Availability of Groundwater for Drinking Purpose in Khulna City

By

Md. Wahiduzzaman

A project report submitted to the Department of Civil Engineering of
Khulna University of Engineering and Technology
in partial fulfillment of the requirements for the degree of
Master of Science in Civil Engineering

Khulna University of Engineering and Technology

Khulna – 9203, Bangladesh

November, 2009

DECLARATION

This is to certify that the Project work on titled as "Availability of Groundwater for Drinking Purpose in Khulna City" has been carried out by Md. Wahiduzzaman, Senior Assistant Engineer, UGIIP- II, LGED Head Office, Dhaka, Bangladesh. The above thesis work has not been submitted anywhere for any award of degree or diploma.

Dr. Quazi Hamidul Bari
Professor, Department of Civil Engineering
KUET, Khulna

Md.Wahiduzzaman
Roll No. 991005

Acknowledgement

First of all the author would like to thank and praise the universal owner, Almighty Allah, the most beneficent and merciful creator who has enabled to complete the project work for the fulfilment of the degree.

The author also would like to express his core regard to his supervisor Dr. Quazi Hamidul Bari, Professor, Department of Civil Engineering, Khulna University Engineering and Technology who guided him in every stage during the progression of the project activities. Always the supervisor's eyes were tracing the author's activities to reach the goal. Without his keen supervision and efforts this project would not be a successful one.

The author also would like to express his core esteem to Dr. Quazi Sazzad Hossain, Professor and Head, Department of Civil Engineering, Khulna University Engineering and Technology who contributed through spending his valuable time to finalize the work. With his valuable advice and encouragement certainly enriched this project task.

The author desires to give thanks to the Mr. F. Jambac, Team Leader of MSP study titled as "Ground Water Resources and hydro-geological investigation in and around Khulna City" for his unparallel support and cooperation during the entire Project period with exchanging the views and knowledge in the field of applied hydro-geology.

The author also remembers the valuable encouragement and support provided by his friend and colleague Mr. Mahboob Hassan and Mr. Syed Nesar Ahammed of LGED for completion of the project.

The author would like to convey his gratefulness to his parents who spent many of their time praying for him as he can succeed to finish the project task properly. At last, the author expressed his regards to his wife and two kids for their great sacrifice and providing him continuous moral supports that enabled him to complete the work.

Md. Wahiduzzaman
November 2009.

To

My beloved parents for their love

and

my dearest wife, for her continuous support and encouragement.

Abbreviations

ADB	Asian Development Bank
°C	Degree Centigrade
dt	Deltaic Deposite
DTW	Deep Tube Well
DPHE	Department of Public Health Engineering
EC	Electrical Conductivity, µS/cm (25°C)
Eds_2	Exploratory Well no. 2 in Shallow Aquifer
Edu_3	Exploratory Well no. 3 in Upper Shallow Aquifer
Exd_2	Exploratory Deep Tube Well no. 2
GIS	Geographic Information System
GPS	Global Positioning System
GWFM	Groundwater Flow Model
HP	Height of Parapet (Well Top)
IWM	Institute of Water Modelling
KCC	Khulna City Corporation
KWSA	Khulna Water Supply and Sewerage Authority
Km	Kilometre
LGED	Local Government Engineering Department
Ma	Million Years Ago
MASL	Metre above Sea Level
MLD	Million Litre per Day
MSP	Municipal Services Project
MSL	Mean Sea Level
Pd_3	Deep Piezometer no. 3
PTW	Production Tube Well
SWL	Static Water Level
T	Temperature in Degree Centigrade
TDMS	Total Dissolved Mineral Salts
TDS	Total Dissolved Solid
TW	Tube Well
Z GL(msl)	Height of Ground Level From MSL
Z HP (msl)	Height of Parapet (Pipe Top) From MSL

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ABSTRACT

Khulna, the industrial and port city, is the third largest city of Bangladesh which is situated in the south west part of Bangladesh and lies in the delta of the Ganges. The city itself stretches 15 km along the River Bhairab and Rupsha, covering the area of approximate 46 sq. km. having population around 1 million. The scarcity of water has been augmented gradually owing to increasing resettlement from the surrounding districts for rapid urbanisation and industrialisation. On the other hand the water supply situation has been aggravated due to lack of necessary parallel growth in the water supply infrastructure.

This study focused on identification of the number of aquifers and potentiality the aquifers by investigating the available geological, hydro-chemical, and hydrodynamic parameter of the aquifers. Comprehensive geological cross-sections and a conceptual model of the deep aquifer have been developed using lithologs of previous LGED study (MSP 2005) and DPHE (Rus, 1985) investigation in Khulna area. The estimation of annual ground water recharges in the most potential aquifer has been performed to identify the exploitable (usable) locations for drinking purposes. Data on lithologs, static water level, electrical conductivity, temperature, pH, arsenic, and pumping tests in different aquifers have been collected and analyzed in order to fulfill the study objectives. The data of two special ground water monitoring sessions in 2009 has been collected in order to assess the present situation, comparison to the situation in 2005, for the deep aquifer in Khulna.

Three different aquifers have been identified such as upper shallow, shallow and deep aquifer. It seems that, in some areas the upper shallow aquifer is connected with shallow aquifer. The observed fluctuating water heights for deep, shallow and upper aquifers are 2.13 m, 2.26 m and 1.97 m, respectively. It has been observed that the transmissivity values of deep aquifer varies from 1.3×10^{-3} m^2/sec to 7.1×10^{-2} m^2/sec and the storage coefficient varies from 9.7×10^{-4} to 4.7×10^{-3}.

It is also observed that the average temperature of KWASA production wells in the central part of the city is much higher than those in other part of the study area. There is no indication of increase of average temperature neither in KWASA production well nor in MSP monitoring well since 2005.There is no increase in the average EC value for the MSP monitoring wells since 2005. The average SWL in the project area was - 1.42 m in 2005 and - 2.06 m in 2009 it from mean sea level (MSL), thus the net average declination of SWL in last four years is 0.63 m. Most important observation is that, this mass of declination of the SWL has affected

neither EC nor Temperature. Note that the average temperature of water in the central area is higher than the normal range.

For highest static water level in the month of October, usable recharge has been obtained as about 40,470 m^3/day which is slightly more than the average abstraction rate of 40,000m^3/day while for lowest static water level in the month of April, usable recharge has been obtained as about 36,070 m^3/day. It is true that the complete dependency on ground water for Khulna city water supply, with the present aquifer system, may not sustainable for long term abstraction planning. Since the fresh water resource of the deep aquifer is limited and cannot sustain substantial increase in abstraction rates, an additional volume of drinking water may be derived from blending of water of different sources. The Electrical Conductivity of the deep aquifer near and south of the city centre is very low. There might have few solutions to mitigate the water crisis of the city; i) small quantity of moderately mineralised water from the shallow aquifer can be mixed with water from deep aquifer within the acceptable limit this will increase substantial amount of overall water production. It can be reminded that the water quality of the shallow aquifer is good (and arsenic free) except for the high concentration of saline and with some iron. Iron of the shallow aquifer might be removed by simple aeration and filtration technique. ii) use of surface water for the period of low salinity in the surface water (7-8 months' time in the Bhairab- Rupsha River) to preserve and restrict the abstraction from deep aquifer for those period and supply the ground water for the period of high saline in the surface water (February to June). iii) under WASA Act: 1996, KWASA can impose control over the industrial abstraction from the deep aquifer. In order to restrict abstraction from deep aquifer, for industrial use, KWASA can provide them alternate water through the surface water sources throughout the year.

Availability of Groundwater for Drinking Purpose in Khulna City

CHAPTER – ONE

INTRODUCTION

1.1 General

Khulna is the third largest city of Bangladesh, located at south western part of the country and approximately one hundred km north of Bay of Bengal. The city is situated in the south west part of Bangladesh and lies in the delta of the Ganges. The city itself stretches 15 km along the river Bhairab and Rupsha, covering the area of approximate 46 sq. km. having population around 1 million (Population of 2009, extrapolating BBS population data of 1981, 1991, 2001). The city is surrounded by lots of industries it has plenty of importance for its geographical, political, historical and financial reasons. The scarcity of water has been augmented gradually owing to increasing resettlement from the surrounding districts, for rapid urbanisation and industrialisation but lack of parallel growth in necessary water supply infrastructure.

The Government of the People's Republic of Bangladesh has established Khulna Water Supply and Sewerage Authority (KWASA) on Mach 02, 2008 by a Gazette Notification. Before formation of KWASA the water supply of Khulna City was under the responsibility of Khulna City Corporation (KCC). KWASA is the third WASA in the country, following the Dhaka WASA and the Chittagong WASA. The current water production capacity of KWASA is only 35 million liters per day (MLD) through 54 production tube wells (PTW) against the theoretical projected demand of 240 MLD. Nevertheless the quality of water is also an issue due to wide spread arsenic contamination and salinity of the ground water.

The water supply system of Khulna dates back to 1921 with a small surface water treatment plant of capacity 0.90 Million liters per day (MLD) [MacDonald. M. (1997)]. The water supply system was expanded in 1960 by the Department of Public Health

Engineering (DPHE). They have opened a new era towards ground water through installing few production tube wells in shallow aquifer. Several studies have been conducted in the past to assess the quantity of available ground water resources and find out dependable water source for the Khulna water supply system. The Department of Public Health Engineering (DPHE) and the Local Government Engineering Department (LGED) has been conducted few studies in the past for this purpose.

After handed over the water supply system by DPHE to KCC in 1997, LGED under the frame work of Municipal Services Project has carried out a feasibility study by Mott MacDonald Ltd to prepare an action plan for further expansion of the city water supply system. The study found that the static water level in deep aquifer is within few meters of the ground surface since starting its abstraction in 1960. This observation suggested that there might have some replenishment in the deep aquifer. This observation also suggested for further study in the area. As a result LGED (2003) has taken up another study called "Groundwater Resources and Hydro-geological Investigations in and around Khulna City (GWRHI)". Under the study they have established a broad groundwater monitoring network for modeling exercise of the aquifers. The project covered around 1000 sq km area where 73 different types of wells/borings have been installed for necessary investigation among them 21 monitoring tube wells has been installed in deep aquifer. Although after March 2005 no monitoring works has been conducted by any organization.

In a significant investigation conducted by the DPHE in 1985 has identified that Khulna City has two aquifers, shallow and deep. They also opined that the deep aquifer of Khulna is in mining state. On the other hand the Local Government Engineering Department (LGED) conducted study in 2005 identified the presence of three different aquifers. That study also determined that these aquifers of Khulna are continuously recharging by the rainfall in the upstream. Nevertheless the upper shallow and shallow aquifer is highly contaminated by saline and upper shallow aquifer contained highly contaminated of arsenic. Other important findings of the LGED study is the deep aquifer in the central and northern part of the city contains good quality potable water with no arsenic contamination but this aquifer is surrounded by highly saline water in the south, south-east part of the city.

This study focused on the existence of number of aquifers and reviewed the independence of the aquifers by investigating the available geological, hydro-chemical, and hydrodynamic parameter of the aquifers. Data on lithologs, static water level, electrical conductivity, temperature, pH, arsenic, and pumping tests in different aquifers have been collected from the past studies and analyzed in order to fulfill the study objectives. In this study a conceptual model of the deep aquifer of the study area has prepared. The renewable reserve of the deep aquifer has calculated and compared to the existing abstraction as estimated in 2005. Under this study an attempt was made to compare the water quality scenarios projected by the computer modeling exercise in 2005 with the 2009 ground water monitoring data. Finally a list of recommendations has prepared for the Khulna water supply.

1.2 Objectives of the Study

- Identify the number and size of aquifers in Khulna Area through study of the cross sections and Litho logs.
- Determination of the direction of groundwater flow at different aquifers.
- Determination of water quality in different aquifers and its seasonal variation by analyzing EC, pH & Temperature.
- Identify the causes of difference of Static Water Level in Shallow and Deep Aquifer at central part of the city to few km far from the city centre.
- Causes and magnitude of spatial variation of water quality, supplied by KCC, at different season.
- Estimate renewable/usable recharge volumes using the obtained aquifer parameters.
- Approximate forecasting on quantify of the Groundwater Resources in KCC area.

1.3 Scope of the Study

This study intends to perform the following works in order to achieve the above objectives

- Collection of relevant data from different sources;
- Draw cross-sections using bore-logs collected from previous studies;
- Estimate the quantity of renewable recharge[1] of main aquifers;
- Delineate the quality of groundwater zones using EC, pH, arsenic, temperature etc;
- Delineate favourable/unfavourable abstraction areas, homogeneity/ heterogeneity of the aquifers and the direction of the predominant groundwater flows; and to evaluate aquifer parameters (transmissivity and storativity)

[1]) the replenishment of an aquifer by the absorption of water into the zone of saturation the water so added.

CHAPTER – TWO

LITERATURE REVIEW

2.1 Definitions

2.1.1 Lithology

Lithology is the physical character of a rock, generally as determined megascopically or the aid of a low-power magnifier. (Weller J.M, 1960) Lithology is the general physical characteristics of a rock, especially as discernible without a microscope; the branch of geology that deals with these characteristics. Lithology is the basic tool for any hydrogeological investigation in the world (Karanath K R, 1989).

Tectonics, depositional environment, Lithology and the hydrogeology of tertiary sediments have been reviewed on a regional scale, with special reference to Kuwait for the investigation of the source of usable groundwater in Kuwait.

2.1.2 Lithostratigraphy

Lithostratigraphy is the element of stratigraphy that deals with the lithology of strata and with their organization in to units based on lithologic character.

2.1.3 Lithostratigraphic Classification

Lithostratigraphic classification is the organization of rock strata into units on the basis of their lithologic character.

2.1.4 Geological Succession of Bangladesh

Table 2-1 Exposed Geological Succession of Bangladesh

ERA	PERIOD	EPOCH	GROUP	FORMATION	LITHOLOGY	THICKNESS (in Meter)
CENOZOIC	Quaternary	Holocene (Up to 0.01 Ma*)		Alluvium	Sand, Silt, clay, peat, Corals	Highly Variable
		....		....Unconformity......	....	....
		Pleistocene (0.01 to 1.8 Ma)		Madhupur Clay	Red & yellow clay with ferruginous & calcareous nodules	32+
				St. Martin's Limestone	Shelly sandstone, limestone & coral clusters	1.7
				.....Unconformity........	....	....
	TERTIARY / NEOGENE	.... Pliocene (1.8 Ma to 5.3 Ma)		Dihing	Silty Sandstone, Claystone, Sandstone containing abundant ferrugenous concretions, boulder bed, yellowish brown.	129
				....Unconformity.....	....	....
				Dupi Tila Claystone	Claystone, siltstone, sub - ordinate sandstone with ferruginous bands, gravels in places	1798
				Dupi Tila Sandstone	Medium to coarse grained, gray to yellow sandstone with clay balls and quartz pebbles, traces of coal lenses.	914
		.... Late Miocene (5.3 Ma to 11.2 Ma)	....	.....Unconformity....	....	....
				Girujan Clay	Claystone, silty shale, and subordinate sandstone.	1067
		Middle Miocene (11.2 Ma to 16.4 Ma)	Tipam	Tipam Sandstone	Massive sandstone with subordinate shale	1203
			....	....	....	....
				Boka Bil	Alternation of well bedded slltstone and shale with subordinate sandstone	1710
			Surma	Upper Bhuban	Siltstone with subordinate shale and sandstone	1953
		Early Miocene (16.4 Ma to 23.8 Ma)		Middle Bhuban	Silty and sandy shale	928
				Lower Bhuban	Sandstone and sandy shale	980

* Million Years Ago ** Maximum Possible Thickness

***Source:Hussain, M.M, and Abdullah, S.K.M (2001)

2.1.5 Lithostratigraphic Units

Lithostratigraphic unit is a body of rock strata that is unified by consisting dominantly of a certain lithologic type or combination of lithologic types or by possessing impressive and unifying lithologic features. A Lithostratigraphic unit may consist of sedimentary, or igneous, or metamorphic rock, or an association of two or more of these. The rock may by consolidated or unconsolidated. The critical requirement of the unit is a substantial degree of overall lithologic homogeneity. (Diversity in detail may in itself constitute a form of overall lithologic unity.) Aggarwal, P.K. (2000). Lithostratigraphic units are recognised and defined by observable physical features and not by inferred geologic history or mode of genesis. Fossils may be important in the recognition of a Lithostratigraphic unit either as minor but distinctive physical constituents or because of their rock-forming character as in coquinas, diatomites, coal beds, and so on. The geographic extent of Lithostratigraphic units is controlled entirely by the continuity and extent of their diagnostic lithologic features. Only major lithologic features readily recognizable in the field should serve as the basis for lithologic units.

2.1.6 Lithofacies

Lithofacies is the record of any sedimentary environment of rock, including both physical and organic characters. (Weller J.M, 1960)

Facies in stratigraphy can be mean aspect, nature, or manifestation of character (usually reflecting conditions of origin) of rock strata or specific constituents of rock strata. It is also used as a substantive for a body of rock strata distinctive in aspect, nature, or character. The general term "facies" has been greatly overworked. Rock strata may show differences in facies, marine facies, volcanic facies, boreal facies, and so on. If the term is used, it is desirable to make clear the specific kind of facies to which reference is made.

2.1.7 Electrical Conductivity

In general, conductivity is a value that represents how easily electrical charges can be transported through a conductor.

Conductors are substances that permit the movement of electrical charge with relative ease. Conductors may be classified into two types: One type is electrode, where charge is carried by the movement of electrons. The other is an electrolyte, where charge is carried by a movement of ions. Electrolytes can be quite different consistencies; they may be liquid, solutions, fused salts or even solids.

Here we shall consider conductivity by ion movement in water-soluble electrolyte solutions. A conductivity cell is an electrochemical cell for measuring the conductivity of an electrolyte solution. This cell consists of two electrodes; anode and a cathode, separated by an electrolyte solution. The two electrodes are in the shape of plates of identical size, both having an identical surface area of a cm2. They are aligned in parallel and are separated by the distance ℓ the space between them is filled completely with a water-soluble electrolyte solution. Alternating current flows through both electrode plates.

The negatively charged ions (anions) in the electrolyte migrate towards the anode the positive charged ions (cations) move towards the cathode. The result is the flow of electrical current by ion movement.

2.1.8 Peat

Vegetable matter partly decomposed in wet acid conditions in bogs and fens to form a firm brown deposit resembling soil, frequently.

