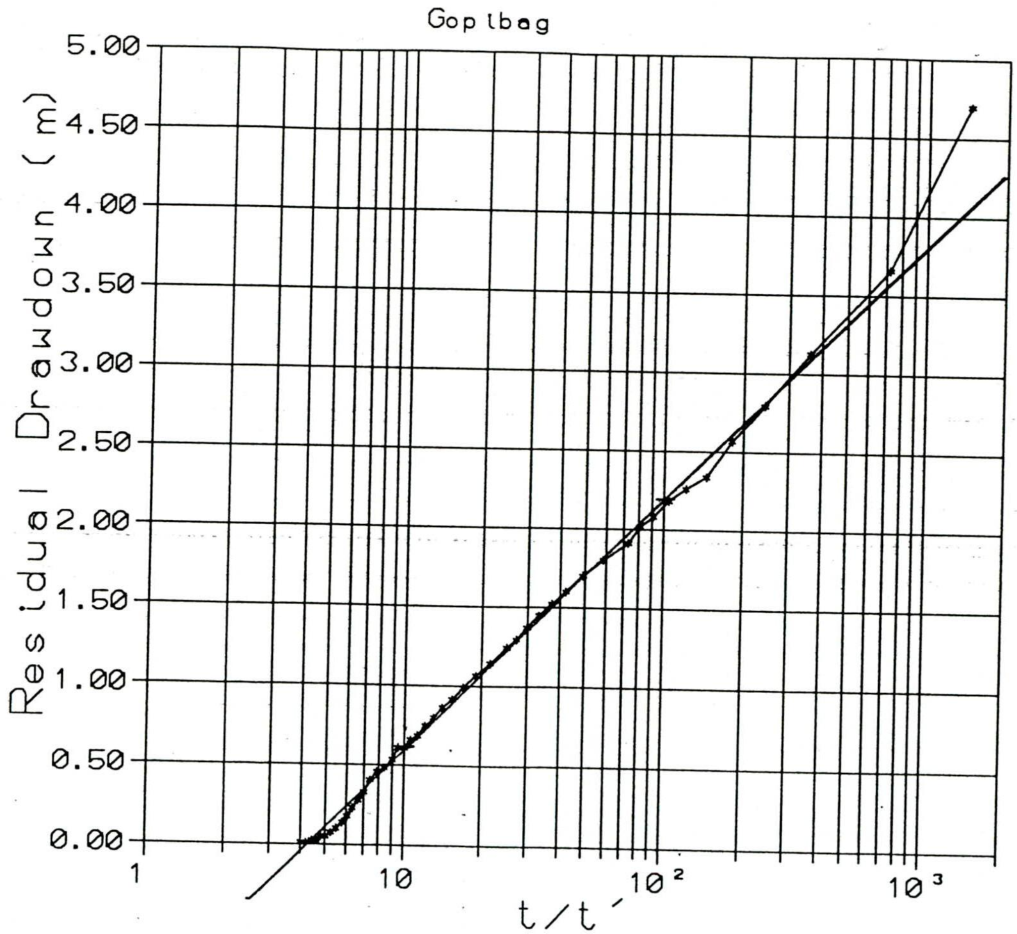


Fig. D-5. Analysis of Recovery Test Data by Theis Recovery Method

APPENDIX-E

Tables for Determining Transmissivities by Hurr-Worthington Method

Table 5.E.1 Transmissivity Determined by Hurr-Worthington Method (B.D.R.Pilkhana)

Time (min.)	Drawdown (m)	Corr. Drawdown (m)	Uw*W(Uw)	Uw	Pseudo. KD	KD
1	5.945	5.709	0.00049275	5.093E-05	496.65613	
2	6.047	5.811	0.00025078	2.469E-05	512.15371	
3	6.146	5.91	0.00017003	1.628E-05	517.80365	
4	6.225	5.989	0.00012923	1.213E-05	521.12762	
5	6.275	6.039	0.00010425	9.638E-06	524.83631	
6	6.301	6.065	8.725E-05	7.964E-06	529.3006	
7	6.326	6.09	7.509E-05	6.781E-06	532.82985	
8	6.352	6.116	6.598E-05	5.904E-06	535.50593	
9	6.377	6.141	5.889E-05	5.227E-06	537.69224	
10	6.402	6.166	5.322E-05	4.689E-06	539.41633	
12	6.441	6.205	4.463E-05	3.883E-06	542.83464	581.7627
14	6.466	6.23	3.841E-05	3.306E-06	546.50837	
16	6.491	6.255	3.374E-05	2.877E-06	549.40351	
18	6.504	6.268	3.006E-05	2.542E-06	552.83209	
20	6.517	6.281	2.711E-05	2.275E-06	555.78931	
25	6.517	6.281	2.168E-05	1.791E-06	564.75437	
30	6.529	6.293	1.811E-05	1.476E-06	571.01736	
35	6.542	6.306	1.555E-05	1.254E-06	576.08897	
40	6.542	6.306	1.361E-05	1.087E-06	581.63183	
45	6.542	6.306	1.209E-05	9.582E-07	586.56522	
50	6.555	6.319	1.091E-05	8.578E-07	589.71076	
60	6.555	6.319	9.09E-06	7.056E-07	597.47143	
70	6.568	6.332	7.807E-06	5.994E-07	602.78348	
80	6.568	6.332	6.831E-06	5.195E-07	608.58318	
90	6.568	6.332	6.072E-06	4.579E-07	613.74517	
100	6.58	6.344	5.476E-06	4.098E-07	617.1463	
120	6.58	6.344	4.563E-06	3.371E-07	625.26802	
140	6.58	6.344	3.911E-06	2.858E-07	632.21816	
160	6.593	6.357	3.429E-06	2.482E-07	636.90225	
180	6.593	6.357	3.048E-06	2.188E-07	642.30445	
200	6.593	6.357	2.743E-06	1.954E-07	647.17569	
250	6.593	6.357	2.195E-06	1.538E-07	657.61485	
300	6.605	6.369	1.832E-06	1.268E-07	664.92388	
350	6.605	6.369	1.571E-06	1.075E-07	672.31482	
400	6.605	6.369	1.374E-06	9.316E-08	678.78352	

Table 5.E.2 Transmissivity Determined by Hurr-Worthington Method (Azimpur)

Time (min.	Drawdown (m)	Corr. Drawdown (m)	Uw*W(Uw)	Uw	Pseudo KD	KD
1	3.557	3.422	0.0002954	0.0000294	859.56	1025.38
2	3.582	3.447	0.0001488	0.0000141	896.34	
4	3.608	3.473	0.0000749	0.0000068	934.47	
6	3.633	3.498	0.0000503	0.0000044	954.67	
8	3.659	3.524	0.0000380	0.0000033	966.86	
10	3.683	3.548	0.0000306	0.0000026	975.34	
12	3.697	3.562	0.0000256	0.0000021	984.01	
14	3.701	3.566	0.0000220	0.0000018	993.76	
16	3.722	3.587	0.0000193	0.0000016	997.02	
18	3.735	3.6	0.0000173	0.0000014	1001.59	
20	3.76	3.625	0.0000156	0.0000013	1001.73	
25	3.773	3.638	0.0000126	0.0000010	1013.99	
30	3.786	3.651	0.0000105	0.0000008	1023.41	
35	3.798	3.663	0.0000090	0.0000007	1031.16	
40	3.811	3.676	0.0000079	0.0000006	1037.13	
45	3.824	3.689	0.0000071	0.0000005	1041.98	
50	3.836	3.701	0.0000064	0.0000005	1046.23	
55	3.849	3.714	0.0000058	0.0000004	1049.46	
60	3.862	3.727	0.0000054	0.0000004	1052.08	
75	3.887	3.752	0.0000043	0.0000003	1061.42	
90	3.913	3.778	0.0000036	0.0000003	1067.46	
105	3.938	3.803	0.0000031	0.0000002	1071.72	
120	3.963	3.828	0.0000028	0.0000002	1074.46	
150	4.002	3.867	0.0000022	0.0000002	1079.99	
180	4.039	3.904	0.0000019	0.0000001	1083.10	
210	4.065	3.93	0.0000016	0.0000001	1087.37	
240	4.09	3.955	0.0000014	0.0000001	1090.40	
270	4.116	3.981	0.0000013	0.0000001	1091.95	
300	4.141	4.006	0.0000012	0.0000001	1092.88	
360	4.166	4.031	0.0000010	0.0000001	1099.90	

Table 5.E.3 Transmissivity Determined by Hurr-Worthington Method (Banani)

Time (min	Drawdown (m)	Corr. Drawdown (m)	Uw*W(Uw)	Uw	Pseudo KD	KD
1	6.529	6.357	0.000548676	5.7146E-05	442.604	
2	6.631	6.459	0.00027874	2.7655E-05	457.29177	
4	6.732	6.56	0.000141549	1.3378E-05	472.67047	
6	6.796	6.624	9.52869E-05	8.7535E-06	481.57854	
8	6.859	6.687	7.21449E-05	6.4966E-06	486.65444	
10	6.91	6.738	5.81561E-05	5.1566E-06	490.49411	
12	6.974	6.802	4.89237E-05	4.2845E-06	491.93968	
14	7.061	6.889	4.2471E-05	3.6819E-06	490.67874	
16	7.088	6.916	3.73078E-05	3.2044E-06	493.32738	
18	7.101	6.929	3.32248E-05	2.8301E-06	496.5115	
20	7.114	6.942	2.99584E-05	2.533E-06	499.27308	531.196
25	7.127	6.955	2.40116E-05	1.9982E-06	506.31032	
30	7.139	6.967	2.00442E-05	1.6466E-06	512.02658	
35	7.152	6.98	1.72128E-05	1.3986E-06	516.68468	
40	7.165	6.993	1.50892E-05	1.2146E-06	520.61675	
45	7.177	7.005	1.34357E-05	1.0725E-06	524.06876	
50	7.189	7.017	1.21128E-05	9.5974E-07	527.07559	
55	7.203	7.031	1.10336E-05	8.684E-07	529.55793	
60	7.203	7.031	1.01142E-05	7.9109E-07	532.87249	
70	7.228	7.056	8.70011E-06	6.7317E-07	536.74998	
80	7.241	7.069	7.62662E-06	5.8457E-07	540.84635	
90	7.254	7.082	6.79168E-06	5.1626E-07	544.36086	
100	7.266	7.094	6.12287E-06	4.6197E-07	547.49502	
110	7.279	7.107	5.57645E-06	4.1794E-07	550.16922	
120	7.292	7.12	5.1211E-06	3.8147E-07	552.52956	
135	7.292	7.12	4.55208E-06	3.3623E-07	557.21611	
150	7.304	7.132	4.10378E-06	3.0087E-07	560.42971	
165	7.304	7.132	3.73071E-06	2.7166E-07	564.27319	
180	7.304	7.132	3.41982E-06	2.4747E-07	567.80503	
200	7.317	7.145	3.08345E-06	2.2148E-07	570.99577	
220	7.317	7.145	2.80313E-06	1.9997E-07	574.91172	
240	7.317	7.145	2.56954E-06	1.8217E-07	578.51014	
260	7.329	7.157	2.37587E-06	1.6749E-07	580.79481	
280	7.329	7.157	2.20616E-06	1.5471E-07	583.88953	
300	7.329	7.157	2.05908E-06	1.4368E-07	586.78547	
330	7.329	7.157	1.87189E-06	1.2973E-07	590.8097	
360	7.341	7.169	1.71878E-06	1.1839E-07	593.44121	