2.1.9 Artesian Aquifer

Aquifer that is under sufficient pressure to rise above the level at which it is encountered by a wall, but which does not necessarily rise to or above the ground surface. (Weller J.M, 1960)

2.2 Historical Overview

Several studies have been organized in and around Khulna City to provide supply water to the city dwellers. Few of them recognized the complex hydro-geological characteristics of the aquifers along with problems developed due to saline water intrusion both in surface and groundwater sources. Increased water demand evolved for ever increasing population, irrigation and industrial development and complex characteristics of the coastal region. The first study in coastal zone held in 1979 by UNDP/ UNDTCD to characterize the regional nature of the aquifers. Later in 1989, under the framework of DPHE water supply and sanitation projects, a study was conducted in KCC for well monitoring and regeneration. However, the availability of those reports could not be ensured from the relevant organizations. Recent available few studies have been described below in brief.

2.2.1 Feasibility Study for Khulna Water Supply

Groundwater investigation survey was conducted by IWACO (DPHE, 1980) in order to find out the favourable area in Khulna district. Apart from resources in and around the City this survey yielded favourable groundwater abstraction areas in the Khulna district, at distances ranging from 10-40 km from the town.

In this study the potential capacity on fresh, exploitable, groundwater in Khulna City and district surroundings was calculated as 820 million cubic meters. These calculations were based on horizontal groundwater flow in a confined aquifer system bounded in the west by an impermeable clay barrier, so that the pumped aquifer in the town was thought to be mainly recharged by (saline/brackish) water from the east. The location of the clay barrier in the west and the salinity distribution were only roughly known. Particularly the lacking information was on the deep formations beneath the pumped aquifer zone. The hypothetical continuity and impermeability of the separating clay layer between the shallow and deep aquifer was based on a limited number of drillings.

2.2.2 Geohydrological Investigations in Khulna

In view of expansion of the groundwater based urban drinking water supply in Khulna, geo-hydrological investigations have been carried out by Rus, J.S. (1985). The investigations were implemented within the framework of the DPHE Water Supply and Sanitation Projects. These projects were a part of the Netherlands-Bangladesh Development Co-operation Program. The period in which the investigations were carried out was from July 1983 to September 1984.

Therefore the investigations had been a continuation of the regional groundwater resources survey, carried out by IWACO in 1979-1980, as a part of the feasibility study for the Khulna water survey.

With respect to the geological build-up as well as the groundwater quality (salinity), the hydrogeological situation in the Khulna area is rather complex. Groundwater in Khulna Town is abstracted from a deep aquifer system at a depth of 150-250m. This fresh water bearing aquifer is separated from a brackish to saline aquifer by a clay zone, which gradually increases in thickness from east to west. The deep fresh water zone in the town is laterally bounded by brackish water in the east and clay barriers in the north and west. The hydrogeological conditions at great depth (> 300m) are not well known.

The main objective of the investigations was to identify the possible groundwater resources in Khulna Town and to locate favourable zones for new wells and well fields.

The major findings of the investigations were;

2.2.2.1 Hydrogeological Context

Fresh groundwater in Khulna is limited to the deep aquifer in the relatively narrow north – south belt, which is confined between brackish groundwater east of it and thick clay deposits west of it, while a clay layer separates the aquifer from a brackish shallow aquifer. The most favourable areas for groundwater abstraction within this zone are found in the southern part of Khulna and south of Khulna (Gollamari – Bagmara). In the northern and central part of the town areas of limited possibilities are encountered as well (Mujgunni – Boyra, Boyra – South). Hasan, S. and Mulamoottil, G. (1994).

Mainly in the central and northern parts of the town no distinct lower boundary of the deep aquifer is encountered. Some areas in the central part of the town (Ferrighat – Pollimangol) produces relatively warm water, these areas are probably underlined by sandy zones of great thickness. In the southern part of Khulna the presence of lower confining layers is more common. Nevertheless the deep aquifer system in Khulna probably extends to great depth.

The separating clay layer between the deep and shallow aquifer is encountered in all deep boreholes in the western part of the town. The clay layer, which contains fresh water, declines in thickness to the east. Only in the eastern part of the town short circuit groundwater flow between shallow and the deep groundwater may be present [Rahman. A. (2003)].

It was found that the deep aquifer has a considerable thickness and extends beyond the present boring dept (~350m).

Regarding the upper boundary conditions of the aquifer zone the investigations have proved the existence of a continuous separating clay layer, between the shallow and the deep aquifer in the western part of the town. The layer decreases in thickness in all the west – east geological cross sections in the town. As a consequence infiltration of saline/brackish water from the shallow aquifer is only to be expected in the eastern part of the town near the River Bhairab – Rupsha.

2.2.2.2 Recharge of the Aquifer

The natural recharge is, in comparison to groundwater abstraction, very limited. Only in some 'leaky hot' areas natural recharge from great depth is likely to occur. Therefore, in general, groundwater abstraction in Khulna can be considered as a 'mining' system of fresh groundwater.

The investigations also point to a very limited natural recharge of fresh groundwater, which is only possible from the deep formation. A very slow natural upward groundwater movement is also supported by the results of the isotope study.

Regarding the whole Khulna town region, however, the natural recharge can be neglected in comparison to the preset and future groundwater abstraction. Therefore groundwater abstraction in Khulna is mainly a mining process of fresh groundwater resources.

In order to obtain more accurate data on the extension of the town's deep aquifer and the salinity distribution the present program was initiated by the execution of 15 reconnaissance drillings, mainly west and south of the town. A second series of 15 test drillings, most of them closed to groundwater pumping stations, was performed to get a better insight in the groundwater flow system. In most of the drillings resistively loggings were carried out. The resistively logs were very useful to determine the vertical salinity distribution. Groundwater level measurements as well as detailed pumping tests (aquifer tests) were carried out to obtain more information on the Transmissivity and thickness of the deep aquifer. In addition to the geo-electrical survey of the Feasibility Study another three geo-electrical soundings were realized for a better estimate of the salinity at great depth. Isotopic analysis were applied to determine the age of the water, whereas an extensive groundwater temperature survey, mainly by temperature logging, was realized to get a better insight in the groundwater flow conditions.

From the investigations (pumping tests, groundwater level surveys and groundwater temperature measurements) it was found that the deep aquifer has a considerable thickness and extends beyond the present boring depth (350m). The investigations also point to a very limited natural recharge of fresh groundwater, which is only possible from the deep formations. A very slow natural upward groundwater movement is also supported by the results of the isotope study. The C-14 analysis of the pumped deep groundwater indicates an age of the water of about 10,000 year. Regarding the whole Khulna Town region, however, the natural recharge can be neglected in comparison to the present and future groundwater abstraction. Therefore groundwater abstraction in Khulna is mainly a mining process of the fresh groundwater resources.

The most suitable and safe zone for groundwater abstraction was to be found in the south-western part of Khulna and south-west of Khulna; the Gollamari-Bagmara area. Two other areas of fewer possibilities are situated in the northern and central part of Khulna: Mujguni-Boyra and Boyra-South. The deep, fresh water bearing, aquifer in the Gollamari-Bagmara area has a large lateral extension, while the salinity is rather low (< 100 mg/l chlorides) and constant. In the study the potential capacity on fresh, exploitable, groundwater in Khulna City and district surroundings was calculated as 645 million cubic meters. The study also forecasted that after 30 years of continuous abstraction at the rate of 59,000m^3/day, the usable groundwater will be ceased.

2.2.3 Final feasibility report, Khulna water supply expansion component

LGED under the framework of Municipal Services Project has carried out a feasibility study by MacDonald, M (1997) to prepare an action plan for further expansion of water supply system for the city dwellers. They reviewed previous works on groundwater resources in Khulna and mainly emphasized the groundwater model study done in Geohydrologial Investigation in Khulna by DPHE (1985). Apart from that they collected data from KCC DTWs. They concluded that the static water level in deep aquifer is still within few meters of the ground surface since starting its abstraction in 1960s. This observation suggested that there might have some replenishment in the deep aquifer. This observation by the feasibility study instigated further detailed study using mathematical modelling.

2.2.4 Groundwater Resources and Hydrogeological Investigation in and around Khulna City

Conclusion of Mott MacDonald (1997) prompted LGED to take a fresh initiative to study the groundwater resource of this important city. Then BRGM-ANTEA-ARMCO, a consortium, conducted this study (LGED, 2005) under the framework of Municipal Services Project (MSP) of LGED. The duration of the investigation was 30 months (two hydrological cycles) starting from December 2002 to May 2005.

They concluded that Khulna has three aquifers system as upper (50-75m), shallow (100-150 m) and deep (200-300m). The reservoir rocks of aquifers are composed by sand (course to fine) with clay layers at top and bottom.

Modelling exercise conducted only for the deep aquifer in the project area. Hydraulic conductivity is set to 5×10-4m/s and the model area is considered 100x100 km. In 70% area the thickness of the aquifer is considered 190m and for the rest 65m.

The main conclusions obtained from the modelling task of the project are:

- The deep aquifer is able to sustain the present day level of abstractions for a fairly long time span. However, due to quality deterioration the fresh water resources will be decreased at least by a half in 2030;
- According to the modelling results the deep aquifer cannot sustain any increase in groundwater draft. This would accelerate the pollution of fresh water resources by inflowing highly-mineralized water;
- Also, in case of increasing groundwater abstractions, due to increased draw-down the risk of salt water intrusion from the south may increase considerably, although at present no reliable data allowed to determine the distance of the salt / fresh water interface south of Khulna.

2.2.4.1 Establishment of Monitoring Network

Under the Groundwater Resources and Hydrogeological Investigations in and around Khulna City the static water level of each well in the study area has been connected to a mean sea level (MSL) datum. All the locations of the monitoring wells and their respective levelling data are taken into the GIS map by MapInfo software. Thus the monitoring parameters such as static water level, electrical conductivity, temperature, arsenic and pH could be identified separately for each location. The monitoring wells of deep, shallow and upper aquifers are shown in Figure 2-1 and Figure 2-2 shows the combined locations of the monitoring wells installed for three different aquifers.

Figure 2-1 Monitoring Network Established by GWRHI (Deep & Shallow Aquifer)

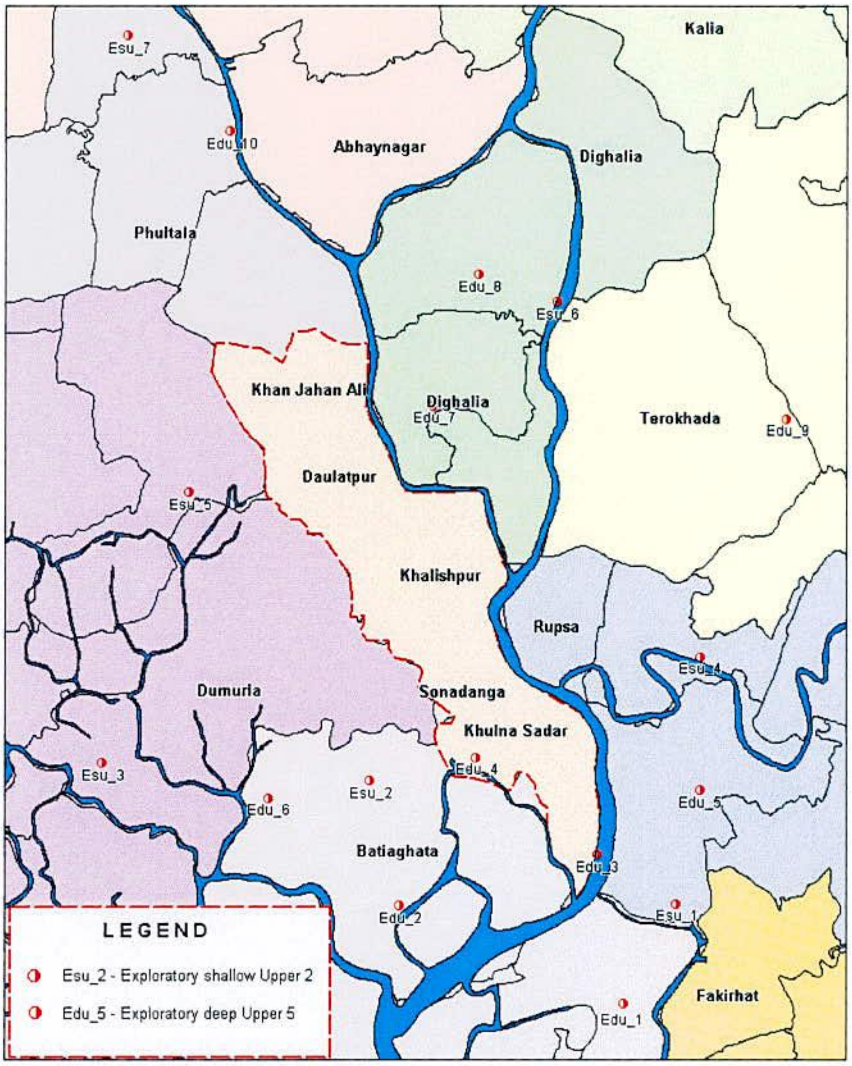


Figure 2-2 Monitoring Network Established by GWRHI (Upper Shallow Aquifer)

2.2.4.2 Geological & Paleo- Geological Studies

Preliminary conclusions concerning many aspects of groundwater occurrence and yield prospects can be drawn from geomorphology and geology of the area and structure of the formations. The type of details required for geological prospecting differs from one rock type to another. Knowledge of stratigraphy and structural geology is useful in understanding the order of superposition of various lithological units and their continuity.

Geomorphologically Bangladesh has been divided in to 20 units. Two of these units have been observed in the Khulna district; they are the Gopalganj-Khulna Peat Basins and the Ganges Tidal Floodplain. Their characteristics are a) a tectonic depression with a thick deposit of a peat (up to 5 meters) covered by clay and by mostly silt and calcareous sediments and b) a flat area crisscrossed by innumerable tidal bays and streams where the sediments are mainly non calcareous clay but more silty in the east with a buried peat layer in the west.

The main Paleo- geological characteristics of the study area are: the fluctuation of the mean sea level and the migration of the rivers. Concerning the mean sea level fluctuations, it has been demonstrated that, the actual level is at least 150m above levels that occurred in the past. The Quaternary study points out an important West to East migration of all rivers in this area.

2.2.4.3 Physico-Chemical Study of the Aquifers

Determination of the physical, bacteriological and chemical quality of water is essential for assessing the suitability of water for various purposes like drinking, domestic use, industries and agriculture. The physical quality of water includes colour, odour, taste, turbidity and temperature.

Water, being an excellent solvent, acquires soluble products from the air and rocks it comes into contact with. Collection and chemical analysis of water samples from surface water bodies, wells and springs form an integral part of hydrogeological studies.

For most of its use, the chemical properties of water are as important as the physical properties and available quantity.

Some Physico-chemical parameters of waters such as the Electrical Conductivity, pH, Temperature were measured systematically during whole monitoring sessions. Their study in high & low static water level periods shows not only their evolution but also determine the recharge area, qualitatively, the favourable area and sometime the origin of the contamination sources.

Note: - In general, conductivity is a value that represents how easily electrical charges can be transported through a conductor. Resistivity is the reciprocal of conductivity. In water quality determinations, conductivity, defined as the conductance of a cube of a substance one centimetre on a side, is reported in mhos/cm. Conductivity is the most readily measurable, and also most useful single indirect chemical determination that can be made on water. For convenience, conductivity is expressed in micromhos/cm, which is equal to one million times the value given in mhos/cm. Conductivities for a given concentration of different salts is not the same. As natural waters commonly contain several salts in solution, no definite relation exists between the conductance and dissolved solids.

Table 2-2 Conductivity of Various Aqueous Solutions (@25 ^{0}C)

Type of Water	Conductivity (μS/cm)
Pure Water	0.05
Distilled Water	0.05 to 1
Drinking Water	500 to 1,000
Brackish Water	1,000 to 80,000
Ocean Water	53,000

Source: - Eutech Instruments Pte. Ltd. 1997

2.2.4.4 Diurnal Auto - Fluctuation of Water Level

An important fluctuation of water level has been observed under static conditions, on the piezometric level. Such auto-fluctuations might be origin of a lot of observed anomalies during the groundwater flow studies (iso-piezometric map) as well as during the evaluation of the sustainable reserve of aquifers.

To identify the extent of this effect on the area, in first step, few TW which are located not far from the river Bhairab, have been continuously surveyed for a period of 36 hours. To widen this study all TW were monitored continuously for 24 hours and Bhairab River for one month.

2.2.4.5 Litho-Stratigraphical Studies

2.2.4.5.1 Lithology

Geological and geophysical surveys are sometimes not adequate to interpret subsurface hydrogeological conditions. Even if surveys indicate the presence of aquifers, the productivity and quality of water needs to be evaluated. Aquifer and reservoir dimensions and boundaries, lithofacies variations and structure of formations are also to be investigated on a regional scale for a planned ground water development. Thus, it may be necessary to know lithological (and sometimes hydrogeological) variations by drilling. [Hassan, M.Q. (1996)].

In absence of the outcrops, the drilling samples of the 63 new boring sites have been analysed -computerised (GIS & database) and by using the software "ACTIF" studied.

2.2.4.5.2 Sub-surface Structural Geology (Reservoir Rock Structure)

Knowledge of stratigraphical and structural geology is useful in understanding the order of superposition of various lithological units and their continuity.

The available lithologs of the previous study has been collected and studied. These litho-stratigraphical cross sections have permitted to study south-north and east-west lithological evolution of the encountered groundwater bearing layers. [Hassan, M.Q. (1994)].

CHAPTER – THREE

METHODOLOGY

3.1 General

The study of Groundwater Resources and Hydrogeological Investigations in and around Khulna City (GWRHI) focused on analysis of collected data from wells of different aquifers located in and around Khulna area. They have conducted twenty five monitoring sessions data (April 2003- March 2005) on static water level, electrical conductivity (EC), temperature and pH have been collected from LGED (2005) and KCC database. There are 21 tube wells in deep aquifer, 25 tube wells in shallow aquifer and 17 tube wells in upper shallow aquifer have been installed to generate hydro-geological data for the above study. In addition, one set (April 2005) of data comprising three aquifers on arsenic have been collected. The available data from different study in Khulna has been used for the study purpose.