Table 5.E.4 Transmissivity Determined by Hurr-Worthington Method (Central Road)

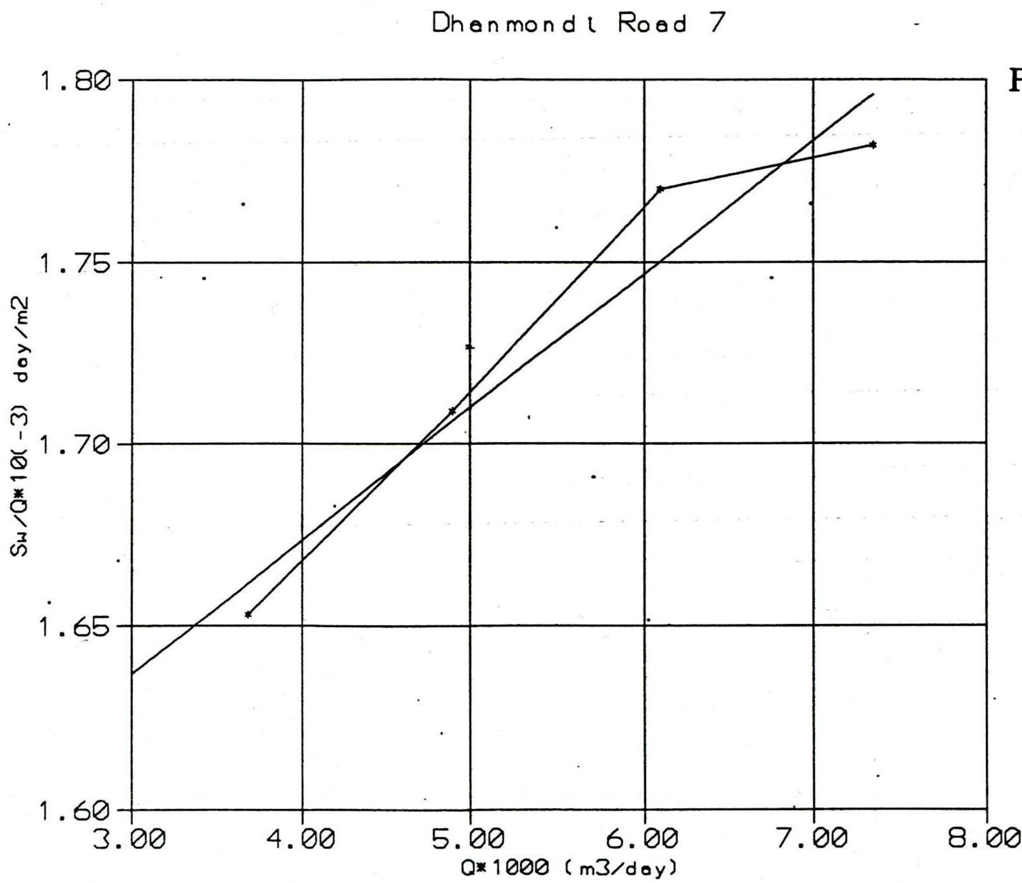
Time (min.	Drawdown (m)	Corr. Drawdown (m)	Uw*W(Uw)	Uw	Pseudo KD	KD
1	5.589	5.09	0.0004393	4.503E-05	561.65839	651.0969
2	5.742	5.243	0.0002263	2.212E-05	571.84022	
3	5.779	5.28	0.0001519	1.443E-05	584.29091	
4	5.805	5.306	0.0001145	1.066E-05	593.33802	
5	5.817	5.318	9.18E-05	8.411E-06	601.45087	
6	5.841	5.342	7.685E-05	6.951E-06	606.43249	
7	5.869	5.37	6.621E-05	5.926E-06	609.74746	
8	5.882	5.383	5.808E-05	5.149E-06	614.02098	
9	5.894	5.395	5.174E-05	4.549E-06	617.75311	
10	5.907	5.408	4.668E-05	4.074E-06	620.83475	
12	5.932	5.433	3.908E-05	3.368E-06	625.9036	
14	5.971	5.472	3.374E-05	2.877E-06	628.02808	
16	5.997	5.498	2.966E-05	2.506E-06	630.85767	
18	6.009	5.51	2.642E-05	2.214E-06	634.72379	
20	6.021	5.522	2.383E-05	1.982E-06	638.0482	
25	6.059	5.56	1.92E-05	1.572E-06	643.59244	
30	6.085	5.586	1.607E-05	1.299E-06	648.81008	
35	6.098	5.599	1.381E-05	1.104E-06	654.38964	
40	6.109	5.61	1.211E-05	9.591E-07	659.2976	
45	6.122	5.623	1.078E-05	8.474E-07	663.24249	
50	6.136	5.637	9.731E-06	7.59E-07	666.49395	
60	6.146	5.647	8.123E-06	6.255E-07	673.98363	
70	6.161	5.662	6.981E-06	5.317E-07	679.5406	
80	6.174	5.675	6.123E-06	4.62E-07	684.39462	
90	6.186	5.687	5.454E-06	4.081E-07	688.63896	
100	6.199	5.7	4.92E-06	3.654E-07	692.16578	
120	6.263	5.764	4.146E-06	3.042E-07	692.93319	
140	6.352	5.853	3.608E-06	2.621E-07	689.22396	
160	6.377	5.878	3.171E-06	2.282E-07	692.68403	
180	6.389	5.89	2.824E-06	2.016E-07	697.03421	
210	6.389	5.89	2.421E-06	1.709E-07	704.78207	
240	6.389	5.89	2.118E-06	1.481E-07	711.56315	
300	6.389	5.89	1.695E-06	1.166E-07	723.0409	
360	6.389	5.89	1.412E-06	9.591E-08	732.55621	

Table 5.E.5 Transmissivity Determined by Hurr-Worthington Method (Pallabi)

Time (min.	Drawdown (m)	Corr. Drawdown (m)	Uw*W(Uw)	Uw	Pseudo KD	KD
1	11.179	10.37	0.00089504	9.65E-05	261.968162	
2	11.319	10.51	0.00045356	4.66E-05	271.389961	
4	11.395	10.586	0.00022842	2.23E-05	283.026482	
6	11.458	10.649	0.00015319	1.46E-05	289.529518	
8	11.522	10.713	0.00011558	1.08E-05	293.672525	
10	11.573	10.764	9.2905E-05	8.52E-06	296.894561	
12	11.609	10.8	7.768E-05	7.03E-06	299.727284	
14	11.649	10.84	6.6829E-05	5.98E-06	301.86056	
16	11.687	10.878	5.868E-05	5.21E-06	303.624086	
18	11.725	10.916	5.2343E-05	4.61E-06	305.057209	
20	11.751	10.942	4.7221E-05	4.12E-06	306.588097	
25	11.776	10.967	3.7863E-05	3.26E-06	310.772441	300.7762
30	11.788	10.979	3.1587E-05	2.68E-06	314.493437	
35	11.801	10.992	2.7106E-05	2.28E-06	317.586148	
40	11.814	11.005	2.3746E-05	1.97E-06	320.2359	
45	11.827	11.018	2.1133E-05	1.74E-06	322.543783	
50	11.839	11.03	1.904E-05	1.56E-06	324.611051	
55	11.852	11.043	1.733E-05	1.41E-06	326.424935	
60	11.878	11.069	1.5923E-05	1.29E-06	327.641262	
70	11.903	11.094	1.3679E-05	1.09E-06	330.483142	
80	11.928	11.119	1.1996E-05	9.5E-07	332.858953	
90	11.954	11.145	1.0688E-05	8.39E-07	334.843066	
100	12.005	11.196	9.6633E-06	7.53E-07	335.735739	
120	12.055	11.246	8.0887E-06	6.23E-07	338.533538	
130	12.093	11.284	7.4918E-06	5.73E-07	339.253578	
140	12.119	11.31	6.9727E-06	5.31E-07	340.221063	
150	12.144	11.335	6.5222E-06	4.94E-07	341.100359	
165	12.169	11.36	5.9424E-06	4.47E-07	342.629716	
180	12.195	11.386	5.4596E-06	4.09E-07	343.930585	
195	12.207	11.398	5.045E-06	3.75E-07	345.520095	
210	12.207	11.398	4.6846E-06	3.47E-07	347.361174	
230	12.219	11.41	4.2818E-06	3.15E-07	349.240555	
250	12.219	11.41	3.9392E-06	2.88E-07	351.335022	
270	12.233	11.424	3.6519E-06	2.66E-07	352.815391	
290	12.233	11.424	3.4E-06	2.46E-07	354.627971	
310	12.233	11.424	3.1807E-06	2.29E-07	356.328019	
330	12.244	11.435	2.9908E-06	2.14E-07	357.560153	
360	12.244	11.435	2.7416E-06	1.95E-07	359.798155	

APPENDIX-F

Specific Drawdown- Discharge Curves for Hantush-Bierschenk Method



From Fig. F-1

$B = 1.64 \times 10^{-3}$
$C = (1.71 - 1.64) \times 10^{-3}/(2 \times 10^{3})$
$= 3.5 \times 10^{-8}$