3.2 Development of Litho-stratigraphiccal Cross Section

New litho-stratigraphical cross sections have been prepared based on the 63 exploratory drilling under GWRHI and the previous available lithologs. Fifteen (15) cross sections have been prepared in Appendix – 3. The correlation of the litho-stratigraphical cross sections has been discussed in Chapter Five (5).

3.3 Review the Aquifer System in Khulna

Depending upon the existing data on lithologs and the water quality data step has been taken to review the aquifer system suggested by the study in 2005.

3.4 Preparation of Thematic Maps

Using the best available GIS technology like MapInfo and Surfer 8 software maps for the all aquifers in different season has been prepared and analyzed for the change occurred in the SWL with the different water quality parameter.

3.5 Special Monitoring Session Conducted in 2009

In order to review the latest situation of ground water around the Khulna City Asian Development Bank (ADB) has provided funds to carry out two ground water monitoring sessions in 2009. These monitoring sessions were conducted over the monitoring network established by MSP study in 2005. The first session was conducted in the summer and second was in the post monsoon. Under each monitoring session two types monitoring activities are conducted, one for the deep aquifer wells for the MSP monitoring network and the other is on the KWASA production tube wells.

3.5.1 MSP Monitoring Network

The monitoring network established by Municipal Services Project (MSP) has been used to compare the Static Water Level (SWL), Electrical Conductivity (EC), pH and Temperature in 2005 and those of in 2009. Due to lack of monitoring activities in last four years one monitoring well (Pd_9) has become damaged completely. Few other wells are being used for water collection by the land owners by installing Electric pumps. Under this circumstance 20 tubewell's monitoring data has recorded having no record of SWL of Exd_1, Exd_10, Pd_6, Pd_8 and Pd_12. The monitoring network is presented in Figure 3.1

3.5.2 KWASA PTW Monitoring

The EC, temperature and pH of the KWASA production tube wells have been monitored and recorded. The SWL of KWASA PTWs has not been considered for monitoring due to lack of previous monitoring record. The location Map of the KWASA production tubewells are shown in the Figure 3.2 Some of the wells under the monitoring in 2003-2005 become chocked up and abandoned. There is no data for those well.

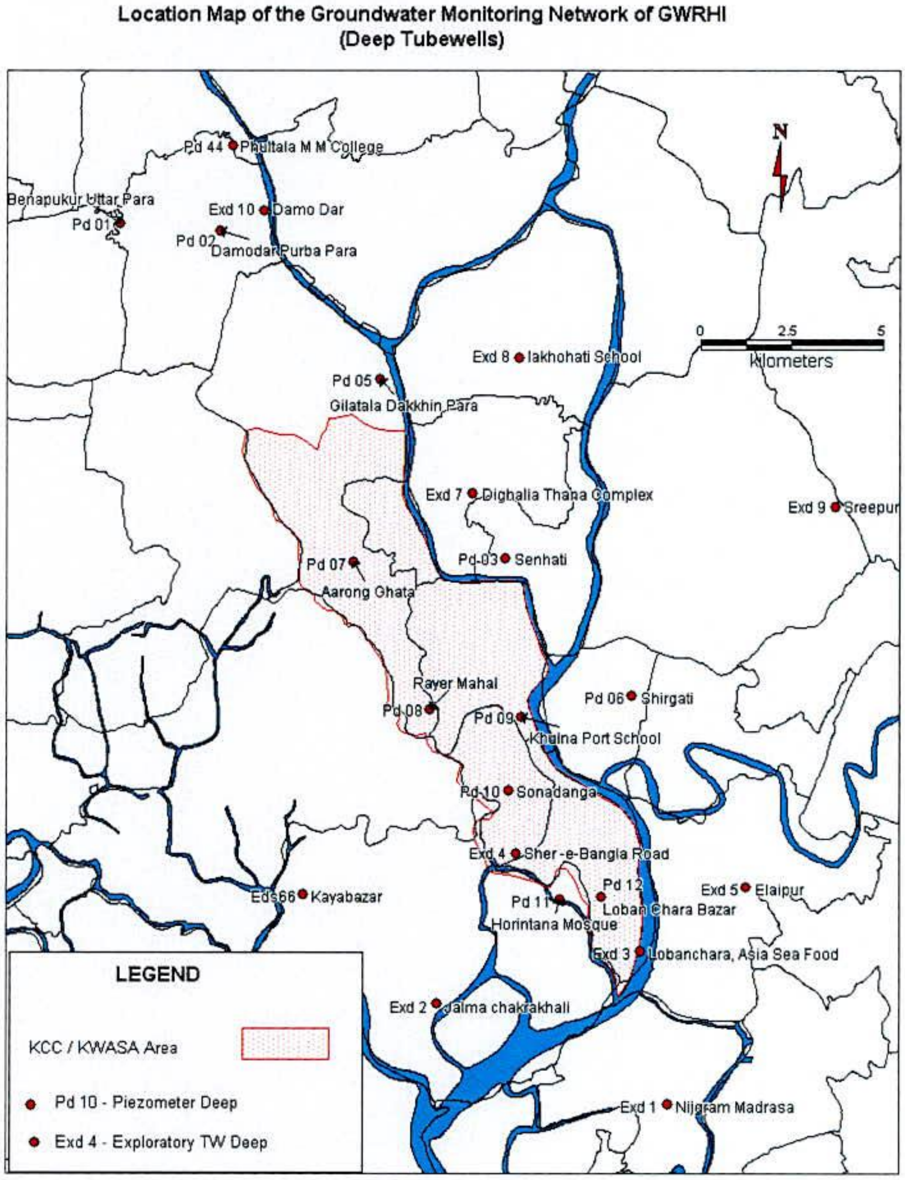


Figure 3-1 Ground Water Monitoring Conducted on MSP Network.

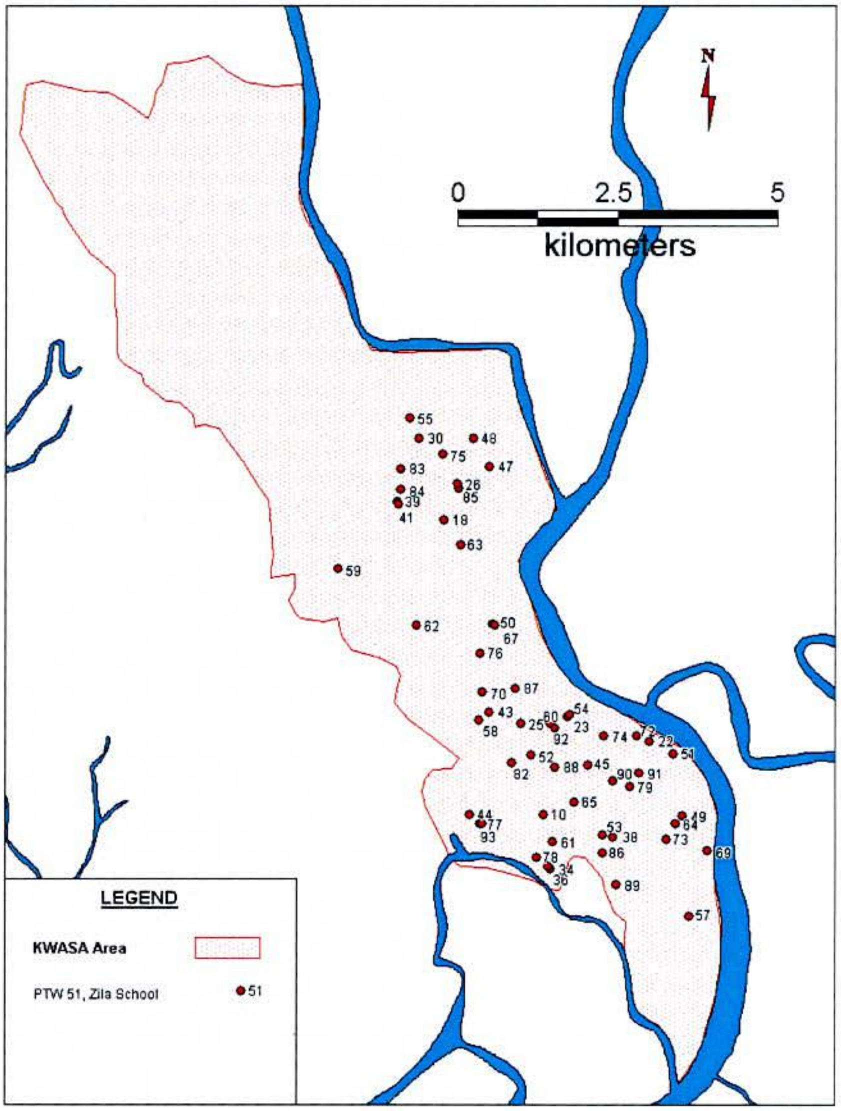


Figure 3-2 Monitoring Network of KWASA Production Wells.

3.5.3 Time of Monitoring

One monitoring session has been conducted in the summer while the concentration of the minerals in the ground water reaches at high level due to the declination of the static water level. This is observed in Khulna that during this period the SWL attains at the lowest level of the hydrogeological cycle. In order to find out the critical condition of the ground water parameters this period has been chosen for ground water monitoring. For MSP network the monitoring work conducted on 28 April, 2009 to 2 May, 2009 and for the KWASA PTW it has been conducted on 3 May, 2009 to 11 May, 2009.

Table 3-1 MSP Tube Well Monitoring Data in 2009

Sl. No.	Inv. Bh	Village	Session-I (April-May, 2009)				Session-II (October, 2009)			
			SWL from hp (m)	EC (μS/cm)	T (°C.)	pH	SWL from hp (m)	EC (μS/cm)	T (°C.)	pH
1	Pd_1	Benapukur Uttar Para	4.42	593	9.70	7.80	1.96	581	29.30	7.83
2	Pd _2	Damodar Purba Para	3.82	662	27.10	8.05	1.53	646	26.70	8.09
3	Pd _3	Senhati	6.72	2,500	29.20	7.12	4.79	2,520	29.00	7.13
4	Pd _5	Gilatala Dakkhin Para	4.70	824	30.10	7.99	-	-	-	-
5	Pd _6	Shirgati	-	1,186	27.20	7.36	-	1,091	28.20	7.36
6	Pd _7	Aarong Ghata	4.62	671	27.20	8.03	2.83	657	26.60	7.98
7	Pd _8	Rayer Mahal	-	1,082	28.60	8.07	-	1,045	29.00	7.97
8	Pd _9	Khulna Port Area	-	-	-	-	-	-	-	-
9	Pd _10	Sonadanga	6.84	766	31.40	7.73	5.16	728	32.00	7.80
10	Pd _11	Horintana Mosque	5.56	715	29.60	8.00	3.76	686	28.20	8.11
11	Pd _12	Loban Chara Bazar	-	886	29.20	7.75	-	855	29.00	7.78
12	Pd _44	Phultala M M College	5.93	819	28.40	7.82	3.45	785	28.10	7.76
13	Exd_ 1	Nijgram Madrasa	-	3,350	30.50	7.54	-	3,240	32.00	7.39
14	Exd _2	Jalma chakrakhali	4.70	2,850	29.50	8.00	2.95	2,680	26.80	8.08
15	Exd _3	Lobanchara, Asia Sea Food	4.68	815	28.20	7.89	3.42	787	27.80	7.97
16	Exd _4	Sher -e-Bangla Road	7.20	752	28.60	8.14	5.13	730	27.50	8.15
17	Exd _5	Elaipur	5.13	5,470	30.10	7.29	3.70	5,110	32.10	7.27
18	Exd _66	Kayabazar	5.55	1,172	26.80	7.54	3.07	1,107	26.20	7.42
19	Exd _7	Dighalia Thana Complex	5.70	2,850	29.70	7.41	3.77	2,840	29.50	7.40
20	Exd _8	lakhohati School	3.60	1,985	29.30	7.30	1.72	1,609	27.10	7.36
21	Exd _9	Sreepur	3.04	5,340	27.10	6.93	1.38	4,085	27.30	6.96
22	Exd _10	Damodar	-	710	28.20	7.80	-	683	29.20	8.03

Table 3-2 KWASA Production Tube Well Monitoring Data in 2009

Sl. No	Name of Well	Well No	Session-I (April-May,2009)			Session II (October, 2009)			Remarks
			EC (μS/cm)	Temp (ºC)	pH	EC (μS/cm)	Temp (ºC)	pH	
1	Gollamari	10	763	32.3	7.92	705	31.1	8.03	Now Mini
2	Baikali R & H	18	1365	31.4	7.84	1257	30.8	7.84	
3	Khulna Cirkit House	22	-	-	-	834	29.1	7.78	(Mini)
4	Ferry ghat 3	23	1668	32.6	7.69	1428	29.3	8.03	Now Mini
5	Pallimongol	25	-	-	-	-	-	-	Chocked Up
6	Khalishpur office	26	-	-	-	-	-	-	Chocked Up
7	Khalishpur 5	30	1941	31.4	7.55	1713	30.7	7.56	Now Mini
8	Nirala well field 1	34	711	31.4	7.78	-	-	-	Chocked Up
9	Nirala well field 3	36	710	31.9	7.95	691	30.7	8.1	
10	Tutpara well field 3	38	-	-	-	-	-	-	Chocked Up
11	Muggunni well field 1	39	1693	30.7	7.69	1592	31.0	7.77	Now Mini
12	Muggunni well field 3	41	-	-	-	-	-	-	Chocked Up
13	Sonadanga 1	43	1387	33.8	7.63	1224	33.9	7.61	
14	Arambag	44	811	30.0	8.02	725	32.1	8.12	
15	Tarer pukur	45	996	30.8	7.75	948	30.7	7.75	
16	Khalishpur Road N° 12	47	1756	31.3	7.45	1556	30.5	7.32	Now Mini
17	Khalishpur TV center	48	-	-	-	-	-	-	Chocked Up
18	Rupsha DPHE 3	49	-	-	-	-	-	-	Chocked Up
19	Nur Nagar 1 (Mini)	50	960	31.0	7.83	916	30.3	7.75	
20	Zila School	51	1670	33.1	7.72	1548	32.7	7.66	
21	Islamabad Community Centre	52	1377	34.6	7.68	1271	34.0	7.67	Now Mini
22	Purba Bania Khamar	53	-	-	-	-	-	-	Chocked Up
23	Ferry ghat 2 (Mini)	54	-	-	-	-	-	-	Chocked Up
24	Khalishpur Durber Shangha	55	3.7	29.0	7.24	3380	28.7	7.24	Now Mini
25	Hazi Malek College	57	746	30.5	8.1	733	31.9	7.91	
26	Sonadanga 2	58	898	34.2	7.87	848	32.5	7.89	
27	Rayir Mohol	59	1088	26.6	8.04	1027	30.7	7.98	Now Mini
28	Shekhpara Bazar 3	60	1554	34.7	7.68	1373	35.3	7.66	
29	Bagmara 2	61	-	-	-	-	-	-	Chocked Up

Sl. No	Name of Well	Well No	Session-I (April-May,2009)			Session II (October, 2009)			Remarks
			EC (µS/cm)	Temp (ºC)	pH	EC (µS/cm)	Temp (ºC)	pH	
30	250 beds Hospital	62	1330	34.2	7.73	1222	30.5	7.77	
31	Boyra Com. Center	63	-	-	-	-	-	-	Chocked Up
32	Collegiete girls School.	64	-	-	-	-	-	-	Chocked Up
33	Darul ulum Madrasa	65	-	-	-	-	-	-	Chocked Up
34	Nur Nagar Fire Service	67	998	31.3	7.85	954	30.4	7.85	
35	Rupsha Koshai Khana	69	782	31.0	7.89	924	30.0	7.79	
36	Sonadanga KCC park	70	897	32.0	7.87	856	32.3	7.91	
37	DC Office Compound	72	1028	28.7	7.77	963	28.7	7.73	
38	Tutpara Taltala 2	73	671	30.8	8.04	672	30.7	7.95	Now Mini
39	Sir Iqbal Road Shisu Park	74	1301	30.2	7.65	1084	26.2	7.79	
40	Khalishpur Jhil Pukur	75	1814	33.0	7.56	-	-	-	Mini (Chocked Up)
41	Boyra Main Road Modina Masjid	76	1051	33.0	7.84	941	31.2	7.72	
42	Miyapara Bazar	77	806	29.5	8.15	785	30.4	7.9	Now Mini
43	Nirala KCC Park	78	721	32.4	7.95	702	31.6	8.03	
44	Babu Khan Road	79	886	23.9	7.98	864	32.5	7.89	
45	Boshupara Koborkhana	82	850	34.0	7.81	809	33.3	7.87	
46	Mujgunni Labutala	83	1550	31.2	7.85	1432	30.6	7.83	
47	Mujgunni Bottala	84	1877	30.0	8.01	1679	31.6	7.83	
48	KCC Office Khalishpur (New)	85	993	29.8	8.02	949	29.4	7.83	
49	Purba Baniakhamar Madrasha	86	713	28.4	8.16	706	30.5	7.91	Now Mini
50	KDA Approach Road	87	1533	33.5	8.12	1454	34.2	7.74	
51	Sher-E-Bangla Rd KCC Park	88	1080	33.5	7.67	1014	32.7	7.75	
52	Tootpara Primari School	89	679	28.6	8.12	701	30.8	7.97	
53	PTI More	90	906	30.8	7.87	868	32.2	7.73	
54	KCC Rest House	91	953	31.5	7.86	957	30.8	7.73	
55	Shekhpara Bazar Mosque	92	1535	34.1	7.74	1389	33.0	7.67	
56	Arambagh - 2 (Old Gallamari Rd)	93	774	32.6	8.12	752	31.3	8.15	

Table 3-3 Comparison of the MSP TW Monitoring Parameters in Mar.'05 with May, '09