Fig. F-1 The Hantush-Bierschnk Method: Determination of B and C

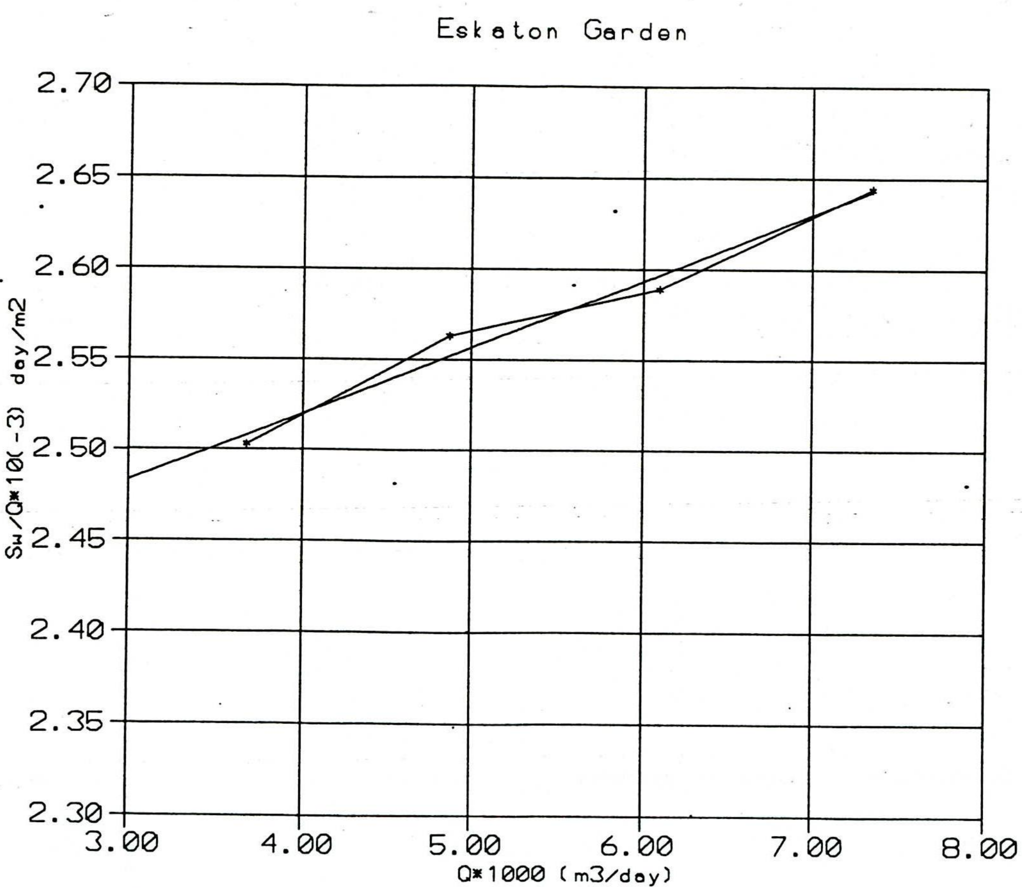


Fig. F-2. The Hantush-Bierschenk Method: Determination of B and C

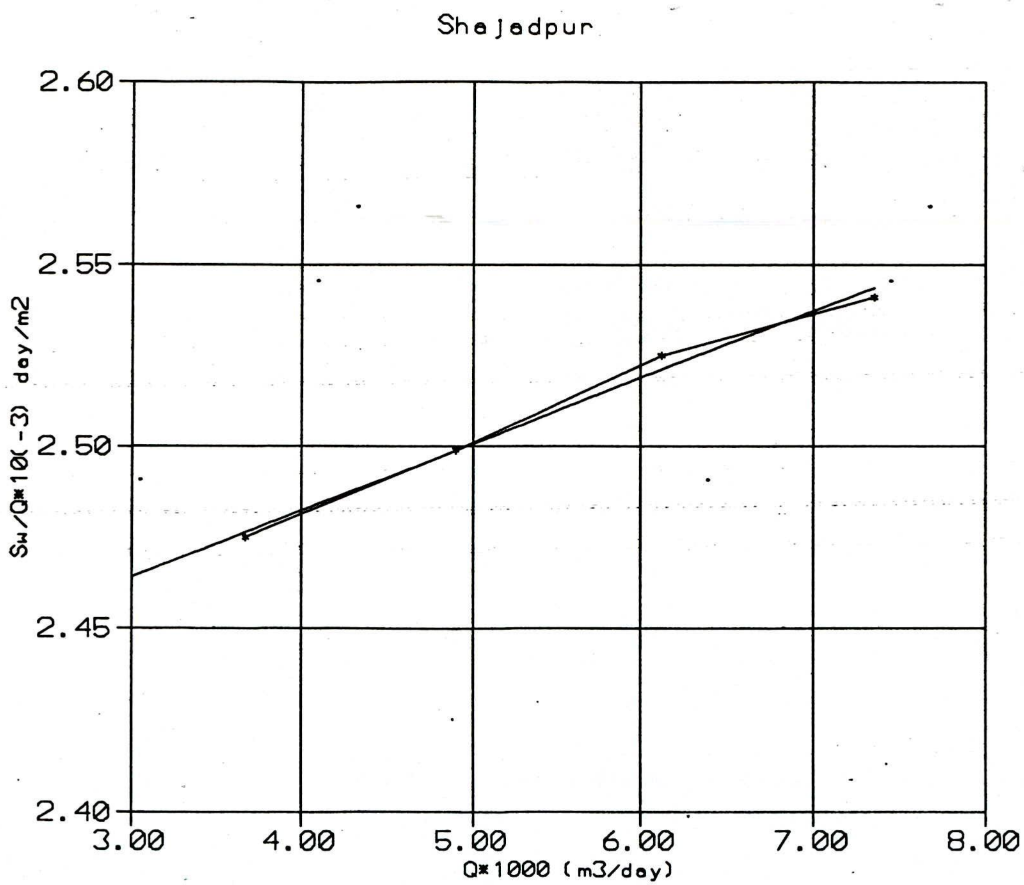


Fig. F-3. The Hantush-Bierschenk Method: Determination of B and C

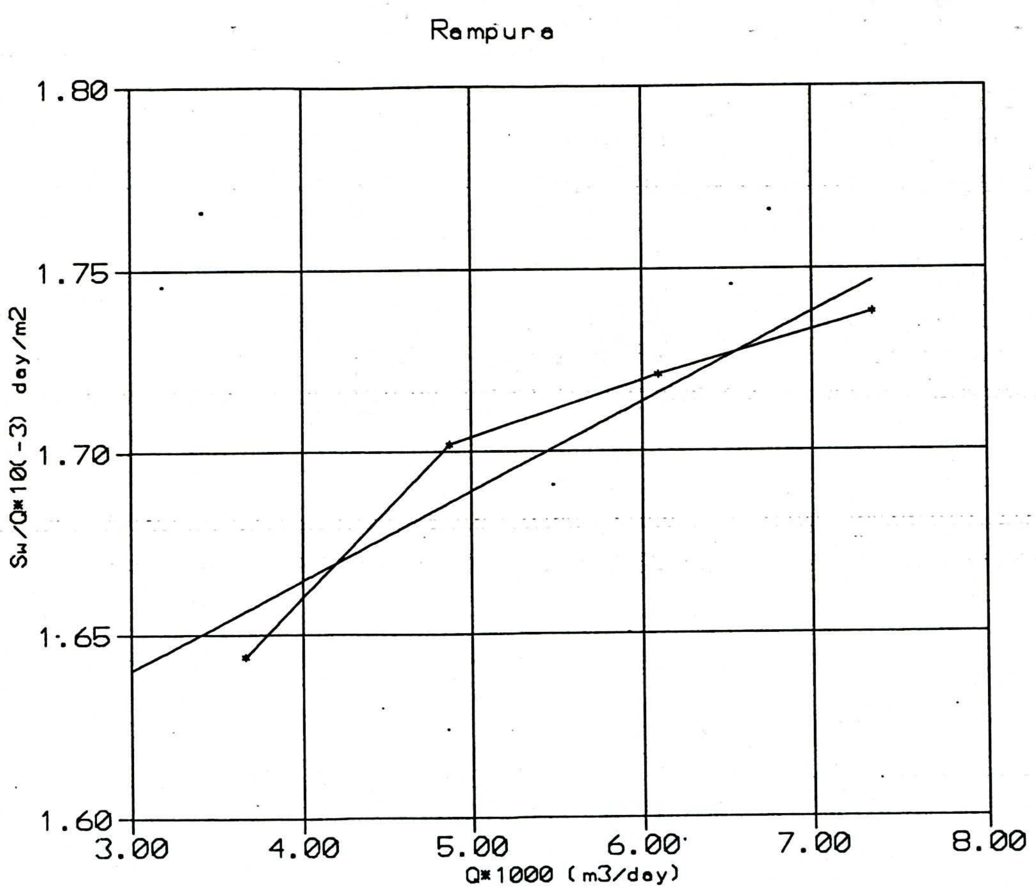


Fig. F-4. The Hantush-Bierschenk Method: Determination of B and C

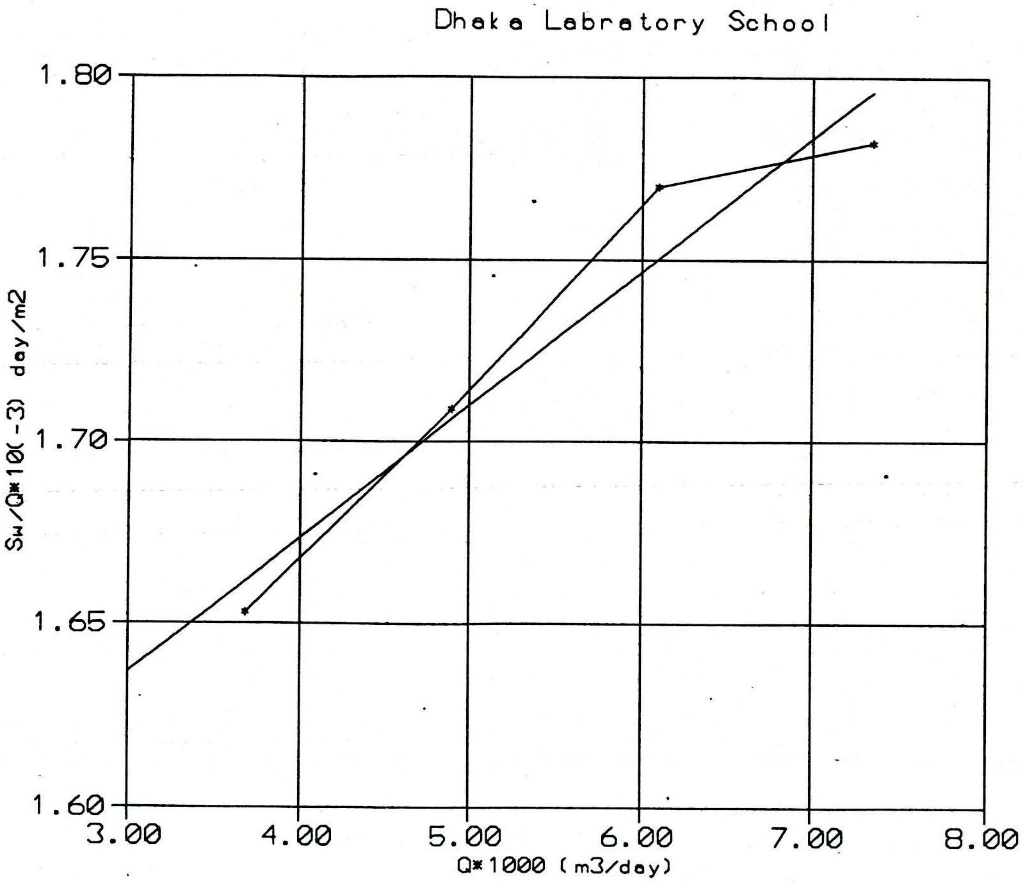


Fig. F-5. The Hantush-Bierschenk Method: Determination of B and C

APPENDIX-G

Pumping Test and Recovery Test Data

PUMPING TEST DATA

Name of well: Banani

Const. Time: September, 89

Discharge: 675 gpm

Time min)	Drawdown(m)
1	6.529
2	6.631
4	6.732
6	6.796
8	6.859
10	6.91
12	6.974
14	7.061
16	7.088
18	7.101
20	7.114
25	7.127
30	7.139
35	7.152
40	7.165
45	7.177
50	7.189
55	7.203
60	7.203
70	7.228
80	7.241
90	7.254
100	7.266
110	7.279
120	7.292
135	7.292
150	7.304
165	7.304
180	7.304
200	7.317
220	7.317
240	7.317
260	7.329
280	7.329
300	7.329
330	7.329
360	7.341

Name of well: Circuit House

Const. Time: November, 89

Discharge: 672 gpm

Time(min)	Drawdown(m)
1	6.847
2	6.999
3	7.101
4	7.152
5	7.203
6	7.254
7	7.304
8	7.329
9	7.355
10	7.381
12	7.431
14	7.482
16	7.533
18	7.584
20	7.609
25	7.634
30	7.66
35	7.685
40	7.71
45	7.736
50	7.749
60	7.787
70	7.813
80	7.838
90	7.851
100	7.863
120	7.889
140	7.914
160	7.939
180	7.965
210	7.976
240	8.003
300	8.016
360	8.003

Name of well: Central Road

Const. Time: May, 90

Discharge: 672 gpm

Time(min)	Drawdown(m)
1	5.589
2	5.742
3	5.779
4	5.805
5	5.817
6	5.841
7	5.869
8	5.882
9	5.894
10	5.907
12	5.932
14	5.971
16	5.997
18	6.009
20	6.021
25	6.059
30	6.085
35	6.098
40	6.109
45	6.122
50	6.136
60	6.146
70	6.161
80	6.174
90	6.186
100	6.199
120	6.263
140	6.352
160	6.377
180	6.389
210	6.389
240	6.389
300	6.389
360	6.389

Name of well: Dhanmondi-7

Const. Time: December, 95

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	4.776
10	4.839
15	4.891
20	4.927
25	4.967
30	5.005
40	5.043
50	5.069
60	5.094
70	5.119
80	5.132
90	5.145
105	5.158
120	5.17
135	5.17
150	5.183
165	5.196
180	5.196
195	5.196
210	5.207
225	5.207
240	5.221
260	5.221
280	5.221
300	5.232
330	5.232
360	5.232

PUMPING TEST DATA

Name of well: Uttara

Const. Time: November, 89

Discharge: 675 gpm

Time min)	Drawdown(m)
1	4.052
2	4.103
4	4.129
6	4.166
8	4.192
10	4.217
12	4.243
14	4.268
16	4.293
18	4.306
20	4.317
25	4.332
30	4.345
35	4.357
40	4.371
45	4.383
50	4.383
55	4.395
60	4.408
70	4.421
80	4.433
90	4.46
100	4.469
110	4.471
120	4.484
135	4.497
150	4.509
165	4.522
180	4.535
195	4.548
210	4.56
225	4.56
240	4.573
260	4.586
280	4.586
300	4.598
330	4.598
360	4.598

Name of well: Sayedbad

Const. Time: February, 90

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	8.308
2	8.486
4	8.638
6	8.765
8	8.841
10	8.918
12	8.981
14	9.032
16	9.083
18	9.121
20	9.159
25	9.223
30	9.286
35	9.337
40	9.388
45	9.426
50	9.451
55	9.476
60	9.5
70	9.553
80	9.604
90	9.642
100	9.679
110	9.718
120	9.756
135	9.794
150	9.819
165	9.845
180	9.87
200	9.883
220	9.896
240	9.909
270	9.921
300	9.934
330	9.947
360	9.959

Name of well: Barabo (Shamoli)

Const. Time: September, 89

Discharge: 675 gpm

Time(min)	Drawdown(m).
1	10.695
2	10.849
4	10.988
6	11.115
8	11.217
10	11.293
12	11.395
14	11.484
16	11.573
18	11.623
20	11.674
25	11.725
30	11.763
35	11.788
40	11.801
45	11.814
50	11.839
55	11.852
60	11.865
70	11.865
80	11.939
90	11.979
100	12.029
110	12.055
120	12.081
135	12.199
150	12.157
165	12.182
180	12.219
200	12.219
220	12.233
240	12.244
260	12.244
280	12.244