Identification		General Information						Monitoring Data in March, 2005					Monitoring Data in May, 2009				
Inv. BH.	Location	Longitude (Degree)	Latitude (Degree)	Depth	Z GL (MSL) (m)	HP (m).	Z HP (MSL) (m)	SWL (HP) (m)	SWL (MSL) (m)	EC (μS/cm)	T (^{0} C.)	pH	SWL (HP) (m)	SWL (MSL) (m)	EC (μS/cm)	T (^{0} C.)	pH
Pd_1	Benapukur Uttar Para	89.44333	22.9575	317	2.114	0.418	2.532	5.8	-3.268	0.645	27.5	7.63	4.42	-1.888	593	29.7	7.8
Pd _2	Damodar Purbapara	89.47028	22.95556	305	2.367	0.335	2.702	3.82	-1.118	0.715	27.2	7.9	3.82	-1.118	662	27.1	8.05
Pd _3	Senhati	89.47639	22.93972	284	4.291	0.275	4.566	6.47	-1.904	2.68	27.7	7.02	6.72	-2.154	2500	29.2	7.12
Pd _5	Gilatala Dakkhinpara	89.51361	22.91917	305	3.218	0.168	3.386	4.78	-1.394	0.908	27	7.85	4.7	-1.314	824	30.1	7.99
Pd _6	Shirgati	89.5811	22.8403	305	3.106	0.267	3.373	4.58	-1.207	1.365	28.4	7.2	-	-	1186	27.2	7.36
Pd _7	Aarong Ghata	89.50639	22.87361	311	2.025	0.274	2.299	3.75	-1.451	0.716	26.6	7.64	4.62	-2.321	671	27.2	8.03
Pd _8	Rayer Mahal	89.52694	22.83694	305	1.822	0.345	2.167	5.13	-2.963	1.271	27.6	7.85	-	-	1082	28.6	8.07
Pd _9	Khulna Port Area	89.55167	22.83528	305	4.045	0.396	4.441	6.95	-2.509	1.261	27.6	7.63	-	-	-	-	-
Pd _10	Sonadanga	89.54806	22.81667	305	2.509	0.35	2.859	6.0	-3.141	0.899	28.7	7.67	6.84	-3.981	766	31.4	7.73
Pd _11	Horintana Mosque	89.56306	22.785	295	2.033	0.442	2.475	4.72	-2.245	0.761	27.7	7.85	5.56	-3.085	715	29.6	8.0
Pd _12	Loban Chara Bazar	89.58083	22.78417	287	3.052	-0.566	2.475	1.984	0.491	0.976	29.3	7.5	-	-	886	29.2	7.75

Identification		General Information						Monitoring Data in March, 2005					Monitoring Data in May, 2009				
Inv. BH.	Location	Longitude (Degree)	Latitude (Degree)	Depth	Z GL (MSL) (m)	HP (m).	Z HP (MSL) (m)	SWL (HP) (m)	SWL (MSL) (m)	EC (μS/cm)	T (^{0} C.)	pH	SWL (HP) (m)	SWL (MSL) (m)	EC (μS/cm)	T (^{0} C.)	pH
Pd _44	Phultala MM College	89.48806	22.91833	341	4.135	0.256	4.391	5.05	-0.659	0.923	27.8	7.92	5.93	-1.539	819	28.4	7.82
Exd_ 1	Nijgram Madrasa	89.5911	22.7383	305	3.284	0.295	3.579	3.55	0.029	3.6	28.7	6.87	-	-	3350	30.5	7.54
Exd _2	Jalma Chakrakhali	89.5291	22.7633	317	2.155	0.277	2.432	3.83	-1.398	3.22	27.8	7.84	4.7	-2.268	2850	29.5	8
Exd _3	Lobanchara, Asia Sea Food	89.5836	22.7763	311	2.817	0.37	3.187	3.48	-0.293	0.92	28.4	7.68	4.68	-1.493	815	28.2	7.89
Exd _4	Sher -e-Bangla Road	89.5502	22.8011	299	2.537	0.262	2.799	6.2	-3.401	0.85	28.6	7.86	7.2	-4.401	752	28.6	8.14
Exd _5	Elaipur	89.6119	22.7927	305	3.793	0.296	4.089	4.44	-0.351	5.99	30.5	7.0	5.13	-1.041	5470	30.1	7.29
Exd _66	Kayabazar	89.5383	22.8908	317	2.401	0.315	3.924	5.65	-1.726	3.01	28.8	7.29	5.55	-1.626	1172	26.8	7.54
Exd _7	Dighalia Thana Complex	89.5508	22.9244	305	3.546	0.378	2.5	3.75	-1.25	2.2	27.5	7.21	5.7	-3.2	2850	29.7	7.41
Exd _8	Lakhohati School	89.6358	22.8875	305	2.178	0.322	2.437	2.68	-0.243	5.74	27.6	6.9	3.6	-1.163	1985	29.3	7.3
Exd _9	Sreepur	89.4822	22.9608	293	2.251	0.186	4.783	4.48	0.303	0.759	27.1	7.52	3.04	1.743	5340	27.1	6.93
Exd _10	Damodar	89.4928	22.7908	305	4.456	0.327	2.716	3.48	-0.764	1.55	27.8	7.23	-	2.716	710	28.2	7.8

Table 3-4 Comparison of the KWASA PTW Monitoring Parameters in Mach, '05 to May, '09

Serial No	Name of Well	Location	Well No	Longitude (Degree)	Latitude (Degree)	Monitoring Data in 2005			Monitoring Data in 2009			Remarks
						EC (µS/cm)	Temp (ºC)	pH	EC (µS/cm)	Temp (ºC)	pH	
1	Gollamari	Nirala Kacha Bazar / Habalibag	10	89.5572	22.8033	956	31.5	7.95	763	32.3	7.92	Now Mini
2	Baikali R & H	Divisional Stadium	18	89.5419	22.845	1434	31.2	7.6	1365	31.4	7.84	
3	Khulna Cirkit House	Khulna Cirkit House	22	89.5733	22.8136	970	29.1	7.79	-	-	-	(Mini)
4	Ferry ghat 3	KCC Central Garage Caompound	23	89.5608	22.8172	1637.5	32.75	7.63	1668	32.6	7.69	Now Mini
5	Pallimongol	Pallimongol / Hazi Bari	25	89.5536	22.8161	1554	34.9	7.86	-	-	-	
6	Khalishpur office	KCC Branch Office	26	89.5439	22.85	-	-	-	-	-	-	
7	Khalishpur 5	Khalishpur ward N° 10 Nayabati	30	89.5381	22.8564	2270	29.75	7.4	1941	31.4	7.55	Now Mini
8	Nirala well field 1	UPHCP, Nirala R / A	34	89.5581	22.7956	673	29.7	8.11	711	31.4	7.78	
9	Nirala well field 3	UPHCP, Nirala R / A	36	89.5578	22.7958	713	30.45	7.78	710	31.9	7.95	
10	Tutpara well field 3	Tutpara	38	89.5678	22.8	1248	30.9	7.85	-	-	-	
11	Muggunni well field 1	Comissioner Office W# 9	39	89.5347	22.8475	-	-	-	1693	30.7	7.69	Now Mini
12	Muggunni well field 3	Comissioner Office W# 9	41	89.535	22.8472	-	-	-	-	-	-	
13	Sonadanga 1	South Herald School , Sonadanga R/A	43	89.5489	22.8178	1260	33.7	7.79	1387	33.8	7.63	
14	Arambag	Gollamari Bus Stand More	44	89.5458	22.8033	678	31	7.83	811	30.0	8.02	

Serial No	Name of Well	Location	Well No	Longitude (Degree)	Latitude (Degree)	Monitoring Data in 2005			Monitoring Data in 2009			Remarks
						EC (µS/cm)	Temp (ºC)	pH	EC (µS/cm)	Temp (ºC)	pH	
15	Tarer pukur	United Nessions Shishu Park	45	89.5639	22.8103	1109	31.6	7.79	996	30.8	7.75	
16	Khalishpur Road N° 12	Khalishpur Road N° 12	47	89.5489	22.8525	-	-	-	1756	31.3	7.45	Now Mini
17	Khalishpur TV center	Khalishpur TV center	48	89.5464	22.8564	2160	28.8	7.76	-	-	-	
18	Rupsha DPHE 3	DPHE Office	49	89.5783	22.8031	854	29.8	-	-	-	-	
19	Nur Nagar 1 (Mini)	Opposite Side of Fire Service	50	89.5494	22.8303	1045	30.2	7.8	960	31.0	7.83	
20	Zila School	Khulna Zila School	51	89.5769	22.8119	1588	33.2	7.78	1670	33.1	7.72	
21	Islamabad Community Center	Gobor Chaka	52	89.5553	22.8117	1449	34.5	7.67	1377	34.6	7.68	Now Mini
22	Purba Bania Khamar	Khademul Islam Madrasha	53	89.5661	22.8003	825	30.2	-	-	-	-	
23	Ferry ghat 2 (Mini)	KCC Central Garage Caompound	54	89.5611	22.8175	-	-	-	-	-	-	
24	Khalishpur Durber Shangha (Mini)	Nayabati Goal Park Chattar, Road # 24	55	89.5367	22.8594	3105	28.8	7.84	3.7	29.0	7.24	Now Mini
25	Hazi Malek College	Molla Para	57	89.5794	22.7889	682	30.5	7.97	746	30.5	8.1	
26	Sonadanga 2	Sonadanga Bowbazar	58	89.5472	22.8167	1024	29.2	7.88	898	34.2	7.87	
27	Rayir Mohol	Rayir Mohol Gov. Primary School	59	89.5258	22.8381	-	-	-	1088	26.6	8.04	Now Mini
28	Shekhpara Bazar 3	Shekhpara Main Road, Fish Market	60	89.5581	22.8161	1798	34.4	7.66	1554	34.7	7.68	
29	Bagmara 2	Bagmara 3rd Lane	61	89.5586	22.7994	1338.5	31.2	7.81	-	-	-	

Serial No	Name of Well	Location	Well No	Longitude (Degree)	Latitude (Degree)	Monitoring Data in 2005			Monitoring Data in 2009			Remarks
						EC (µS/cm)	Temp (ºC)	pH	EC (µS/cm)	Temp (ºC)	pH	
30	250 beds Hospital	Comissioner Office W # 16	62	89.5378	22.83	1315.5	32.85	7.84	1330	34.2	7.73	
31	Boyra Com. Center	Boykali CSD Road	63	89.5444	22.8414	1568	31	7.55	-	-	-	
32	Collegiete girls School.	Darogapara	64	89.5772	22.8019	878	29.4	7.96	-	-	-	
33	Darul ulum Madrasa	Musalman Para Main road	65	89.5619	22.805	805	32.9	7.49	-	-	-	
34	Nur Nagar Fire Service	Fire Service Compound	67	89.5497	22.83	1050	29	7.86	998	31.3	7.85	
35	Rupsha Koshai Khana	Rupsha Stand Road	69	89.5822	22.7981	919	29.6	7.79	782	31.0	7.89	
36	Sonadanga KCC park	Sonadanga R/A	70	89.5478	22.8206	938	32.7	7.86	897	32.0	7.87	
37	DC Office Compound	DC Office Compound	72	89.5714	22.8144	804	28	7.87	1028	28.7	7.77	
38	Tutpara Taltala 2	Tutpara	73	89.5758	22.7997	568	28.3	8.09	671	30.8	8.04	Now Mini
39	Sir Iqbal Road Shisu Park	UPHCP, Diabatic Hospital	74	89.5664	22.8144	1315.5	30.7	7.74	1301	30.2	7.65	
40	Khalishpur Jhil Pukur	Khalishpur Jhil Pukur	75	89.5417	22.8542	1971	30.4	7.52	1814	33.0	7.56	12" Mini
41	Boyra Main Road Modina Masjid	Boyra Main Road	76	89.5475	22.8261	1030	32.1	7.8	1051	33.0	7.84	
42	Miyapara Bazar	Miyapara Bazar	77	89.5475	22.8019	-	-	-	806	29.5	8.15	
43	Nirala KCC Park	Nirala R/A	78	89.5561	22.7972	783	31.3	8.07	721	32.4	7.95	
44	Babu Khan Road	Babu Khan Road	79	89.5703	22.8072	-	-	-	886	23.9	7.98	

Serial No	Name of Well	Location	Well No	Longitude (Degree)	Latitude (Degree)	Monitoring Data in 2005			Monitoring Data in 2009			Remarks
						EC (µS/cm)	Temp (ºC)	pH	EC (µS/cm)	Temp (ºC)	pH	
45	Boshupara Koborkhana	Boshupara Graveyeard	82	89.5522	22.8106	791.5	33.7	7.88	850	34.0	7.81	
46	Mujgunni Labutala	Goalkhali Bus Stand	83	89.5353	22.8522	1432	30.8	7.9	1550	31.2	7.85	
47	Mujgunni Bottala	Behind Navy Colony	84	89.5353	22.8492	-	-	-	1877	30.0	8.01	
48	KCC Office Khalishpur (New)	KCC Branch Office	85	89.5442	22.8494	989	29.1	7.53	993	29.8	8.02	
49	Purba Baniakhamar Madrasha	Near Baitunnajat Mosque	86	89.5661	22.7978	-	-	-	713	28.4	8.16	
50	KDA Approach Road	KDA Approach Road	87	89.5528	22.8211	1378	30.1	7.51	1533	33.5	8.12	
51	Sher-E-Bangla Road KCC Park	Near KCC Park	88	89.5589	22.81	-	-	-	1080	33.5	7.67	
52	Tootpara Primari School	West Tootpara High School	89	89.5683	22.7933	-	-	-	679	28.6	8.12	
53	PTI More	PTI More	90	89.5678	22.8081	-	-	-	906	30.8	7.87	
54	KCC Rest House	Hazi Mohshin Road	91	89.5717	22.8092	-	-	-	953	31.5	7.86	
55	Shekhpara Bazar Mosque	Astana Jame Mosque	92	89.5589	22.8156	-	-	-	1535	34.1	7.74	
56	Arambagh - 2 (Old Gallamari Rd)	Behind Lions School	93	89.5478	22.8019	-	-	-	774	32.6	8.12	

CHAPTER – FOUR

STUDY AREA

4.1 Introduction

The study area is around 470 sq km comprising KCC area (KCC area: 45 sq km) and its surroundings (Figure 4-1). Data has collected from this extended area in a view to see the impact taking place into the KCC area. The city has a population of over one million. The topography is flat (only few meters above the mean sea level), slopes gently to southeast towards the Bay of Bengal. Previous studies reveal that groundwater is available in and around Khulna City in the shallow and deep aquifers. Water quality varies depending on the proximity to the rivers, level of confinement, depth below ground surface, and natural conditions. Previous literature related to Khulna reveals that the difference of opinion is persisting regarding the number of aquifers. According to DPHE (1985), shallow aquifers are unconfined or semi-confined. The thickness of the shallow aquifers near Khulna is sometimes difficult to ascertain, but typically varies from 0 to 100 meters. Thick silty clay layer, with or without saline groundwater, usually separate the shallow and deep aquifers. Currently, the primary source of water supply is from wells constructed into the deep aquifers, ranges between 200 and 300 m depths. BRGM-ANTEA-ARMCO (2003) classified that Khulna has three aquifers and these are upper shallow 50-75m, shallow 100-150m, and deep 200-300m thick aquifers.

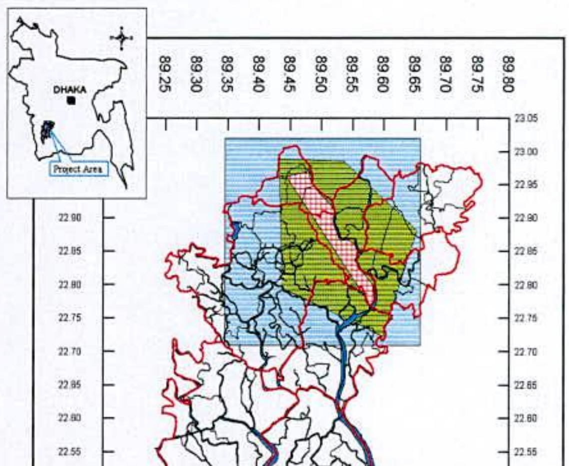


Figure 4-1 The Study Area

4.2 Topography

The Khulna is situated at approximately one hundred km north of the Bay of Bengal. It is a flat area with a land gradient less than 0.02m / km without any topographic anomaly. The area is break up by the north-south rivers and channels. Geomorphologically Bangladesh has been divided into 20 units. Two of these units have been observed in the Khulna district; they are the Gopalganj-Khulna Peat Basins and the Ganges Tidal Floodplain. Their characteristics are, the first, a tectonic depression with a thick deposit of peat (up to 5 m) covered by clay and by mostly silty calcareous sediments and, the second, a flat area criss-crossed by innumerable tidal bays and streams where the sediments are mainly non-calcareous clay but more silty in the east with a buried peat layer in the west. Figure 4-2 shows the physiographic map of Bangladesh.

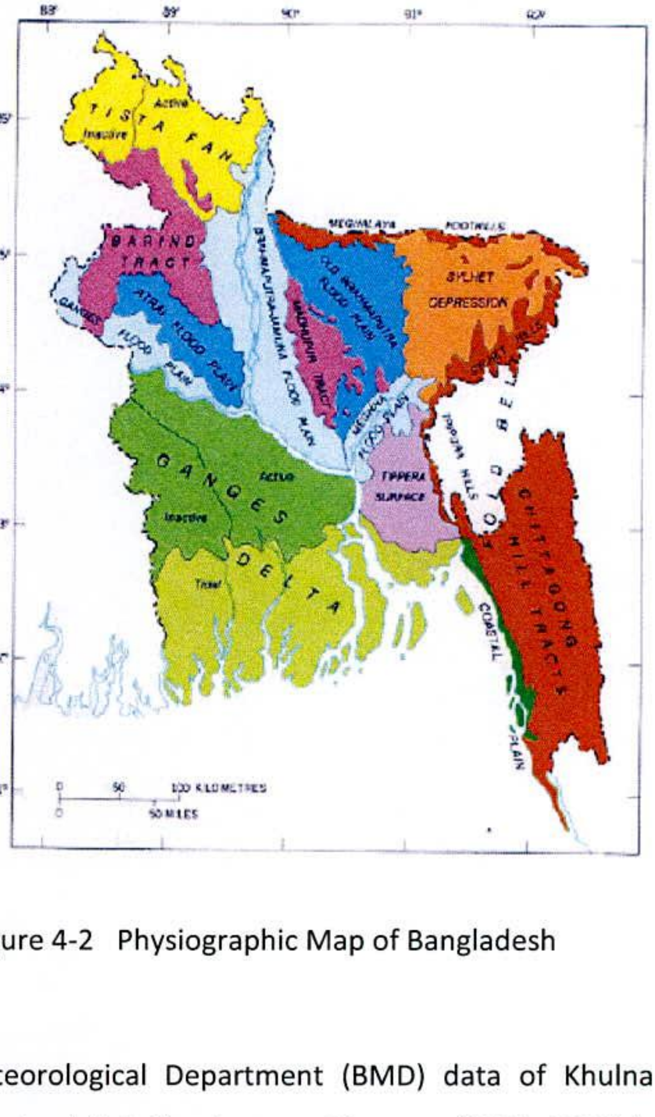


Figure 4-2 Physiographic Map of Bangladesh

4.3 Climate

According to the Bangladesh Meteorological Department (BMD) data of Khulna monitoring station, the mean annual rainfall, for the past 21 years (1984–2004) is 1,802 mm as shown in Figure 4-3. During this period the most humid and the driest years were 2002 with 2,668 mm and 1994 with only 1,130 mm respectively. Due to the monsoon climate 80% of the rainfall occurs between May and September.

According to the same source, rainfall distribution over Khulna district is varying from north-west to south-east, from 1,700 mm at Jessore to over 2,100 mm at Bagherat. However, over the studied area the average rainfall will be considered homogeneous and equal to 1,800 mm. Analyzing the data obtained from BMD, The inter-annual monthly average from 1984-2004 as shown in Figure 4-4.

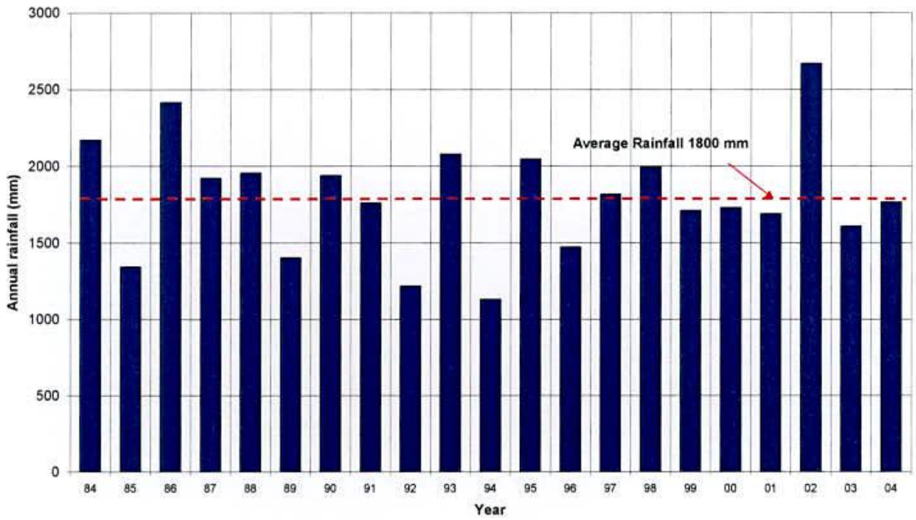


Figure 4-3 Annual Rainfall at Khulna 1984-2004

Concerning the temperature in average it varies between 19°C (January) and 28°C (July). Average temperature of the year stands to 26.3°C. The lowest relative humidity sustains in the month of March (75%) and maximum is observed in the month of July (85%). The measured yearly average humidity is 82%.

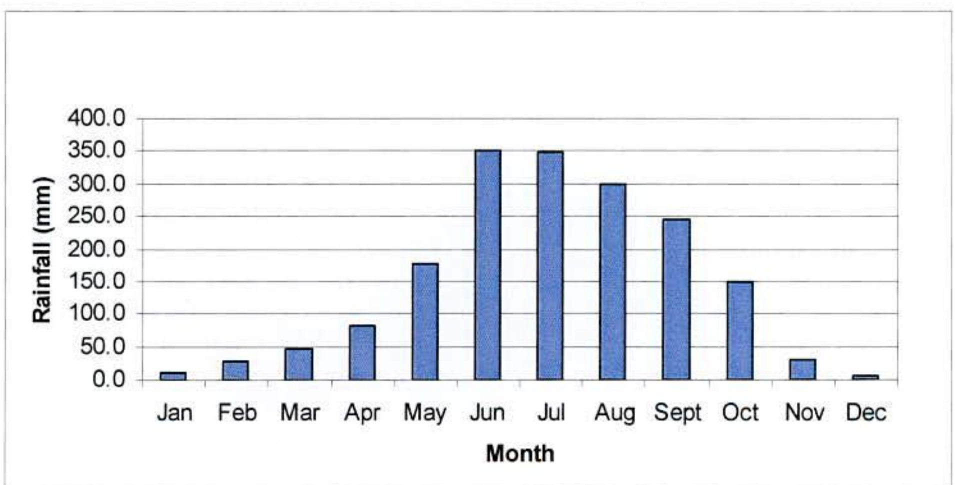


Figure 4-4 Inter-Annual Monthly Average Rainfalls

4.4 Other Climatic Parameters

The other scanned parameters within the framework of the project are as follows:

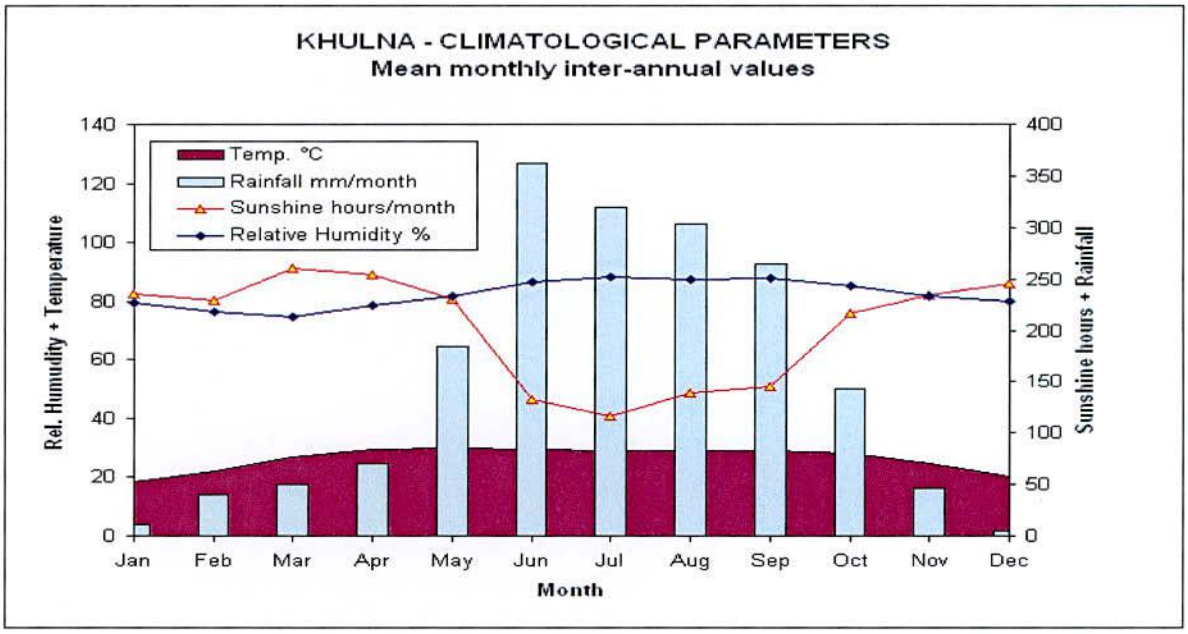
- daily average temperature
- daily average relative humidity
- daily average sunshine hours

The interest of the examination of these parameters, in addition to climatic information that they bring, is to allow the calculation of the monthly potential evapotranspiration, data which could be used thereafter for the evaluation of the aquifer recharge.

The daily data were gathered at the BMD over the duration 1981-2004. However, a significant number of missing data obliges to reduce the period of study to 1984-2004.

The statistical parameters of this treatment are indicated in Figure 4-5. They show the dominance of the Monsoon climate not only on rainfall but also on other linked parameters.

Parameter	Unit	Number of Observations	Minimum	Maximum	Average	Standard Deviation
Daily Temperature	°C	7665	12.5	35.1	26.3	4.2
Daily Relative Humidity	%	7671	48	100	82	7.8
Daily Sunshine	Hrs	7190	0	13	6.75	3.3



Climatic Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp. °C	18.52	21.99	26.67	29.37	29.85	29.51	29.05	29.17	29.05	28.03	24.54	20.34
Relative Humidity %	79.56	76.31	74.44	78.54	81.81	86.33	88.15	87.40	87.97	85.19	81.7	80.08
Sunshine hours/month	236.1	229.5	261.1	254.8	231.0	132.3	116.8	139.2	145.00	217	234.4	245.4
Rainfall mm/month	11.29	40.05	49.67	70.14	184.7	362.4	320.3	303.2	265.00	143.2	46.19	5.095

Figure 4-5 Climatic Parameters - Khulna - 1984-2004

4.5 Geological History of Khulna Region

Belonging to the Bengal Basin, the sediments encountered in Khulna as well as in most of the country have been deposited by the Ganges Delta. The geological basement (the ocean crust) is believed to be at a depth of 10 to 12 km. This huge thickness of sediments is due to the tectonic history of the basin.

During the Oligocene and Miocene period, the collision of Indian plate and Asia provoked the Himalayan uplift. Located at the border of the Indian plate the present Bengladesh which was first a passive continental margin became the Bay of Bengal receiving sediments from a precursor of the Brahmaputra River. Toward the East a similar scenario was taking place with the Indo Burman uplift. Thus the Bengal basin became the "sink" of the surrounding uplifts, where all drainage patterns were converging, accumulating the products of erosion of the newly formed mountains. Tectonic activity, load of sediments, uprising of neighbouring lands resulted in significant subsidence and additional sediment accumulation.

During the late Miocene and Pliocene periods, the sedimentary environment changed. Instead of being delta fan sediments (marine deposition) the deposition of "Tipam" and "Dupi Tila" formations which follow the Miocene formations are mainly of continental origin. They correspond to an interlacing of river branches, digging their ways through the clayey Miocene deposition. Their extension is so wide that the so-called Dupi Tila sandstone is found all over the country and is exposed along the eastern and north-eastern ridges (Sylhet). This formation corresponds to the deep aquifer in Khulna area.

This type of sedimentation extends during the quaternary epoch. The age and name of Khulna most recent layers were not investigated in the frame of the project. Several authors have tried to classify the quaternary deposit into several members but the assignation of the sediments encountered during the project drillings to one or several of these members would require a detailed geological study which is not the objective of the present project. However, some geological publications are of particular interest. The most important of them seems to be Umitsu (1993). In this paper, the author describes the paleogeographic changes of the Ganges delta since 18000 BP. What is of special interest for the hydrogeological study is that 18000 years ago, the sea water level was about 130 m below its present level. During this period of low base level (called "lowstand" period) the sea was located hundreds of kilometres from Khulna and a stronger erosion phase must have taken place.

Evidence of this phase is found in the project tubewells lithological logs. Fine and Medium sand of yellow and brown colour are found all over the project area between 40 and 130 m. At a depth varying between 95 and 130 m finer sediments and clay are systematically encountered corresponding to the maximum depth of the erosion action in Khulna. However, coarse material were never found in these layers, indicating that Khulna area was not located in the main channel of the Ganges River

Above these sediments, generally much finer sediments are encountered, also with higher variability, resulting in discontinuous sandy and clayey levels, without possible correlation of these formations. This change in sedimentation was due to a rapid rise of sea level, following the deep erosion phase, followed by slight fluctuations and climate change, with the establishment of a monsoon climate and increase in rainfall in the last 10 000 years. The fine to very fine sandy layers constitutes a reservoir for local small aquifers, designed in this study as Upper aquifer. This upper layer of finer sediments begins with intermittent clay and silt encountered between 50 and 40 m on most of the project tube well, which presumably correspond to the Holocene base.

4.6 Geology

The analysis of the geological maps of Bangladesh show that nearly 85% of the country is covered by deltaic and alluvial deposits of the Ganges, Brahamaputra and Meghna River systems. Concerning the study area, at surface, it is mainly constituted by the sediments of the active delta. In general we observed two formations; tidal deltaic deposits (dt) and paludal deposits (ppc).

The tidal deltaic deposits (dt), lithlogically, is composed by the light to greenish-grey weathering to yellowish grey silt to clayey silt with lenses of very fine to fine sand. It is present along active and abandoned stream channels.

The paludal deposits (ppc) are composed by the grey or bluish-grey clay, black herbaceous peat and yellowish-grey silt. The thickness of peat increases with depth.

On the base of the drilling information, the subsurface lithological units, from the top to 300 m are surface clay, upper sand (alternation of fine and medium sands, sandy clay and clayey sands), medium clay and lower sand (alternation of fine and medium sands, sandy clay and clayey sands).

4.7 Paleogeography

Paleo means ancient, old; of or belonging to ancient, especially prehistoric, times. The geographical features of an area in the geological past; the branch of science that deals with the investigation of such features.

The main Paleogeoraphical characteristics of the project area are: the fluctuation of the mean sea level and the migration of the rivers.

Concerning the mean sea level fluctuations, it has been demonstrated that, the actual level is at least 150 m above the past one.

The quaternary study has pointed out an important East-West migration of the rivers in the Project area.

4.8 Hydrology

The high, mean annual rainfall, the very low land gradient and finally the east-west migration of the rivers are the origin of the presence of innumerable rivers and channels, nearly all, tributary of Ganges River.

The commissioning of Farakka barrages in India has modified the natural discharge and also the quality of water of these rivers and channel. Normally, during 4 to 5 months per year not only the discharge of them becomes unimportant roughly zero but also their salinity increase significantly. The saline water front move far to the north and has been observed at least at 50 km of Khulna City.

4.9 Hydro-Geology

Three hydrogeological units has been identified and recognised in and around Khulna City. These three units are called commonly, upper aquifer, shallow and deep aquifer. Later two are confined type.

- **An upper shallow aquifer**, most of the time confined or semi-confined in the study area, discontinuous and poorly permeable. Its range varies from 0 to about 50 m deep. Its average conductivity over the project duration is 2600 μS/cm.

- **A shallow aquifer**, confined mostly between 80 and 125 m lying over a geological discontinuity which can be identified in almost every litholog. The aquifer is made of fine sand and seems to have a nation-wide extension. Its average conductivity over the project duration is 3200 µS/cm.

- **A deep confined aquifer** of variable thickness which can be found between 220 and more than 300 m deep. It is a composite aquifer mainly composed of medium sand with local coarse levels as well as very fine sand and clay levels. Good hydrodynamic properties characterise this aquifer whose water level (under pressure) rises up to a few meters below the surface. This aquifer is the main aquifer for the water supply of Khulna City and is highly solicited. Its average conductivity over the project duration is 1200 µS/cm which shows that this aquifer has the lowest salinity of the whole groundwater system around Khulna.

The presence of arsenic in one hand and the problem of salinity in the other hand, in some area, are the mains restrictions for their exploitation. In reference to the study of LGED (2005), the reservoir rock is composed by fine sand and sand and frequently, in spite of unfavourable nature of reservoir rock, they have the excellent hydrodynamic parameter (transmissivity in particular). The origin of their water and corresponding recharge areas are not well known. During the previous studies, it had been tried to clarify the reason of the simultaneous presence of the brackish / salty water in these aquifers; to delimited the freshwater area and finally to evaluate and quantify the extractable reserve of each of them.

4.10 Development of Water Supply System of Khulna

The Khulna water supply system dates back to 1921 with a small surface water treatment plant of capacity 0.90 MLD. Apart from the small surface water source the municipal supply relies on groundwater as its source which was started since 1962. [MacDonald. M. (1997)]. A significant feature of water supply of Khulna city is its dependence on groundwater, due to the seasonal nature of discharge and salinity in the perennial surface water source, the River Bhairab.

The water supply system has started to farther expand since 1960 under the Department of Public Health Engineering (DPHE) by sinking deep production well and expansion of distribution system. The quantity of supply was 14.85 MLD during 1980-81, through 12 production tube wells (PTWs). The capacity of the well head water production was 25.70 MLD in 1994 through 34 PTWs [MacDonald. M.(1997)]. DPHE handed over the water supply system to Khulna City Corporation (KCC) in 1987 after up-gradation of Khulna Pourashava as Khulna City Corporation. But DPHE extended its cooperation providing technical and project assistance to KCC by implementing development projects up to 1997. After the IWACO study in the 1980's, the number of tube wells in the deep aquifer began to rise. In 1988, 35 wells were pumping in the deep aquifer. [BRGM/ANTEA: (2005)].

By implementing few development programs by DPHE in 1997, the water production capacity augmented up to 32.5 MLD through 55 deep pumping wells. After that the growth of the water supply capacity declined due to limited manpower and development activity up to 2003. During that period few production wells and some mini pumping wells were installed. On the other hand significant number of the old production tube wells became abandoned due to chocked up that causes the depletion of growth of water supply. In 2003 the number of total pumping wells became 50 and the capacity of production declined up 25 MLD. In 2004 MSP, LGED started to install 10 good capacity wells as a result in 2005 the production raised up 37.59 MLD. [BRGM/ANTEA: (2005)]. KWASA records estimated in 2009 that, piped water supply in the Khulna City is declining again and reached up to 35 MLD through 54 PTWs. KCC/ KWASA productions from deep aquifer is shown in Figure 4-6

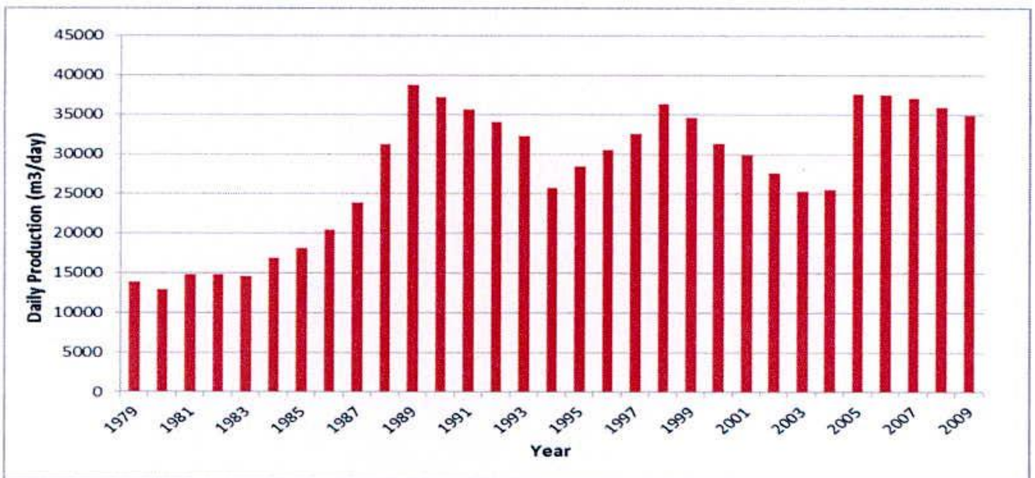


Figure 4-6 KCC Production from Deep Aquifer (1979 – 2009)

4.11 Present Water Demand and Water Abstraction

Based on the growth rate of three population censuses 1971, 1981 and 2001 and extrapolating the population of Khulna City Corporation area the present population is around 1.0 million in 2009. Out of total KCC population only 30 % has the access from KCC support and this demand is taken 90 l/c/day. Rest 70% population's demand is considered as a rural demand that stands to 40 l/c/day. Groundwater abstraction is by far the most difficult data to get or to estimate. To assess the abstraction of groundwater from Khulna deep aquifer, it is necessary to consider production from Khulna City Corporation (KCC) tube wells, industrial and institutional wells, KCC hand pumps, private wells, public hand pumps and abstraction for irrigation. However, deep aquifer abstraction from different sources is as follows: KCC wells 25,000 m^3/day, industrial wells 15,000 m^3/day, public hand pump (outside KCC) 25,000 m^3/day, public hand pump (within KCC) 8,000 m^3/day. Now approximate total abstraction becomes 73,000 m^3/day in whole district. Roughly it can be estimated the abstraction in KCC area is; KCC wells 25000 m^3/day, industrial wells in KCC 7,000 m^3/day, private abstraction 8,000 m3/day. Now total abstraction stands approximate to 40,000m^3/day [BRGM/ANTEA. (2005)].