300	12.271
330	12.271

Name of well: Mitford H.

Const. Time: May, 79

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	
2	5.259
4	5.309
6	5.361
8	5.399
10	5.412
12	5.437
14	5.462
16	5.475
18	5.488
20	5.501
25	5.512
30	5.526
35	5.537
40	5.555
45	5.564
50	5.578
55	5.578
60	5.589
70	5.589
80	5.589
90	5.602
100	5.602
110	5.602
120	5.602
135	5.615
150	5.615
165	5.615
180	5.628
195	5.628
210	5.628
225	5.628
240	5.634
260	5.634
280	5.64
300	5.64
320	5.652
340	5.666
360	5.666

PUMPING TEST DATA

Name of Well: Bangababan

Const. Date : September, 90

Discharge: 675 gpm

Time (min.)	Drawdown (m)
1	11.634
2	11.712
4	11.776
6	11.827
8	11.878
10	11.928
12	11.992
14	12.043
16	12.081
18	12.132
20	12.182
25	12.219
30	12.309
35	12.36
40	12.411
45	12.462
50	12.513
55	12.549
60	12.602
70	12.652
80	12.703
90	12.754
100	12.792
110	12.829
120	12.868
135	12.932
150	12.995
165	13.046
180	13.084
195	13.109
210	13.134
225	13.148
240	13.186
260	13.211
280	13.237
300	13.249
320	13.262
340	13.275
360	13.275
390	13.288
420	13.288
450	13.288

Name of Well: Ashkona

Const. Date : January, 90

Discharge: 675 gpm

Time (min.	Drawdown (m)
1	5.869
2	5.932
4	5.983
6	6.021
8	6.059
10	6.098
12	6.122
14	6.161
16	6.186
18	6.212
20	6.237
25	6.275
30	6.301
35	6.326
40	6.352
45	6.377
50	6.402
55	6.427
60	6.441
70	6.491
80	6.517
90	6.542
100	6.568
110	6.593
120	6.618
135	6.618
150	6.618
165	6.631
180	6.644
195	6.644
210	6.637
225	6.669
240	6.695
260	6.695
280	6.72
300	6.732
330	6.745
360	6.745

Name of Well: Hazaribag

Const. Date : July, 91

Discharge: 675 gpm

Time (min.	Drawdown (m)
2	4.217
4	4.369
6	4.446
8	4.497
10	4.522
15	4.548
20	4.573
25	4.586
30	4.598
35	4.611
40	4.611
50	4.622
60	4.637
70	4.637
80	4.637
90	4.649
100	4.649
110	4.649
120	4.649
130	4.662
140	4.662
150	4.662
160	4.662
170	4.662
180	4.662
195	4.662
210	4.662
225	4.662
240	4.662
255	4.675
270	4.675
285	4.675
300	4.675
330	4.675

Name of Well: Bangla Motor

Const. Date : February, 96

Discharge: 675 gpm

Time (min.	Drawdown (m)
5	5.817
10	5.869
15	5.919
20	5.958
25	5.996
30	6.034
40	6.072
50	6.11
60	6.136
70	6.161
80	6.186
90	6.212
105	6.225
120	6.237
135	6.25
150	6.263
165	6.275
180	6.288
195	6.288
210	6.301
225	6.301
240	6.314
260	6.314
280	6.314
300	6.326
330	6.326
360	6.326

PUMPING TEST DATA

Name of well: B.D.R.Pilkhana

Const. Time: September, 89

Discharge: 672 gpm

Time(min)	Drawdown(m)
1	5.945
2	6.047
3	6.146
4	6.225
5	6.275
6	6.301
7	6.326
8	6.352
9	6.377
10	6.402
12	6.441
14	6.466
16	6.491
18	6.504
20	6.517
25	6.517
30	6.529
35	6.542
40	6.542
45	6.542
50	6.555
60	6.555
70	6.568
80	6.568
90	6.568
100	6.58
120	6.58
140	6.58
160	6.593
180	6.593
200	6.593
250	6.593
300	6.605
350	6.605
400	6.605

Name of well: Azimpur

Const. Time: June, 90

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	3.557
2	3.582
4	3.608
6	3.633
8	3.659
10	3.683
12	3.697
14	3.701
16	3.722
18	3.735
20	3.76
25	3.773
30	3.786
35	3.798
40	3.811
45	3.824
50	3.836
55	3.849
60	3.862
75	3.887
90	3.913
105	3.938
120	3.963
150	4.002
180	4.039
210	4.065
240	4.09
270	4.116
300	4.141
360	4.166

Name of well: Islambag

Const. Time: October, 89

Discharge: 672 gpm

Time(min)	Drawdown(m)
1	4.713
2	4.764
4	4.776
6	4.827
8	4.853
10	4.878
12	4.902
14	4.916
16	4.942
18	4.967
20	4.979
25	5.005
30	5.018
35	5.03
40	5.043
45	5.056
50	5.056
55	5.069
60	5.081
70	5.1
80	5.132
90	5.158
100	5.17
110	5.183
120	5.196
135	5.232
150	5.284
165	5.309
180	5.323
200	5.335
220	5.335
240	5.335
260	5.348
280	5.361
300	5.361
330	5.373
360	5.386

Name of well: Jagonnath C.

Const. Time: February, 92

Discharge: 672 gpm

Time(min)	Drawdown(m)
1	7.317
2	7.444
3	7.546
4	7.646
5	7.723
6	7.799
7	7.851
8	7.901
9	8.256
10	8.333
12	8.409
14	8.435
16	8.46
18	8.486
20	8.511
25	8.561
30	8.585
35	8.613
40	8.638
45	8.651
50	8.664
60	8.689
70	8.714
80	8.739
90	8.765
100	8.791
120	8.841
140	8.918
160	8.968
180	9.007
210	9.045
240	9.07
300	9.096
360	9.108

PUMPING TEST DATA

Name of well: Rajnarayan

Const. Time: November, 90

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	3.468
2	3.506
4	3.569
6	3.608
8	3.646
10	3.683
12	3.707
14	3.722
16	3.735
18	3.747
20	3.759
25	3.786
30	3.811
35	3.836
40	3.862
45	3.874
50	3.884
55	3.899
60	3.913
70	3.938
80	3.951
90	3.963
100	3.976
110	3.988
120	4.002
135	4.002
150	4.039
165	4.052
180	4.062
195	4.065
210	4.068
225	4.078
240	4.09
260	4.09
280	4.09
300	4.116
330	4.129
360	4.129

Name of well: Rajarbagh

Const. Time: October, 89

Discharge: 672 gpm

Time(min)	Drawdown(m)
1	9.108
2	9.463
3	9.693
4	9.845
5	9.972
6	10.048
7	10.124
8	10.175
9	10.226
10	10.277
12	10.353
14	10.429
16	10.48
18	10.506
20	10.531
25	10.582
30	10.658
35	10.734
40	10.785
45	10.836
50	10.887
60	10.938
70	10.988
80	11.014
90	11.039
100	11.065
120	11.115
140	11.166
160	11.217
180	11.255
210	11.293
240	11.365
300	11.446
360	11.496

Name of well: Shajahanpur

Const. Time: June, 95

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	10.695
2	10.849
4	10.988
6	11.115
8	11.217
10	11.293
12	11.395
14	11.484
16	11.373
18	11.623
20	11.674
25	11.725
30	11.763
35	11.788
40	11.801
45	11.814
50	11.839
55	11.852
60	11.865
70	11.865
80	11.939
90	11.979
100	12.029
110	12.055
120	12.081
135	12.119
150	12.157
165	12.182
180	12.219
200	12.219
220	12.233
240	12.244
260	12.244
280	12.244
300	12.271
330	12.271

Name of well: Shajatpur

Const. Time: February, 92

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	9.121
10	9.195
15	9.248
20	9.324
25	9.362
30	9.388
40	9.4
50	9.426
60	9.476
70	9.489
80	9.553
90	9.578
105	9.604
120	9.616
135	9.616
150	9.629
165	9.629
180	9.642
195	9.642
210	9.654
225	9.667
240	9.667
260	9.679
280	9.679
300	9.679
330	9.705

PUMPING TEST DATA

Name of well: Mirpur 12 B- D

Const. Time: June, 88

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	11.834
10	11.865
15	11.979
20	12.093
25	12.144
30	12.195
35	12.271
40	12.297
45	12.322
50	12.348
55	12.373
60	12.398
65	12.424
70	12.444
75	12.462
80	12.475
90	12.487
95	12.5
100	12.513
105	12.513
110	12.513
115	12.525
120	12.525
125	12.532
130	12.532
135	12.532
140	12.538
145	12.538
150	12.538
165	12.538
180	12.538
195	12.538
210	12.551
220	12.551
230	12.576
240	12.602
250	12.627
260	12.652
270	12.678
280	12.703
285	12.729
290	12.741
300	12.749
310	12.767
320	12.779
330	12.779
340	12.792
350	12.792
360	12.792

Name of well: Mirpur 10

Const. Time: October, 78

Discharge: 672 gpm

Time(min)	Drawdown(m)
2	5.235
4	5.387
6	5.515
8	5.616
10	5.64
14	5.652
16	5.692
18	5.716
20	5.744
25	5.78
30	5.805
40	5.82
50	5.845
60	5.857
70	5.869
80	5.884
90	5.909
100	5.921
120	5.945
140	5.97
160	5.997
180	6.009
200	6.021
220	6.037
240	6.049
260	6.073
280	6.085
300	6.098
320	6.11
340	6.122
360	6.134

Name of well: Mirpur 7

Const. Time: June,73

Discharge: 2994 gal/hr

Time(min)	Drawdown(m)
4	5.44
6	5.51
8	5.56
10	5.61
15	5.69
20	5.72
25	5.77
30	5.79
40	5.87
50	5.89
60	5.92
75	5.95
90	6
105	6
120	6.02
140	6.07
160	6.1
180	6.12
210	6.12
240	6.17
270	6.17
300	6.17
330	6.22
360	6.22

Name of well: Mirpur 2

Const. Time: October, 78

Discharge: 672 gpm

Time(min)	Drawdown(m)
2	6.529
4	6.756
6	7.061
8	7.139
10	7.19
12	7.266
14	7.317
16	7.341
18	7.355
20	7.366
25	7.431
30	7.469
40	7.52
50	7.571
60	7.609
70	7.635
80	7.646
90	7.671
105	7.685
120	7.698
140	7.723
160	7.736
180	7.749
200	7.762
220	7.774
240	7.787
260	7.799
280	7.799
300	7.799
320	7.799
340	7.799
360	7.799

PUMPING TEST DATA

Name of well: Nakhalpara

Const. Time: May, 96

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	9.096
10	9.195
15	9.273
20	9.337
25	9.4
30	9.451
40	9.515
50	9.553
60	9.578
70	9.604
80	9.629
90	9.642
105	9.667
120	9.679
135	9.693
150	9.705
165	9.718
180	9.731
195	9.743
210	9.756
225	9.768
240	9.78
260	9.78
280	9.794
300	9.794
330	9.805
360	9.805

Name of well: Monipuripara

Const. Time: June, 95

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	5.335
10	5.386
15	5.424
20	5.462
25	5.488
30	5.512
40	5.537
50	5.564
60	5.589
70	5.615
80	5.628
90	5.64
105	5.653
120	5.666
135	5.678
150	5.691
165	5.704
180	5.704
195	5.716
210	5.729
225	5.729
240	5.742
260	5.742
280	5.755
300	5.755
330	5.767
360	5.767

Name of well: Mugdapara

Const. Time: July, 95

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	8.384
10	8.473
15	8.537
20	8.585
25	8.638
30	8.689
40	8.753
50	8.803
60	8.854
70	8.89
80	8.918
90	8.943
105	8.981
120	9.032
135	9.057
150	9.07
165	9.096
180	9.121
195	9.146
210	9.171
225	9.184
240	9.185
260	9.223
280	9.235
300	9.235
330	9.248

Name of well: Mirpur B.C,

Const. Time: November, 80

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	8.15
10	8.29
15	9
20	9.04
25	9.07
30	9.08
35	9.09
40	9.09
45	9.09
50	9.1
55	9.1
60	9.1
70	9.43
80	9.81
90	9.81
100	9.81
110	9.83
120	9.83
130	9.84
140	9.85
150	9.85

PUMPING TEST DATA

Name of well: Pallabi

Const. Time: August, 89

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	11.179
2	11.319
4	11.395
6	11.458
8	11.522
10	11.573
12	11.609
14	11.649
16	11.687
18	11.725
20	11.751
25	11.776
30	11.788
35	11.801
40	11.814
45	11.827
50	11.839
55	11.852
60	11.878
70	11.903
80	11.928
90	11.954
100	12.005
120	12.055
130	12.093
140	12.119
150	12.144
165	12.169
180	12.195
195	12.207
210	12.207
230	12.219
250	12.219
270	12.233
290	12.233
310	12.233
330	12.244
360	12.244

Name of well: Paterbagh

Const. Time: April, 90

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	8.803
2	8.866
4	8.905
6	8.943
8	8.994
10	9.032
12	9.07
14	9.108
16	9.146
18	9.171
20	9.171
25	9.223
30	9.248
35	9.273
40	9.299
45	9.324
50	9.349
55	9.375
60	9.4
70	9.439
80	9.476
90	9.489
100	9.54
110	9.566
120	9.591
135	9.616
150	9.646
165	9.667
180	9.679
195	9.693
210	9.705
225	9.718
240	9.718
260	9.731
280	9.743
300	9.743
330	9.756
360	9.769

Name of well: Pisci,M.pur

Const. Time: June, 90

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	8.244
2	8.295
4	8.333
6	8.371
8	8.409
10	8.448
12	8.486
14	8.511
16	8.537
18	8.561
20	8.585
25	8.613
30	8.638
35	8.664
40	8.689
45	8.714
50	8.727
55	8.739
60	8.753
70	8.778
80	8.803
90	8.816
100	8.829
110	8.841
120	8.854
135	8.866
150	8.879
165	8.89
180	8.905
195	8.918
210	8.93
225	8.943
240	8.956
260	8.968
280	8.981
300	8.994
330	9.007
360	9.007

Name of well: Rampura

Const. Time: February, 90

Discharge: 672 gpm

Time(min)	Drawdown(m)
1	5.132
2	5.284
3	5.386
4	5.462
5	5.537
6	5.589
7	5.615
8	5.653
9	5.691
10	5.716
12	5.755
14	5.779
16	5.817
18	5.841
20	5.869
25	5.919
30	5.971
35	5.996
40	6.021
45	6.047
50	6.059
60	6.085
70	6.109
80	6.136
90	6.146
100	6.161
120	6.199
140	6.212
160	6.237
180	6.237
210	6.25
240	6.25
300	6.263
360	6.263