CHAPTER – FIVE

RESULTS AND DISCUSSIONS

5.1 Aquifers of Khulna

Using the lithologs of the boreholes of the study area, from top to bottom three aquifers have been distinguished namely Upper Shallow Aquifer, Shallow Aquifer and Deep Aquifer. In some places locally, intermediate aquifer level could be identified. This is for instance the case in Tootpara area, where a sand layer is encountered between the shallow and the deep aquifer, vertically isolated by clay layers. However these clay layers have no significant lateral extension (less than a few square kilometres) and communication with the deep aquifer occurs north and south. At the scale of the present study, such details cannot be taken into account. Litho-stratigraphic cross sections are presented in Appendix – 3.

5.1.1 Upper Shallow Aquifer

5.1.1.1 Aquifer structure

The geology of the upper shallow aquifer is highly heterogeneous both vertically and laterally. An idea of its vertical heterogeneity is given by a Gamma Ray logging performed in the project tube well Exd_11 (Figure 5-1).

The Upper shallow aquifer is in fact a pile of impervious and pervious layers presenting possible connections between them but not necessarily of wide extension. The water contained in these layers can be hydraulically connected with surface water, mainly rivers (the River Bairhab at Khulna can be up to 10 m deep), channels, ditches and some ponds. However most of the numerous ponds of the area are filled up by flood and rainfall and disconnected from upper shallow aquifer. The lithological nature of the top formations favours existence of such ponds as it can be seen in Figure 5-2. The two maps represented here show with a different colour the nature of the lithology found in IWACO project tubewells (within KCC area) at 3 m and 10 m depth. Most of these points (at least 85%) indicate that the first 10 m is of clayey or silty nature, i.e. of very low permeability. This fact is well known by local farmers as well as brick factories. Shahidul. I and Tooley (1999) have studied in detail these sediments near Daulatpur, showing that they were deposited in a mangrove environment with low energy such as the present Sundurbans.

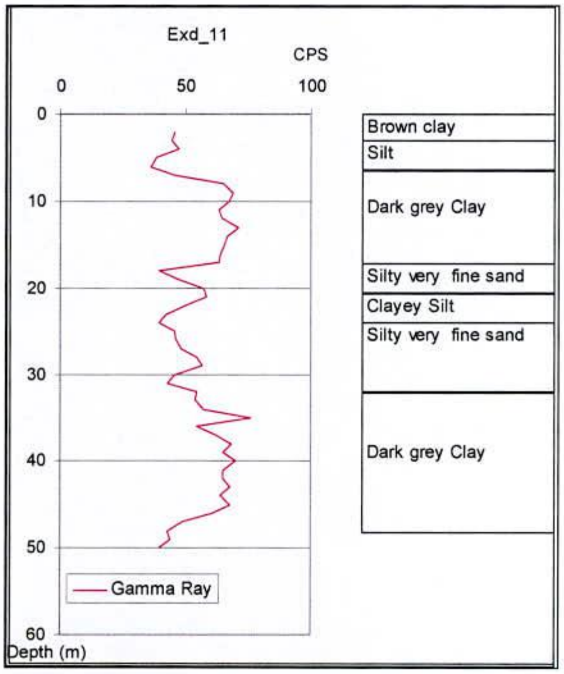


Figure 5-1 Gamma Ray logging in the Upper shallow Aquifer

5.1.1.2 Water level

The rather impervious nature of the top layers suggests that the upper shallow aquifer is most of the time confined in the Khulna area. In the project wells during the project duration which extends over a complete hydrological cycle, the water level was encountered between 0.6 and 4.6 m from the surface and the amplitude of observed fluctuation varied from 1.3 to 3.1 m. The average water level depth (2.1 m) is thus very close to the surface above the bottom of the top clayey layer. The confined or semi confined condition of the upper shallow aquifer is also attested by its sharp fluctuation (parallel and of same order of magnitude as the confined aquifer beneath) and by the delay (1 month) between the rise of water level and the freshening of water (Figure 5-4)

5.1.1.3 Hydrodynamic Characteristics

It is assumed that the fine to very fine size of grains constituting the water bearing layers, the small thickness of these layers and their relatively local extension confers poorer hydrodynamic characteristics to this aquifer in comparison with the deeper ones. However good productivity has been observed on irrigation wells and the above statement should only be considered relatively to deeper aquifers. Despite the absence of pumping test data, the upper shallow aquifer certainly have a fair transmissivity.

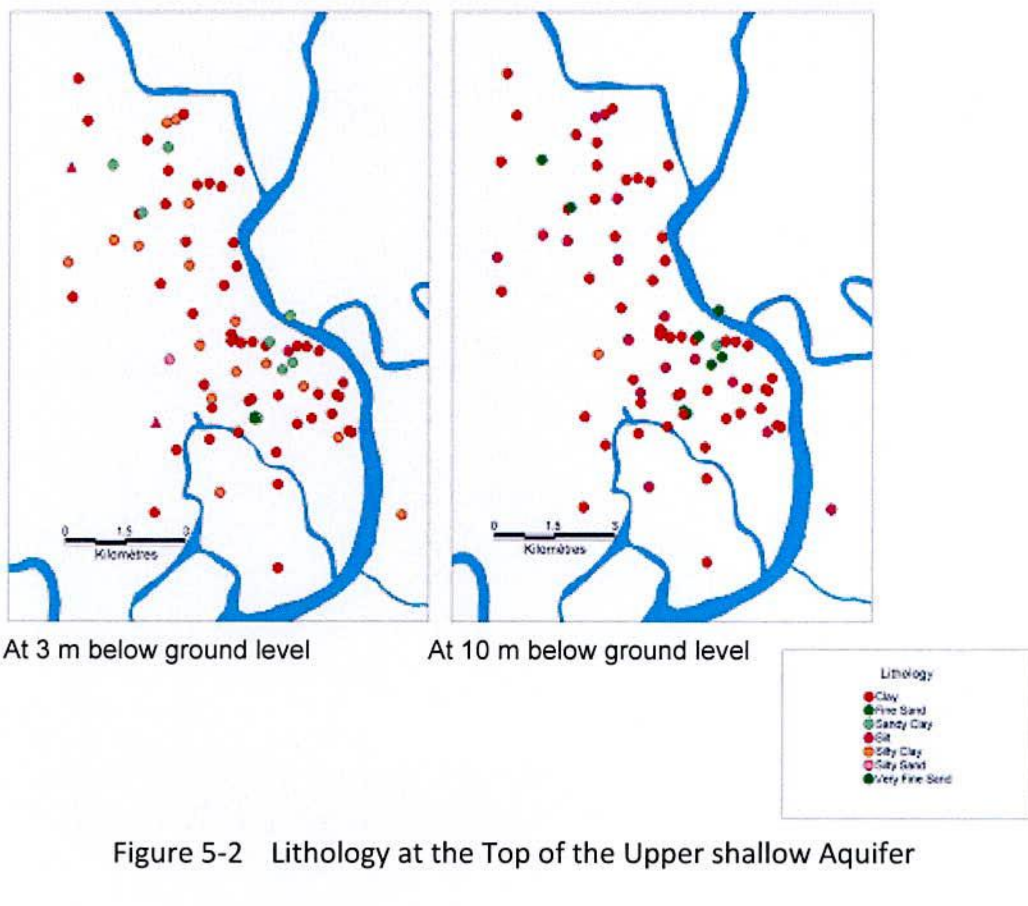


Figure 5-2 Lithology at the Top of the Upper shallow Aquifer

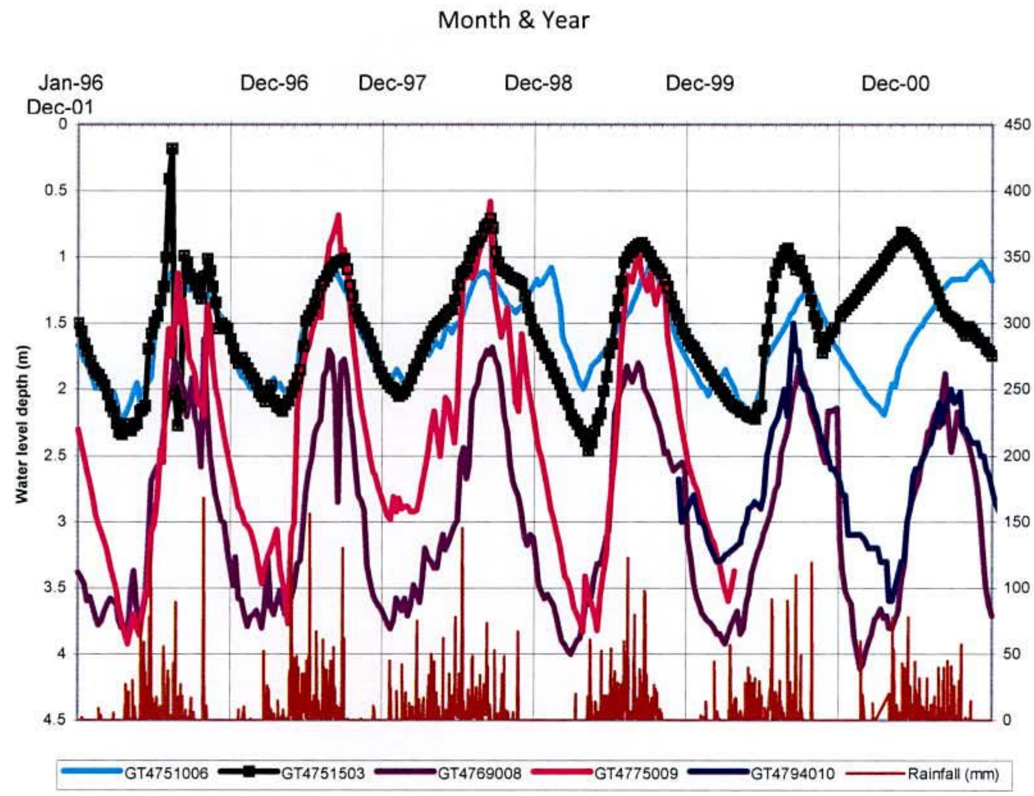


Figure 5-3 Water Level Fluctuations in Khulna District (Source: BWDB)

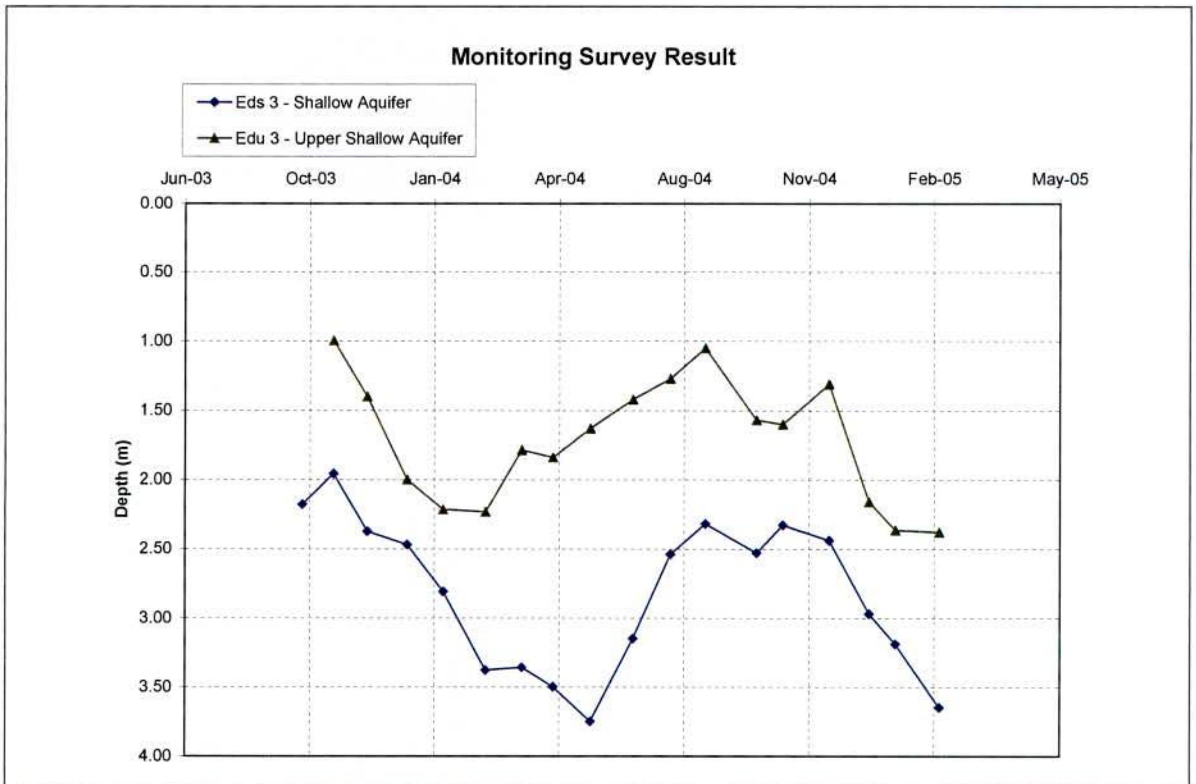


Figure 5-4 Static Water Level Fluctuation at Lobanchara Twin Wells (Eds_03 and Edu_03)

5.1.1.4 Recharge

The presence of clay at the surface also interrogates about the recharge of the upper shallow aquifer. How does recharge occurs if the top of the aquifer is impervious? It is of no doubt that recharge occurs directly through silts and very fine sediments presents at the surface in some areas of the project and in other locations to further north and to the west where the top layers are less clayey. However, such recharge is rather slow and does not spontaneously react to rainfall events. But in many of the tube wells in the upper shallow aquifer recharge is faster and starts quickly after the first rainfall events, sometimes even with anticipation, showing the influence of surface water on the recharge. As a matter of fact, river levels are rising before monsoon as a result of snow melt in upper shallow regions of the Ganges Basin (Figure 5-8). The upper shallow aquifer water body starts reacting by the end of April while the dry season is not yet finished. This suggests that, although recharge obviously occurs through the low permeability of the first layers during monsoon, the recharge of the upper shallow aquifer starts through surface water during the pre-monsoon period. The upper shallow aquifer water level rises when river water level, canals and ditches rise. This is well illustrated by the project tube well Edu_03 located at Lobanchara near the Rupsha Bridge (Figure 5-4). Together with this rise (but slightly delayed) the electrical conductivity and the temperature decreases as fresh (monsoon) water enter the aquifer (Figure 5-10). The observed delay in the freshening of the water table may have two causes: the semi-confined character of the upper shallow aquifer on one hand (the observed level rise is due to pressure transfer), and on the other hand the fact that when the rivers start rising at Khulna, they still show high salinity (around 4000 μS/cm at the beginning of May).

Another characteristic of the upper shallow aquifer is that the maximum level seems to remain a constant depth (except for short peaks) as can be seen in BWDB water level series presented in Figure 5-3. Abstraction (mainly for irrigation) influence the water level during the dry season with variable intensity, however the water level after monsoon remains the same every year. This maximum level corresponds to a threshold determined by natural drainage and surface water level. This suggests that groundwater level is controlled by local base levels in the rivers. This is an additional evidence of connection between surface water and upper shallow aquifer. A consequence of this statement is that the actual recharge is less than the potential recharge because the aquifer gets full during the recharge period and excess of rainfall water does not infiltrate.