PUMPING TEST DATA

Name of well: Dhaka Lab. S

Const. Time: December, 90

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	4.927
2	5.056
3	5.183
4	5.284
5	5.335
6	5.399
7	5.437
8	5.488
9	5.564
10	5.602
12	5.628
14	5.653
16	5.678
18	5.704
20	5.767
25	5.817
30	5.869
35	5.894
40	5.919
45	5.945
50	5.983
60	6.009
70	6.021
80	6.034
90	6.034
100	6.047
120	6.047
140	6.059
160	6.059
180	6.059
210	6.072
240	6.072
300	6.072
360	6.072

Name of well: Eskaton Garden

Const. Time: October, 95

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	8.308
10	8.435
15	8.511
20	8.585
25	8.651
30	8.702
40	8.778
50	8.803
60	8.841
70	8.89
80	8.93
90	8.968
105	8.994
120	9.019
135	9.045
150	9.07
165	9.096
180	9.121
195	9.134
210	9.146
225	9.146
240	9.159
260	9.159
280	9.171
300	9.184
330	9.195
360	9.195

Name of well: Gopibag

Const. Time: October, 95

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	7.114
2	7.495
4	7.266
6	7.329
8	7.393
10	7.469
12	7.546
14	7.622
16	7.671
18	7.736
20	7.799
25	7.863
30	7.927
35	7.997
40	8.054
45	8.117
50	8.168
55	8.219
60	8.269
70	8.308
80	8.346
90	8.384
100	8.422
110	8.46
120	8.498
135	8.537
150	8.561
165	8.585
180	8.613
195	8.638
210	8.664
225	8.689
240	8.702
260	8.714
280	8.727
300	8.727
330	8.739
360	8.739

Name of well: Goran

Const. Time: January, 90

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	6.745
2	6.809
4	6.859
6	6.898
8	6.936
10	6.974
12	6.999
14	7.025
16	7.05
18	7.076
20	7.088
25	7.114
30	7.139
35	7.165
40	7.19
45	7.215
50	7.228
55	7.241
60	7.254
70	7.279
80	7.304
90	7.329
100	7.341
110	7.355
120	7.366
135	7.381
150	7.393
165	7.393
180	7.406
195	7.419
210	7.419
225	7.431
240	7.431
260	7.457
280	7.469
300	7.482
330	7.482
360	7.495

PUMPING TEST DATA

Name of well: Jurain

Const. Time: February, 90

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	8.638
2	8.689
4	8.739
6	8.778
8	8.816
10	8.854
12	8.879
14	8.905
16	8.93
18	8.943
20	8.956
25	8.981
30	9.007
35	9.019
40	9.032
45	9.045
50	9.057
55	9.07
60	9.083
70	9.108
80	9.134
90	9.159
100	9.186
110	9.223
120	9.248
135	9.286
150	9.311
165	9.337
180	9.349
195	9.362
210	9.375
225	9.388
240	9.388
260	9.4
280	9.413
300	9.413
330	9.426
360	9.426

Name of well: Jatrabari

Const. Time: April, 90

Discharge: 895 gpm

Time(min)	Drawdown(m)
1	14.723
2	14.914
3	14.988
4	15.028
5	15.066
6	15.104
7	15.142
8	15.168
9	15.193
10	15.206
12	15.218
14	15.257
16	15.282
18	15.282
20	15.345
25	15.371
30	15.42
35	15.473
40	15.511
45	15.536
50	15.549
60	15.573
70	15.597
80	15.638
90	15.663
100	15.689
120	15.727
140	15.777
160	15.816
180	15.841
210	15.878
240	15.902
300	15.929
360	15.968

Name of well: Kafrul

Const. Time: January, 90

Discharge: 675 gpm

Time(min)	Drawdown(m)
1	9.51
2	9.65
3	9.75
4	9.84
5	9.87
6	9.91
7	9.96
8	9.99
9	10.07
10	10.09
12	10.14
14	10.2
16	10.22
18	10.26
20	10.27
25	10.31
30	10.37
35	10.39
40	10.4
45	10.42
50	10.44
60	10.45
70	10.47
80	10.48
90	10.49
100	10.5
120	10.52
140	10.54
160	10.59
180	10.6
200	10.61
250	10.62
300	10.63
350	10.63

Name of well: Gudaraghat

Const. Time: May, 89

Discharge: 562 gpm

Time(min)	Drawdown(m)
1	13.88
2	15.82
4	17.18
6	17.34
8	17.38
10	17.43
15	17.46
20	17.48
25	17.5
30	17.46
35	17.48
40	17.34
45	17.43
50	17.48
55	17.28
60	17.38
70	17.43
80	17.47
90	17.48

PUMPING TEST DATA

Name of well: Kallyanpur

Const. Time: September, 82

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	14.33
10	14.68
15	14.79
20	14.98
25	15.19
30	15.37
35	15.57
40	15.65
45	15.75
50	15.88
55	15.98
60	16.11
70	16.16
80	16.21
90	16.28
100	16.34
110	16.36
120	16.39
130	16.41
140	16.44
150	16.46
160	16.51
170	16.56
180	16.59
195	16.64
210	16.67
225	16.72
240	16.74
255	16.74
270	16.77
285	16.77
300	16.77
320	16.79
340	16.79
360	16.82

Name of well: Khilgaon

Const. Time: April, 97

Discharge: 675 gpm

Time(min)	Drawdown(m)
5	10.061
10	10.226
15	10.302
20	10.366
25	10.415
30	10.455
40	10.493
50	10.531
60	10.556
70	10.582
80	10.607
90	10.619
105	10.658
120	10.709
135	10.734
150	10.759
165	10.785
180	10.798
195	10.81
210	10.823
225	10.836
240	10.836
260	10.849
280	10.849
300	10.849
330	10.861
360	10.861
390	10.861
420	10.861
480	10.874
540	10.874
600	10.874
660	10.874
720	10.874

Name of well: Kuratoli

Const. Time: February, 90

Discharge: 672 gpm

Time(min)	Drawdown(m)
1	4.065
2	4.243
3	4.318
4	4.345
5	4.369
6	4.395
7	4.408
8	4.421
9	4.433
10	4.446
12	4.484
14	4.509
16	4.522
18	4.535
20	4.548
25	4.586
30	4.611
35	4.637
40	4.662
45	4.675
50	4.688
60	4.713
70	4.738
80	4.751
90	4.764
100	4.776
120	4.802
140	4.827
160	4.853
180	4.865
210	4.878
240	4.902
300	4.927
360	4.954

Name of well: Laxmibazar

Const. Time: December, 89

Discharge: 672 gpm

Time(min)	Drawdown(m)
1	6.682
2	6.834
3	6.961
4	7.037
5	7.114
6	7.189
7	7.266
8	7.317
9	7.366
10	7.444
12	7.495
14	7.546
16	7.571
18	7.597
20	7.622
25	7.646
30	7.671
35	7.698
40	7.723
45	7.749
50	7.774
60	7.825
70	7.876
80	7.927
90	7.951
100	7.976
120	8.016
140	8.054
160	8.079
180	8.105
200	8.117
250	8.155
300	8.181
360	8.206

RECOVERY TEST DATA

Name of well:Mirpur 12 Block D		Name of well:Bangla Motor		Name of well:Azimpur		Name of well:Ashkona	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)
1	7.825	2	1.778	2	1.219	1	3.633
2	5.386	4	1.385	4	0.838	2	3.011
3	5.207	6	1.143	6	0.737	4	2.566
4	4.622	8	1.029	8	0.659	6	7.542
5	3.683	10	0.915	10	0.609	8	2.121
7	3.328	15	0.788	15	0.534	10	1.994
9	3.125	20	0.699	30	0.457	12	1.878
11	2.744	25	0.622	45	0.381	14	1.804
13	2.313	30	0.572	60	0.305	16	1.727
15	2.159	40	0.483	75	0.229	18	1.664
20	1.982	50	0.406	90	0.203	20	1.613
25	1.809	60	0.354	105	0.178	25	1.601
30	1.703	70	0.305	120	0.152	30	1.397
35	1.626	80	0.254	150	0.127	35	1.321
40	1.384	90	0.216	180	0.102	40	1.244
45	1.244	105	0.165	210	0.076	45	1.184
55	1.118	120	0.102	240	0.049	50	1.118
60	1.041	135	0.089	270	0.024	55	1.067
65	0.963	150	0.076	300	0.013	60	1.016
70	0.889	165	0.064	360	0.013	70	0.939
75	0.788	180	0.064			80	0.877
80	0.609	200	0.051			90	0.813
85	0.534	220	0.051			100	0.762
90	0.483	240	0.051			110	0.711
95	0.419					120	0.659
100	0.395					130	0.659
105	0.364					140	0.559
110	0.341					150	0.521
115	0.341					160	0.483
125	0.341					170	0.445
135	0.291					180	0.406
145	0.267					195	0.329
155	0.229					210	0.292
165	0.229					225	0.254
175	0.203					240	0.216
205	0.203					255	0.178
235	0.178					270	0.152
265	0.152					285	0.127
295	0.145					300	0.102
325	0.127					320	0.089
355	0.114					340	0.089
385	0.102					360	0.089
415	0.102					380	0.083
445	0.096					400	0.064
475	0.059					420	0.051
505	0.059					450	0.051
535	0.059					480	0.051
565	0.049						
595	0.038						
625	0.038						
655	0.03						
685	0.03						
715	0.024						
745	0.024						
775	0.024						

RECOVERY TEST DATA

Name of well:Gopibag		Name of well: Eskaton Garden		Name of well: Dhaka Lab. S.		Name of well: Dhanmondi R-7	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)
1	4.7	2	3.506	2	2.363	2	1.194
2	3.659	4	2.718	4	1.753	4	0.851
4	3.125	6	2.312	6	1.321	6	0.634
6	2.793	8	1.878	8	1.118	8	0.534
8	2.566	10	1.499	10	0.963	10	0.457
10	2.337	15	1.143	15	0.659	15	0.354
12	2.261	20	0.889	20	0.483	20	0.318
14	2.183	25	0.8	25	0.354	25	0.292
16	2.083	30	0.686	30	0.254	30	0.254
18	2.019	40	0.572	40	0.178	40	0.229
20	1.913	50	0.495	50	0.076	50	0.195
25	1.804	60	0.419	60	0.025	60	0.165
30	1.702	70	0.318	70	0.013	75	0.139
35	1.601	80	0.241	80	0.013	90	0.114
40	1.524	90	0.191			105	0.089
45	1.448	105	0.152			120	0.064
50	1.372	120	0.114			135	0.051
55	1.296	135	0.089			150	0.038
60	1.244	150	0.076			165	0.038
70	1.143	165	0.063			180	0.025
80	1.067	180	0.051			210	0.025
90	0.991	200	0.038			240	0.025
100	0.915	220	0.025				
110	0.864	240	0.025				
120	0.8						
130	0.749						
140	0.686						
150	0.659						
160	0.609						
170	0.609						
180	0.534						
195	0.483						
210	0.457						
225	0.406						
240	0.329						
255	0.279						
270	0.229						
285	0.178						
300	0.139						
320	0.102						
340	0.076						
360	0.049						
380	0.049						
400	0.024						
420	0.024						
450	0.012						
480	0.012						

RECOVERY TEST DATA

Name of well: Barabo (shamoli)		Name of well: Psci. M.pur		Name of well: Paterbagh		Name of well: Nakhalpara	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)
1	5.841	1	4.726	1	3.214	2	3.481
2	4.622	2	3.303	2	2.579	4	2.528
4	3.341	4	2.388	4	2.248	6	1.982
6	2.768	6	2.032	6	2.045	8	1.626
8	2.528	8	1.778	8	1.867	10	1.474
10	2.274	10	1.601	10	1.778	15	1.359
12	2.083	12	1.474	12	1.664	20	1.169
14	1.931	14	1.359	14	1.573	25	1.016
16	1.753	16	1.268	16	1.499	30	0.877
18	1.626	18	1.194	18	1.423	40	0.686
20	1.549	20	1.131	20	1.359	50	0.559
25	1.397	25	1.004	25	1.308	60	0.445
30	1.244	30	0.902	30	1.219	70	0.368
35	1.143	35	0.8	35	1.181	80	0.305
40	1.042	40	0.749	40	1.105	90	0.254
45	0.991	45	0.686	45	1.054	105	0.191
50	0.939	50	0.634	50	1.016	120	0.139
55	0.889	55	0.584	55	0.978	135	0.114
60	0.813	60	0.546	60	0.889	150	0.089
70	0.724	70	0.495	70	0.864	165	0.076
80	0.634	80	0.445	80	0.8	180	0.064
90	0.597	90	0.406	90	0.749	200	0.064
100	0.559	100	0.381	100	0.711	220	0.051
110	0.521	110	0.354	110	0.673	240	0.051
120	0.483	120	0.329	120	0.634		
135	0.445	130	0.305	130	0.597		
150	0.406	140	0.279	140	0.559		
165	0.368	150	0.254	150	0.521		
180	0.329	160	0.229	160	0.495		
200	0.292	170	0.203	170	0.47		
220	0.267	180	0.178	180	0.445		
240	0.241	195	0.165	195	0.406		
260	0.216	210	0.152	210	0.354		
280	0.191	225	0.139	225	0.318		
300	0.165	240	0.127	240	0.292		
320	0.139	255	0.114	255	0.241		
340	0.127	270	0.102	270	0.216		
360	0.114	285	0.089	285	0.191		
390	0.089	300	0.076	300	0.178		
420	0.076	320	0.064	320	0.152		
450	0.064	340	0.051	340	0.127		
480	0.05	360	0.044	360	0.102		
540	0.038	390	0.038	380	0.089		
600	0.038	420	0.038	400	0.076		
				420	0.064		
				450	0.051		
				480	0.044		
				510	0.038		
				540	0.038		

RECOVERY TEST DATA

Name of well: Jurain		Name of well: Khilgaon		Name of well: Kuratoli		Name of well: Jatrabari	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)
1	3.76	2	2.566	2	1.804	2	5.716
2	3.201	4	2.019	4	1.499	4	4.243
4	2.845	6	1.753	6	1.143	6	3.608
6	2.439	8	1.563	8	1.042	8	3.214
8	2.083	10	1.448	10	0.991	10	2.959
10	1.778	15	1.308	15	0.788	15	2.488
12	1.702	20	1.194	20	0.711	20	2.183
14	1.347	25	1.118	25	0.659	25	1.931
16	1.219	30	1.042	30	0.609	30	1.753
18	1.092	40	1.016	40	0.584	40	1.499
20	0.951	50	0.877	50	0.483	50	1.296
25	0.864	60	0.762	60	0.432	60	1.169
30	0.788	75	0.687	75	0.354	75	1.016
35	0.711	90	0.622	90	0.305	90	0.963
40	0.659	105	0.572	105	0.267	105	0.788
45	0.609	120	0.521	120	0.229	120	0.711
50	0.559	140	0.457	135	0.203	135	0.634
55	0.534	160	0.406	150	0.178	150	0.584
60	0.508	180	0.343	165	0.165	165	0.534
70	0.457	210	0.254	180	0.152	180	0.521
80	0.406	240	0.216	195	0.139	195	0.457
90	0.368	270	0.165	210	0.127	210	0.419
100	0.329	300	0.165	225	0.127	225	0.381
110	0.292	330	0.165	240	0.114	240	0.354
120	0.267			255	0.114	255	0.329
130	0.241			270	0.102	270	0.305
140	0.216			285	0.089	285	0.279
150	0.191			300	0.089	300	0.254
160	0.165			315	0.076	315	0.241
170	0.152			330	0.076	330	0.229
180	0.139			345	0.076	345	0.216
195	0.127			360	0.076	360	0.203
210	0.114					375	0.191
225	0.102					390	0.178
240	0.089					405	0.165
255	0.076					420	0.152
270	0.064						
285	0.051						
300	0.044						
320	0.038						
340	0.032						
360	0.025						
390	0.025						
420	0.025						

RECOVERY TEST DATA

Name of well: Bangababan		Name of well: Sayedabad		Name of well: Rajarbag		Name of well: Rampura	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)
1	5.589	1	5.666	2	4.408	2	2.159
2	3.862	2	4.243	4	3.366	4	1.753
4	3.277	4	3.429	6	2.693	6	1.512
6	2.947	6	3.073	8	2.451	8	1.372
8	2.693	8	2.896	10	2.236	10	1.219
10	2.488	10	2.642	15	1.854	15	1.042
12	2.388	12	2.439	20	1.626	20	0.864
14	2.21	14	2.261	25	1.461	25	0.775
16	2.083	16	2.109	30	1.334	30	0.699
18	2.007	18	2.007	40	1.131	40	0.597
20	1.956	20	1.905	50	0.991	50	0.521
25	1.854	25	1.753	60	0.864	60	0.457
30	1.778	30	1.626	75	0.762	75	0.381
35	1.715	35	1.499	90	0.673	90	0.329
40	1.651	40	1.359	105	0.609	105	0.279
45	1.573	45	1.258	120	0.559	120	0.229
50	1.512	50	1.169	135	0.508	135	0.191
55	1.448	55	1.079	150	0.457	150	0.152
60	1.397	60	0.991	165	0.419	165	0.127
70	1.308	70	0.889	180	0.681	180	0.102
80	1.232	80	0.838	195	0.343	195	0.076
90	1.156	90	0.775	210	0.305	210	0.064
100	1.105	100	0.699	225	0.267	225	0.051
110	1.054	110	0.622	240	0.229	240	0.038
120	1.004	120	0.559	255	0.191	255	0.025
130	0.953	130	0.508	270	0.165	270	0.013
140	0.902	140	0.457	285	0.134	285	0.013
150	0.851	150	0.406	300	0.114	300	0.013
160	0.813	160	0.368	315	0.102		
170	0.775	170	0.329	330	0.089		
180	0.737	180	0.292	345	0.076		
195	0.686	195	0.254	360	0.076		
210	0.634	210	0.229	375	0.064		
225	0.597	225	0.203	390	0.064		
240	0.559	240	0.178	405	0.064		
255	0.534	255	0.152	420	0.051		
270	0.47	270	0.139	435	0.051		
285	0.457	285	0.127	450	0.051		
300	0.419	300	0.114	465	0.038		
320	0.381	320	0.102	480	0.038		
340	0.343	340	0.089				
360	0.305	360	0.076				
380	0.279	380	0.064				
400	0.254	400	0.049				
420	0.241	420	0.038				
450	0.229	450	0.038				
480	0.216	480	0.024				
510	0.191	510	0.024				
540	0.191	540	0.024				
600	0.191						

RECOVERY TEST DATA

Name of well: Mirpur 2		Name of well: Mirpur 7		Name of well: Mirpur 10		Name of well: Kallyanpur	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)
2	4.24	2	2.363	2	2.412	1	1.878
4	2.83	4	1.854	4	1.869	2	1.524
6	2.33	6	1.753	6	1.473	4	1.296
8	1.91	8	1.651	8	1.296	6	1.169
10	1.61	10	1.549	10	1.182	8	1.109
15	1.22	15	1.347	12	1.119	10	0.991
20	0.81	20	1.291	14	0.991	12	0.927
25	0.77	25	1.245	16	0.887	14	0.877
30	0.71	30	1.09	18	0.799	16	0.838
40	0.64	40	0.986	20	0.738	18	0.8
50	0.56	50	0.786	25	0.686	20	0.749
60	0.5	60	0.635	30	0.609	25	0.699
75	0.36	75	0.412	40	0.509	30	0.659
90	0.31	90	0.279	50	0.457	35	0.622
105	0.28	105	0.176	60	0.409	40	0.584
120	0.2	120	0.108	70	0.357	45	0.559
140	0.16	150	0.051	80	0.305	50	0.534
160	0.13			90	0.277	55	0.508
180	0.11			105	0.253	60	0.489
200	0.08			120	0.235	70	0.432
220	0.05			135	0.216	80	0.381
240	0.03			150	0.204	90	0.329
270	0.02			165	0.189	100	0.292
300	0.02			180	0.177	110	0.254
				195	0.152	120	0.229
				210	0.137	135	0.203
				240	0.113	150	0.178
				270	0.101	165	0.152
						180	0.139
						200	0.127
						220	0.114