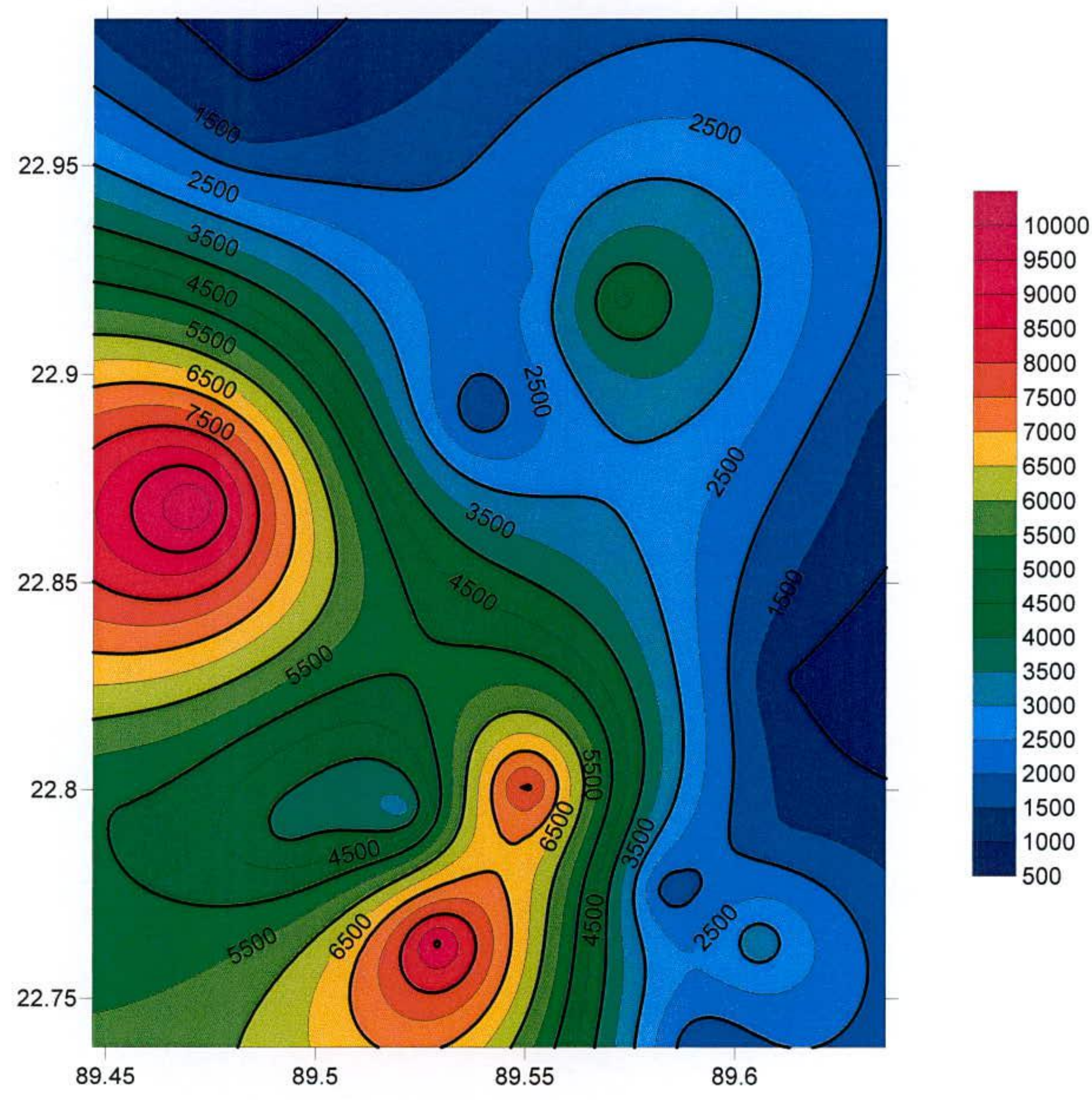


Figure 5-5 Thematic Contour Map of EC (μS/cm) of upper Shallow Aquifer March, 2005

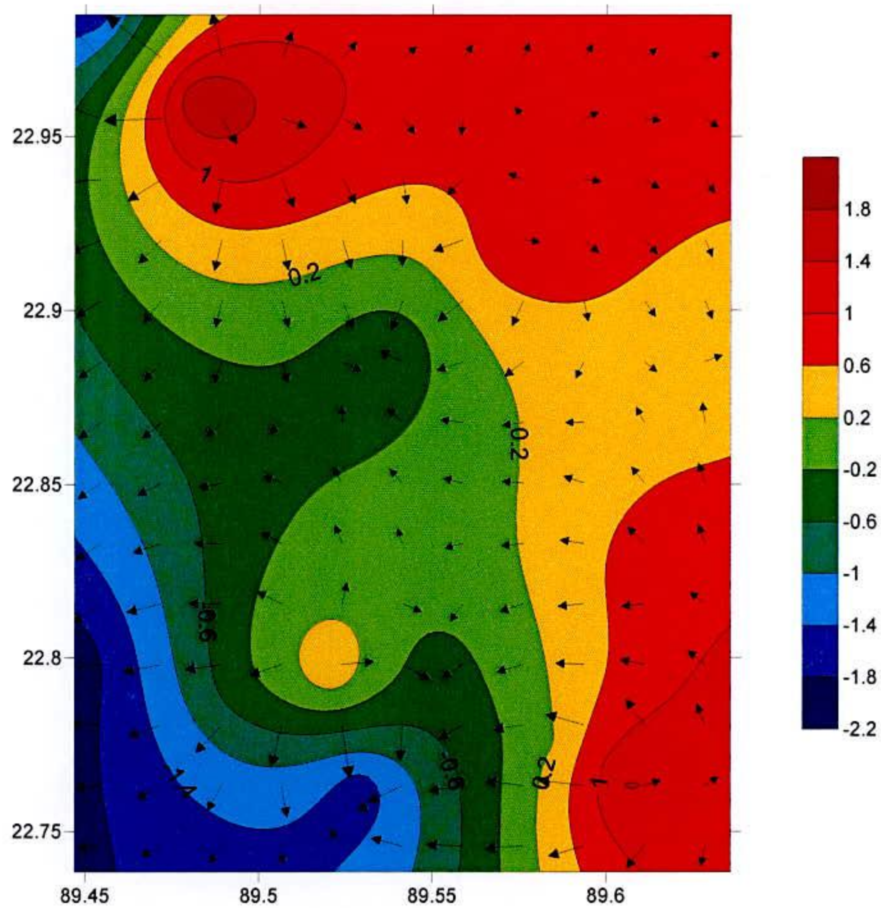


Figure 5-6 SWL and Direction of Flow of Upper Shallow Aquifer (March, 2005).

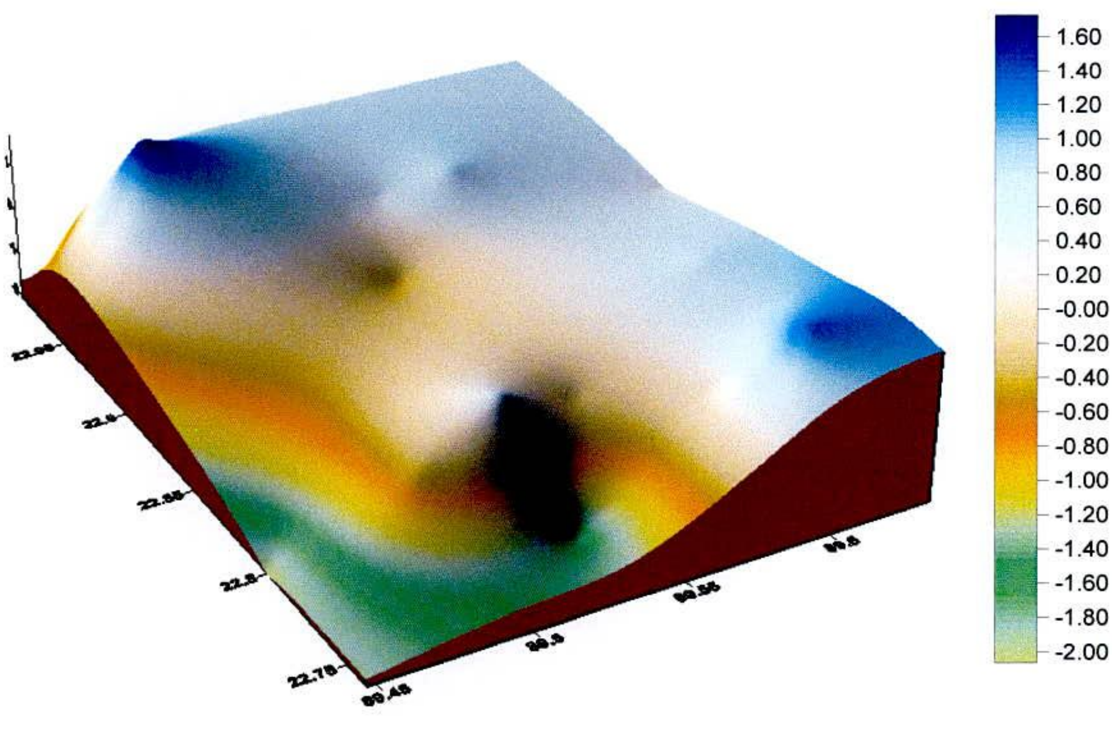


Figure 5-7 3-D Model of SWL of Upper Shallow Aquifer (March, 2005).

Figure 5-8 Average Water Level on the Rupsha River at Khulna 1980 – 2003

(Station SW214, Bangladesh Water Development Board (BWDB).(2000)

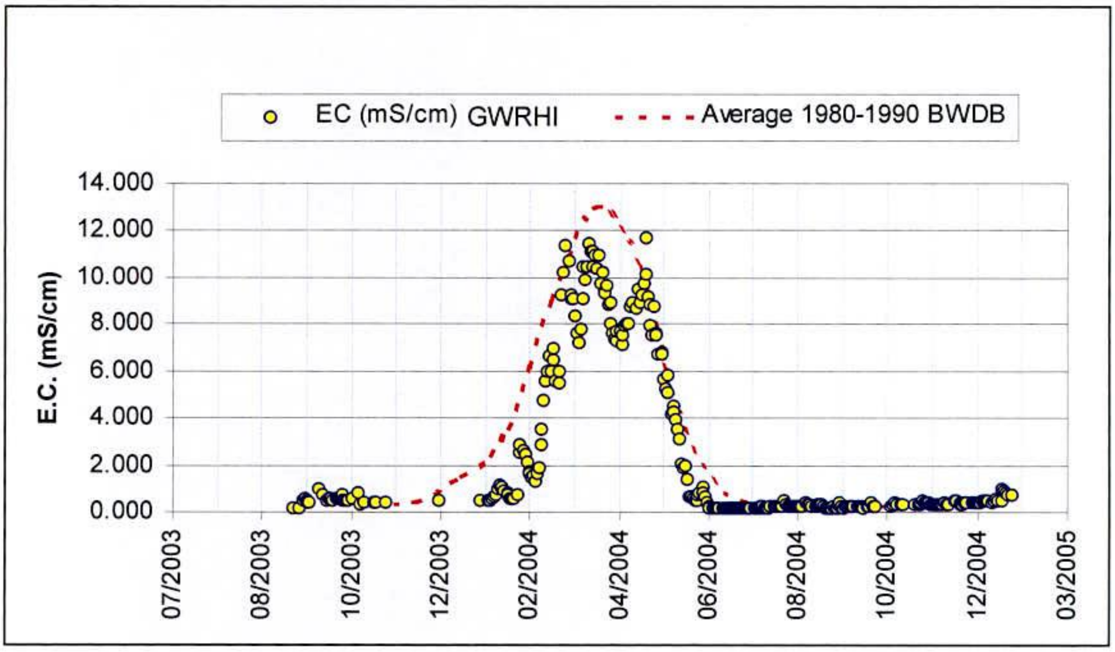


Figure 5-9 Salinity in the Rupsha River at Khulna

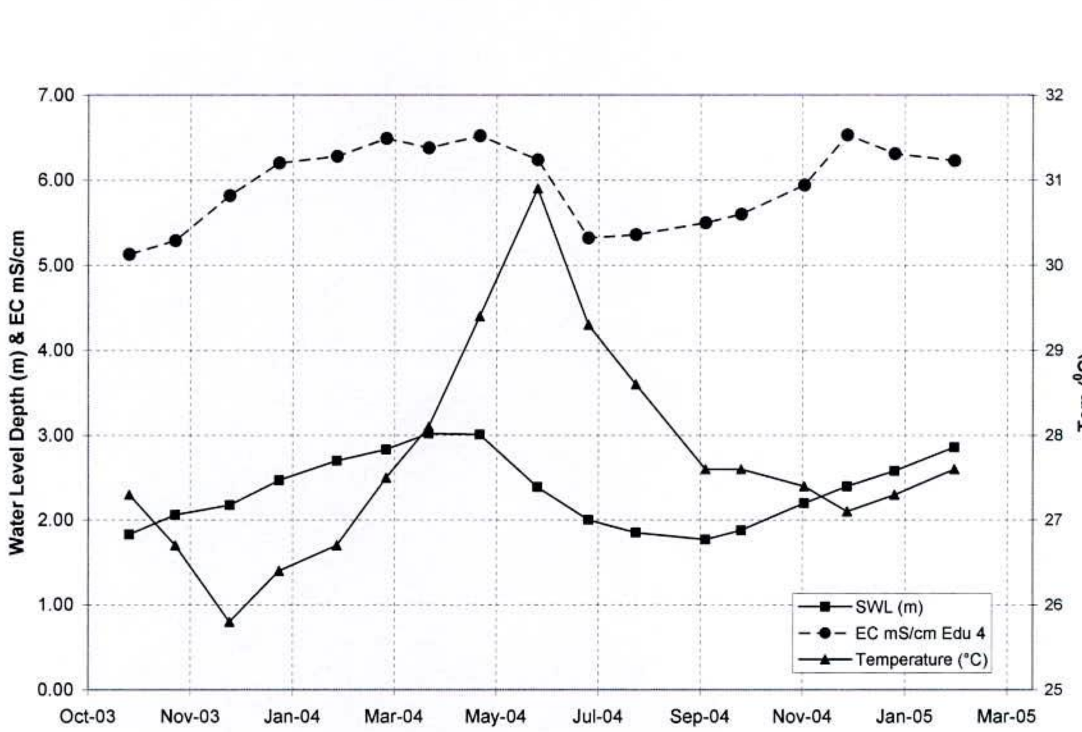


Figure 5-10 Upper Shallow Aquifer Water Level Depth (well top), EC and Temp. at Edu_04

5.1.1.5 Water salinity

The quality of the upper shallow aquifer is marked by high to very high conductivity during the dry season (Figure 5-11). The amplitude of conductivity variation between dry and rainy season is very high, from 600 to 3000 µS/cm on average over the project tube well. Salinity during dry season reached in some points 10 000 µS/cm which is the average river water salinity at Khulna during the same period (Figure 5-9).

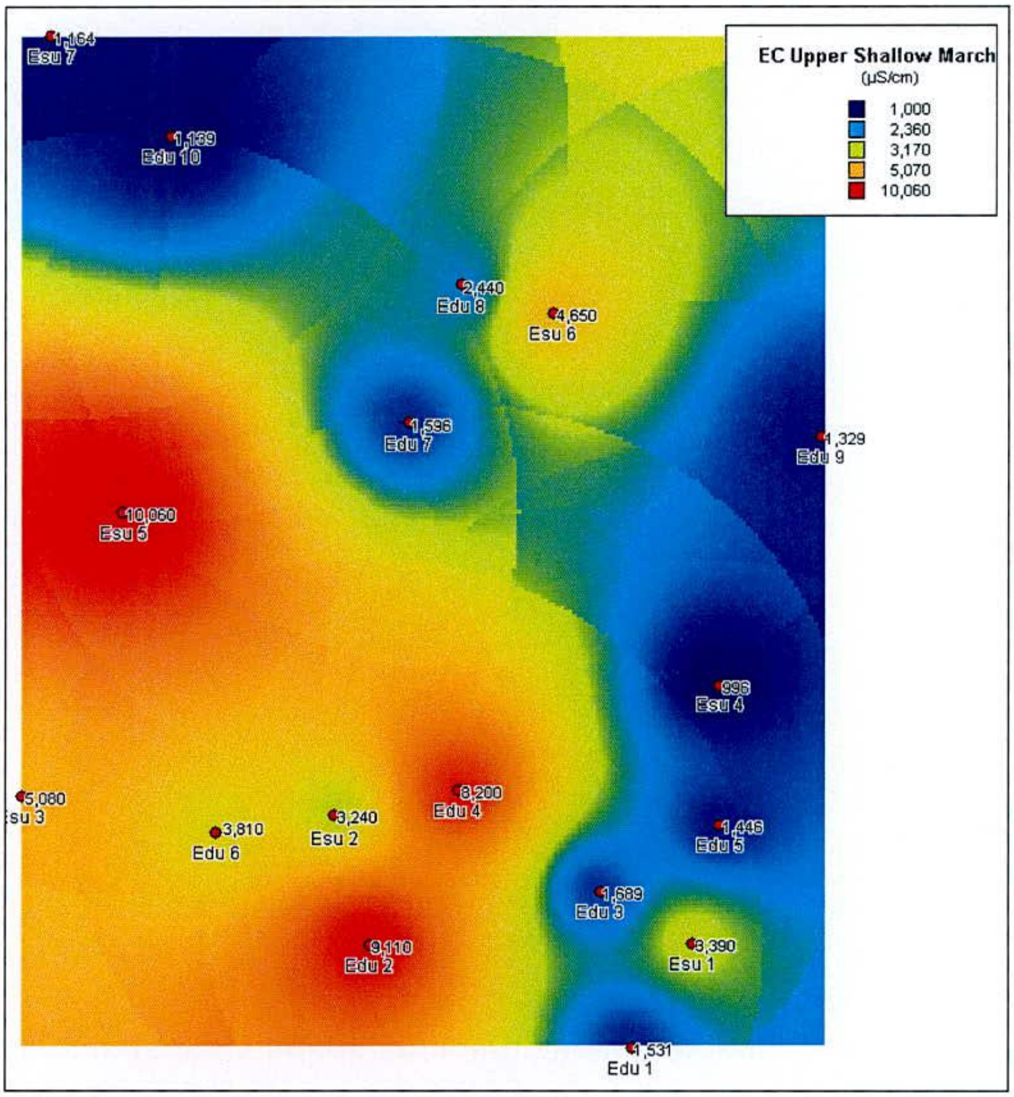


Figure 5-11 Conductivity of the Upper Shallow Aquifer March 2005

5.1.2 Shallow Aquifer

5.1.2.1 Aquifer Structure

By the observation of lithological logs and geological cross sections below the depth of 40 m to 50 m a change in nature of sediments has identified. While the upper shallow 40 m are rather silty and clayey, the range between 40 and 130 m is generally composed of yellow to brown fine sand, varying from very fine sand to medium sand. This layer is continuous all over the study area and as well as all over the country. It is known as the shallow aquifer.

In Khulna, the shallow aquifer substratum is almost flat, at an average depth of 125m, overlying clay and silty formation (See Appendix-3). This discontinuity correspond to the low sea level period, approximately 18000 years BP (Before Present), during which active erosion took place and new fluvial deposit replaced the finer sediments in place.

The aquifer is confined below the finer sediments presents above 40 to 50m, and thus benefit of a natural protection. At this depth, the aquifer is not in direct contact with river system. Variations of pressure in the upper shallow aquifer or in river beds can however affect the shallow aquifer water level.

5.1.2.2 Water Level

The water level fluctuation in different tube wells, during the observation period (May 2003 – March 2005), varies between 0.5m (at Ps_04) after monsoon to 6.8m (PS_05) during dry season. The amplitude of the water body fluctuation is of 2.4 m on an average but can vary between 1.1 to 4.6m.

It should be noted also that over the two hydrological cycles of observations which correspond to two years with rainfall close to average rainfall, the water level does not show any significant decrease. The high water level recovers to the previous year high level. The observation period is not long enough to determine any trend but it shows that the replenishment of the aquifer is efficient and not perturbed by human activity.