		RECOVERY TEST DATA					
Name of well:Islambag		Name of well: Hazaribag		Name of well:Gudaraghat		Name of well: Goran	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw
1	1.944	2	0.927	1	7.622	1	3.481
2	1.537	4	0.737	2	4.902	2	2.871
4	1.283	6	0.622	3	2.744	4	2.414
6	1.118	8	0.521	4	2.308	6	2.134
8	1.029	10	0.47	5	1.524	8	1.931
10	1.156	15	0.394	10	1.372	10	1.804
12	0.915	20	0.343	15	1.016	12	1.702
14	0.864	25	0.305	20	0.838	14	1.601
16	0.826	30	0.267	25	0.711	16	1.524
18	0.788	40	0.229	35	0.658	18	1.461
20	0.762	50	0.203	45	0.457	20	1.41
25	0.711	60	0.178	55	0.466	25	1.258
30	0.673	70	0.165	70	0.329	30	1.258
35	0.634	80	0.152	85	0.305	35	1.156
40	0.609	90	0.152	100	0.229	40	1.004
45	0.584	100	0.139	115	0.203	45	1.016
50	0.559	110	0.139	145	0.178.	50	0.953
55	0.534	120	0.127	175	0.152	55	0.902
60	0.508	130	0.127	205	0.127	60	0.851
70	0.47	140	0.114	237	0.102	70	0.775
80	0.483	150	0.114	285	0.076	80	0.724
90	0.406	160	0.102	345	0.051	90	0.673
100	0.381	170	0.102	405	0.038	100	0.622
110	0.354	180	0.089	465	0.038	110	0.584
120	0.329	195	0.076	525	0.03	120	0.546
135	0.305	210	0.064	565	0.03	130	0.495
150	0.279	225	0.064			140	0.445
165	0.254	240	0.051			150	0.394
180	0.229	270	0.038			160	0.495
210	0.203	300	0.025			170	0.305
225	0.178					180	0.267
240	0.165					195	0.216
260	0.152					210	0.178
280	0.139					225	0.152
300	0.127					240	0.127
320	0.114					255	0.102
340	0.102					270	0.089
360	0.089					285	0.076
380	0.076					300	0.064
400	0.069					320	0.064
420	0.064					340	0.051
450	0.057					360	0.044
480	0.051					380	0.038
510	0.044					400	0.038
540	0.038					420	0.038
570	0.038					450	0.038
600	0.038					480	0.038

RECOVERY TEST DATA

Name of well: Uttara		Name of well: Shajadpur		Name of well: Shahajanpur		Name of well: Rajnarayan D. R.	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)
1	1.944	2	3.277	2	3.582	1	1.878
2	1.537	4	2.616	4	3.023	2	1.524
4	1.283	6	2.338	6	2.668	4	1.296
6	1.118	8	2.235	8	2.388	6	1.169
8	1.029	10	2.134	10	2.159	8	1.109
10	1.156	15	1.942	15	1.931	10	0.991
12	0.915	20	1.805	20	1.753	12	0.927
14	0.864	25	1.729	25	1.626	14	0.877
16	0.826	30	1.668	30	1.499	16	0.838
18	0.788	40	1.549	40	1.423	18	0.8
20	0.762	50	1.473	50	1.397	20	0.749
25	0.711	60	1.396	60	1.219	25	0.699
30	0.673	70	1.32	75	1.143	30	0.659
35	0.634	80	1.244	90	1.054	35	0.622
40	0.609	90	1.207	105	0.991	40	0.584
45	0.584	105	1.143	120	0.927	45	0.559
50	0.559	120	1.119	135	0.877	50	0.534
55	0.534	135	1.067	150	0.813	55	0.508
60	0.508	150	1.043	165	0.711	60	0.489
70	0.47	165	1.107	180	0.559	70	0.432
80	..463	180	0.991	200	0.483	80	0.381
90	0.406	210	0.966	220	0.229	90	0.329
100	0.381	240	0.951	240	0.139	100	0.292
110	0.354	270	0.939			110	0.254
120	0.329	300	0.915			120	0.229
135	0.305	330	0.915			130	0.203
150	0.279	360	0.89			140	0.178
165	0.254	165	0.254			150	0.152
180	0.229	180	0.229			160	0.139
195	0.203	195	0.203			170	0.127
210	0.178	210	0.178			180	0.114
225	0.165	225	0.165			195	0.102
240	0.152	240	0.152			210	0.089
260	0.139	260	0.139			225	0.076
280	0.127	280	0.127			240	0.064
300	0.114	300	0.114			260	0.051
320	0.102	320	0.102			280	0.038
340	0.089	340	0.089			300	0.038
360	0.076	360	0.076			320	0.038
380	0.069	380	0.069			340	0.038
400	0.064	400	0.064			360	0.038
420	0.057	420	0.057			390	0.025
450	0.051	450	0.051			420	0.025
480	0.044	480	0.044				
510	0.044	510	0.044				
540	0.038	540	0.038				
570	0.038	570	0.038				
600	0.038	600	0.038				

RECOVERY TEST DATA

Name of well: Central Road		Name of well: Circuit House		Name of well: Banani		Name of well: B.D.R.Pilkhana	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)
2	1.268	2	1.791	1	3.582	2	1.791
4	0.915	4	1.499	2	2.82	4	1.499
6	0.686	6	1.244	4	2.388	6	1.244
8	0.546	8	1.079	6	1.931	8	1.079
10	0.432	10	0.953	8	1.766	10	0.953
15	0.279	15	0.749	10	1.626	15	0.749
20	0.152	20	0.597	12	1.524	20	0.597
25	0.051	25	0.495	14	1.423	25	0.495
30	0.038	30	0.394	16	1.321	30	0.394
40	0.025	40	0.241	18	1.244	40	0.241
50	0.025	50	0.165	20	1.194	50	0.165
60	0.025	60	0.114	25	1.054	60	0.114
75	0.013	75	0.064	30	0.939	75	0.064
90	0.013	90	0.038	35	0.851	90	0.038
105	0.013	105	0.025	40	0.788	105	0.025
120	0.013	120	0.025	45	0.724	120	0.025
		135	0.013	50	0.659	135	0.013
		150	0.013	55	0.597	150	0.013
		165	0.013	60	0.546		
				70	0.457		
				80	0.406		
				90	0.368		
				100	0.329		
				110	0.292		
				120	0.254		
				135	0.216		
				150	0.191		
				165	0.165		
				180	0.139		
				200	0.114		
				220	0.089		
				240	0.064		
				260	0.051		
				280	0.032		
				300	0.032		
				330	0.025		
				360	0.025		
				390	0.025		
				420	0.025		

RECOVERY TEST DATA

Name of well:Mirpur B.C.		Name of well: Kafrul		Name of well:Pallabi	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min	Res. Draw. (m)
1	3.302	2	2.63	1	7.09
2	2.923	4	2.06	2	5.81
4	2.784	6	1.83	4	4.05
6	2.704	8	1.53	6	3.48
8	2.649	10	1.19	8	2.96
10	2.604	15	0.84	10	2.63
12	2.573	20	0.61	12	2.44
14	2.539	25	0.46	14	2.2
16	2.512	30	0.36	16	2.05
18	2.503	40	0.23	18	1.89
20	2.488	50	0.16	20	1.82
25	2.476	60	0.08	25	1.6
30	2.463	75	0.04	30	1.47
35	2.442	90	0.03	35	1.32
40	2.436	105	0.03	40	1.18
45	2.418	120	0.015	45	1.12
50	2.409	135	0.051	50	1.05
55	2.396	150	0.015	55	0.98
60	2.396	165	0	60	0.95
65	2.378	180	0	70	0.86
70	2.357			80	0.81
80	2.348			90	0.76
90	2.326			100	0.71
100	2.326			110	0.66
110	2.326			120	0.62
120	2.317			130	0.58
140	2.317			140	0.55
160	2.317			150	0.53
180	2.296			170	0.5
200	2.296			190	0.46
220	2.296			210	0.42
240	2.262			230	0.38
260	2.262			250	0.34
280	2.262			270	0.32
300	2.241			290	0.29
320	2.241			310	0.27
340	2.241			330	0.24
360	2.222			360	0.2
380	2.222			390	0.17
400	2.222			420	0.14
420	2.221			450	0.11
440	2.221			480	0.1
460	2.205			510	0.09
480	2.205			570	0.06
500	2.205			630	0.05
520	2.205			690	0.04
540	2.205				
560	2.205				
590	2.205				
620	2.205				
650	2.205				
680	2.205				
710	2.205				
740	2.205				
770	2.205				
800	2.205				

RECOVERY TEST DATA							
Name of well:Mugdapara		Name of well: Monipuripara		Name of well: Mitford H.		Name of well: Laxmibazar	
Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)	Time (min)	Res. Draw. (m)
2	2.591	2	1.702	2	2.058	2	3.328
4	1.931	4	1.296	4	1.702	4	3.023
6	1.677	6	1.118	6	1.397	6	2.718
8	1.474	8	0.963	8	1.219	8	2.515
10	1.322	10	0.838	10	1.143	10	2.376
15	1.143	15	0.659	12	1.079	15	2.109
20	1.016	20	0.521	14	1.042	20	1.931
25	0.864	25	0.457	16	0.991	25	1.791
30	0.737	30	0.432	18	0.953	30	1.688
40	0.634	40	0.381	20	0.915	40	1.537
50	0.559	50	0.354	25	0.838	50	1.41
60	0.483	60	0.292	30	0.775	60	1.283
70	0.419	75	0.254	35	0.724	75	1.131
80	0.354	90	0.216	40	0.673	90	1.004
90	0.292	105	0.178	45	0.648	105	0.889
105	0.241	120	0.152	50	0.609	13	0.788
120	0.191	135	0.127	55	0.572	135	0.699
135	0.152	150	0.102	60	0.546	150	0.622
150	0.114	165	0.089	70	0.508	165	0.546
165	0.076	180	0.076	80	0.457	180	0.483
180	0.049	200	0.064	90	0.432	195	0.419
200	0.038	220	0.051	100	0.406	210	0.354
220	0.024	240	0.038	110	0.381	225	0.305
240	0.024			120	0.354	240	0.254
				135	0.318	255	0.203
				150	0.279	270	0.165
				165	0.229	285	0.152
				180	0.191	300	0.089
				195	0.139	315	0.064
				210	0.102	330	0.038
				225	0.064	345	0.025
				240	0.051	360	0.013
				260	0.013	375	0.013
						390	0.013