5.1.2.3 Hydrodynamic Characteristics

Due to the presence of relatively thick (60-80m) medium sand, the shallow aquifer is likely to present good transmissivity. KCC wells in shallow aquifer (Khalishpur 1 and 2) showed very high specific capacity of 40 to 100 m3/h/m of drawdown (Rus, J.S. 1985). Khan, L.R. (1993) also represented a value of 2980 m2/d (3.4 x10-2) for Khulna shallow aquifer and storability of 1x10-3.

Specific yield is considered to be around 20% which is the common value for medium sand.

5.1.2.4 Recharge

Recharge occurs with a slight delay compared to upper shallow aquifer. An example is given on Jabusa tube wells where, as in several other locations, twin tube wells were realised during the project. Whereas the upper shallow recharge starts in April, the shallow aquifer recharge starts in May. This delay is linked to the mode of recharge of this aquifer which takes place presumably hundreds of kilometres from Khulna City. Direct recharge occurs over outcropping area of the sandy layer, along the northern and north-eastern relief. The rise of the water level corresponds to the recharge from Monsoon rainfall and floods in these remote areas. It induces a variation of pressure in the aquifer which is transmitted almost spontaneously.

Additionally indirect recharge occurs through the upper shallow layers by vertical leaching between aquifers. In Khulna area, the water table elevation in the upper shallow aquifer is higher than the shallow aquifer. This observation refers to higher hydrostatic pressure in the upper shallow aquifer than the shallow aquifer which allows vertical leakage of water. However such transfers are likely to be slow and may occur all year round, as the upper shallow and shallow follow parallel fluctuations (Figure 5-13).

Locally the upper shallow aquifer may be in contact with the Shallow aquifer. Over the domain study, such contact seem to occur in the North-Western part, near Phultala, where no upper shallow aquifer has been identified (project tube wells Edu_10, Edu_7, Edu8, Esu7), towards the ease (Edu_09) and in the south eastern part, south of the Rupsha River. At Nijgram Madrasa two tube wells were tapped in to the upper shallow (Edu_01) and the shallow aquifer (Eds_01) respectively. The water level is found at a similar depth and its conductivity is almost identical in the two wells (Figure 5-15). It refers to inter connection of the two aquifers.

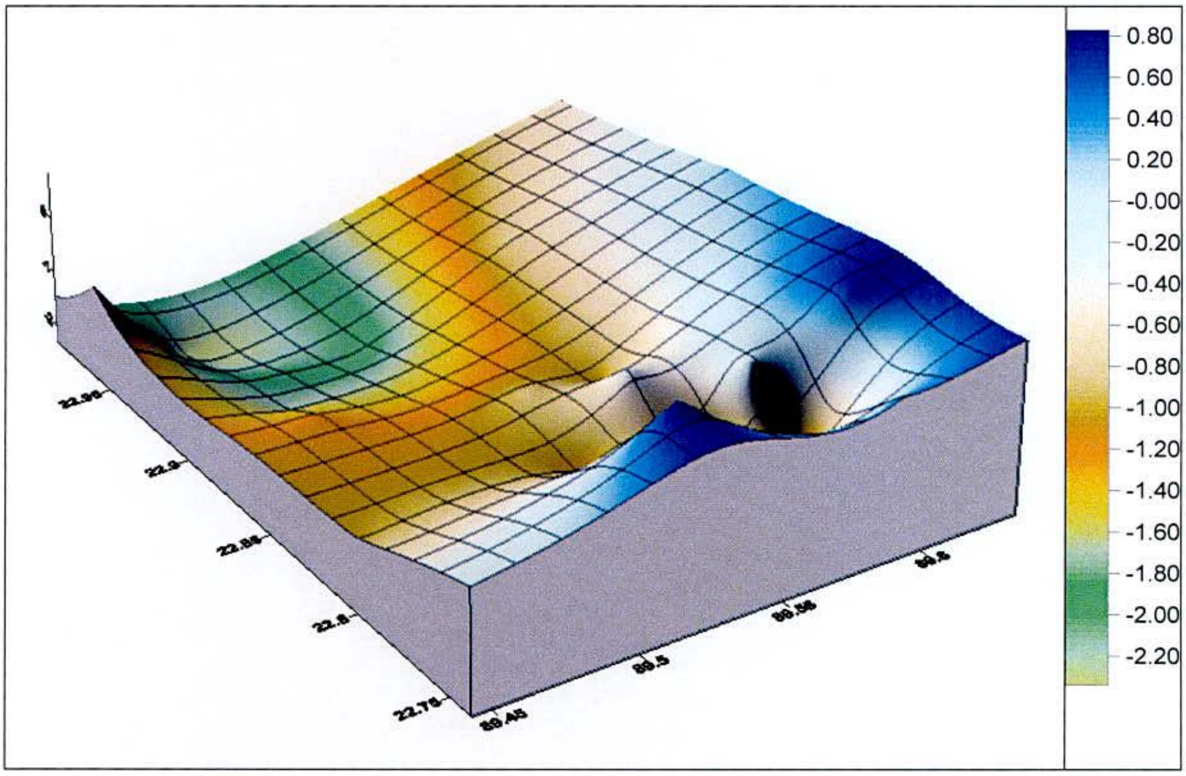


Figure 5-12 3-D Model of SWL of Shallow Aquifer March, 2005.

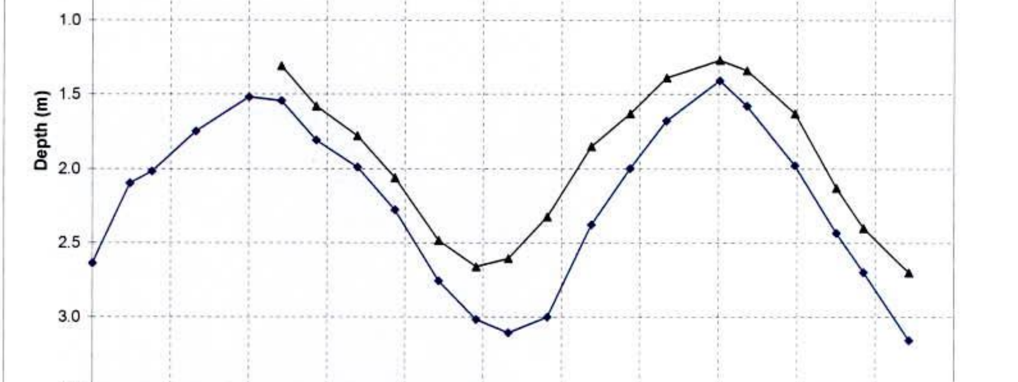


Figure 5-13 Water Level Fluctuations at Jabusa Twin Tube Well

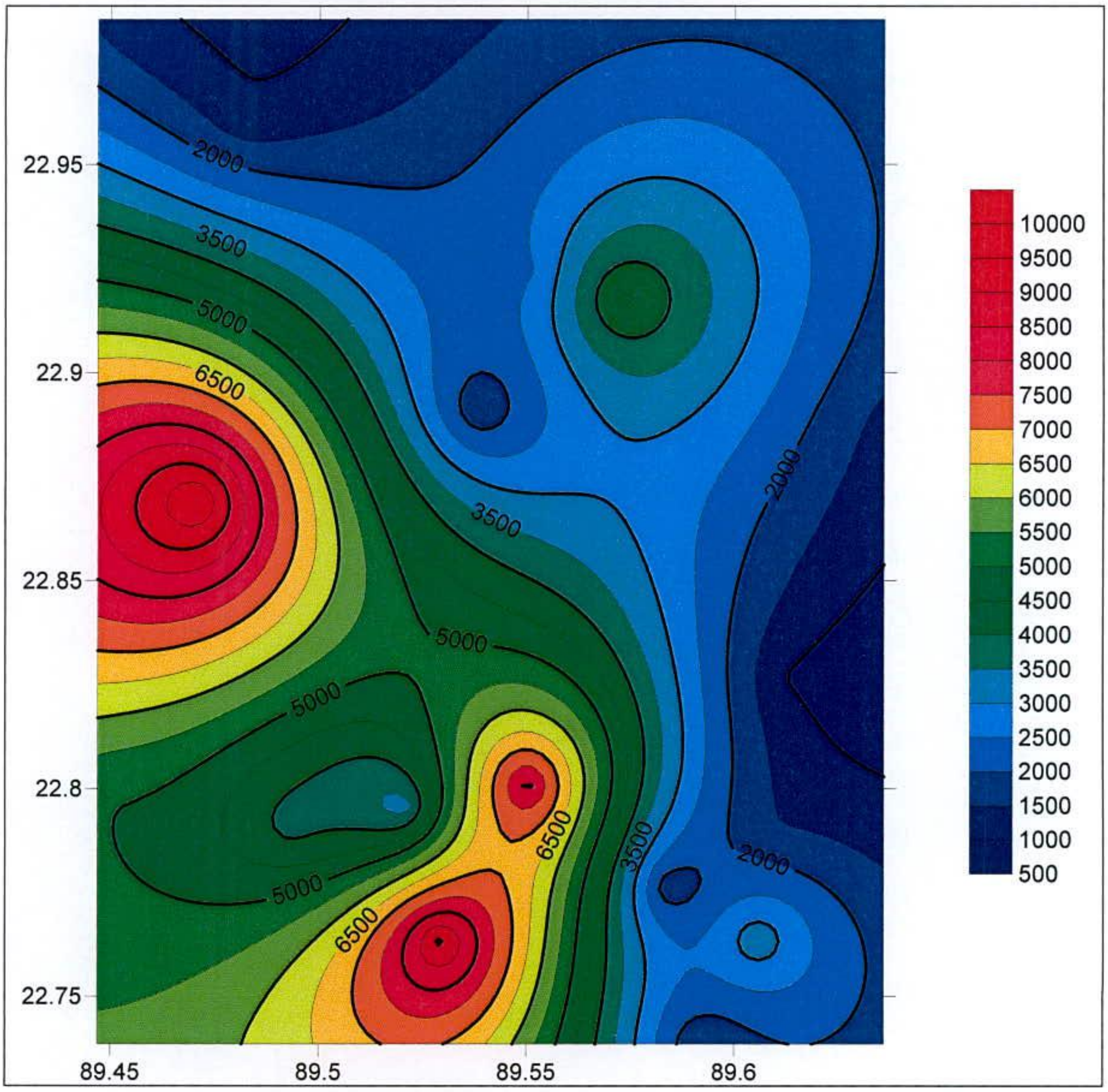


Figure 5-14 Contour Map of EC for Shallow Aquifer in March, 2005 (Dry Season)

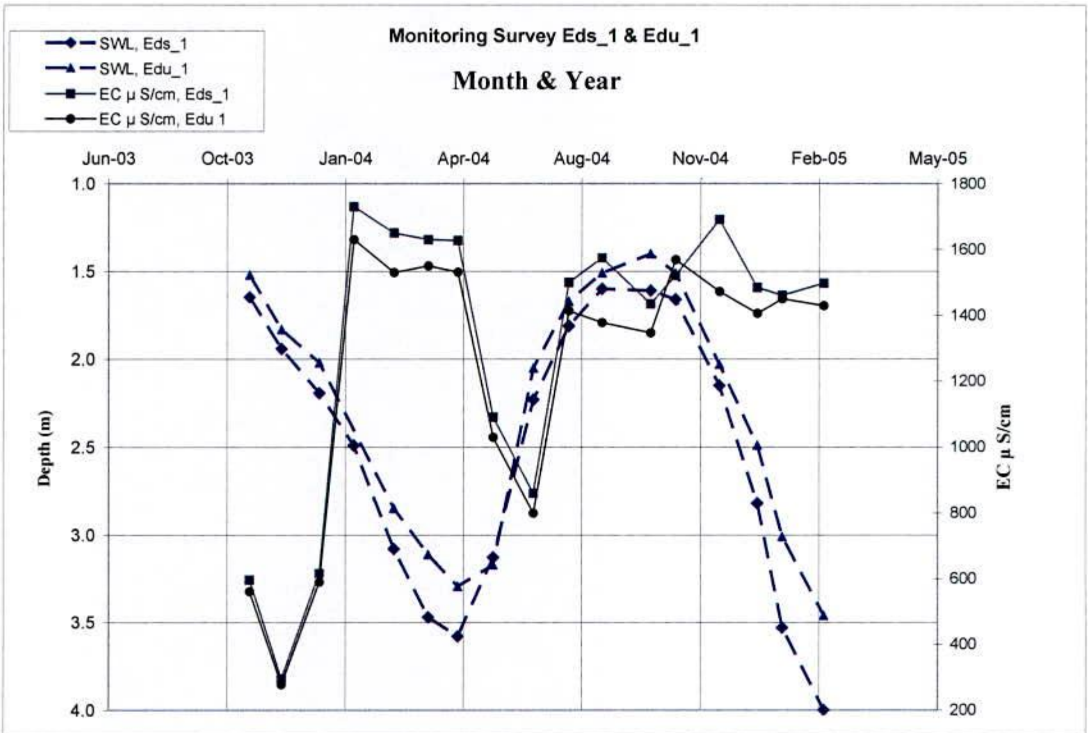


Figure 5-15 Comparison of Upper shallow and Shallow Aquifer at Nijgram Madrasa

5.1.2.5 Water salinity

Despite its good potentiality, the shallow aquifer in Khulna region is characterised by a very high salinity, with an average of 3000 µS/cm (average of 25 project tube wells in the shallow aquifer). This renders it improper to its exploitation for water supply and for this reason the shallow aquifer is not the main focus for the water supply of Khulna City.

Previous progress reports, particularly the "Bi-Monthly report n°5" have provided maps showing the extent of the salinity contamination. Those maps clearly demonstrate that there is no place with acceptable conductivity that is below 1500 µS/cm (or TDS=1000 ppm). Temporarily, a few spots south-east of Bairhab river and south west of Khulna may show conductivities around 1000 µS/cm indicating that they locally get fresh water recharge from the upper shallow aquifer during monsoon (Figure 5-17).

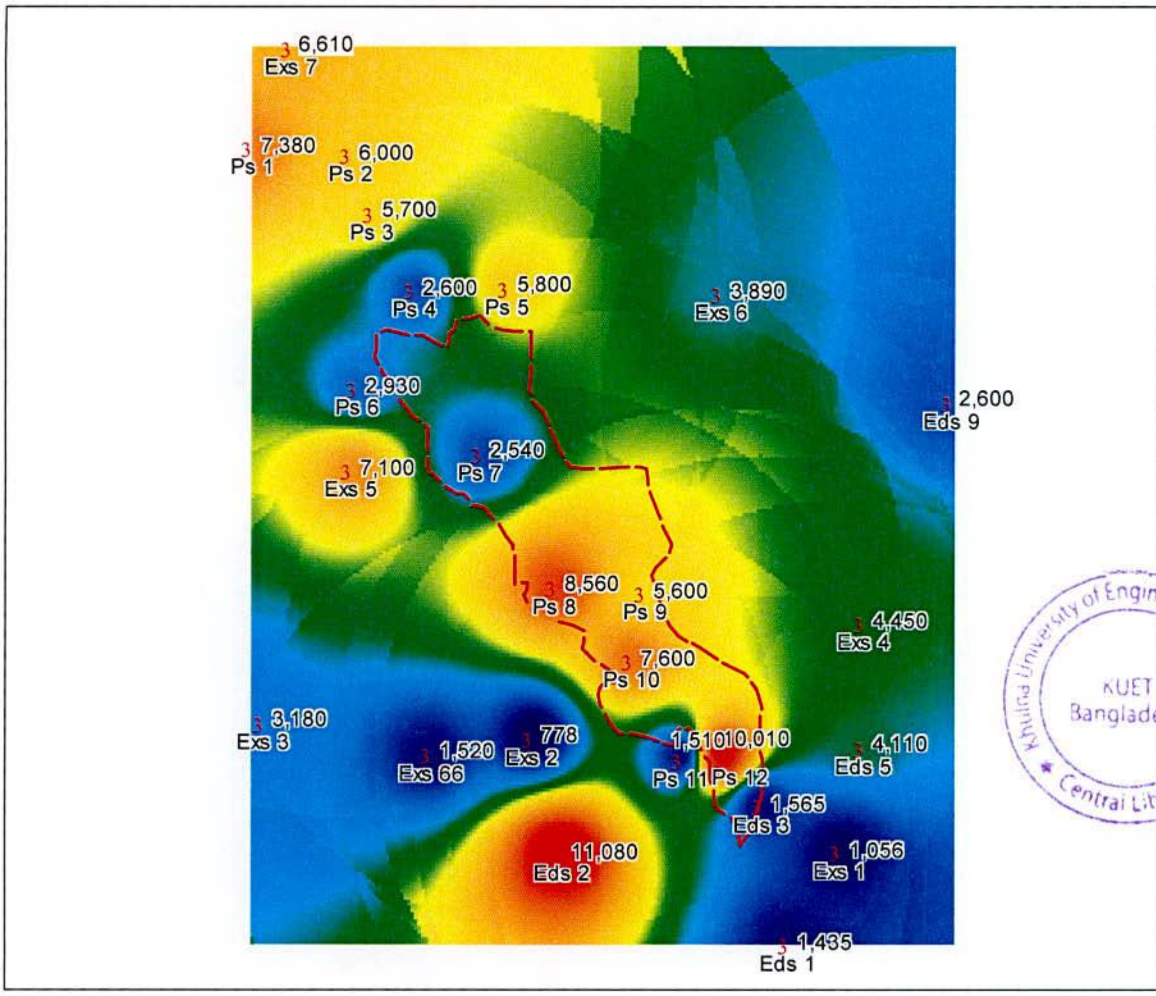


Figure 5-16 Pre-monsoon Conductivity Map of the Shallow Aquifer (April, 2005)

The origin of the salinity of the shallow aquifer is questionable. It is a widespread saline zone which extends more than 100 km from the sea shore, and it should be kept in mind that the contact point between the aquifer layer and the sea could be much further offshore. It is important to notice that this invasion concern only the south western part of Bangladesh. It is not found with so much extent in the central and eastern coastal area.

Water analysis in past studies has proved the marine origin of the brackish water. It could be considered that the shallow aquifer is invaded by sea water encroachment. However, with water level elevation at about 3 to 4 m above sea level and with regular recharge there is no physical argument to sustain this hypothesis. Under present condition, the natural salt water - fresh water interface should be located much further towards the south.

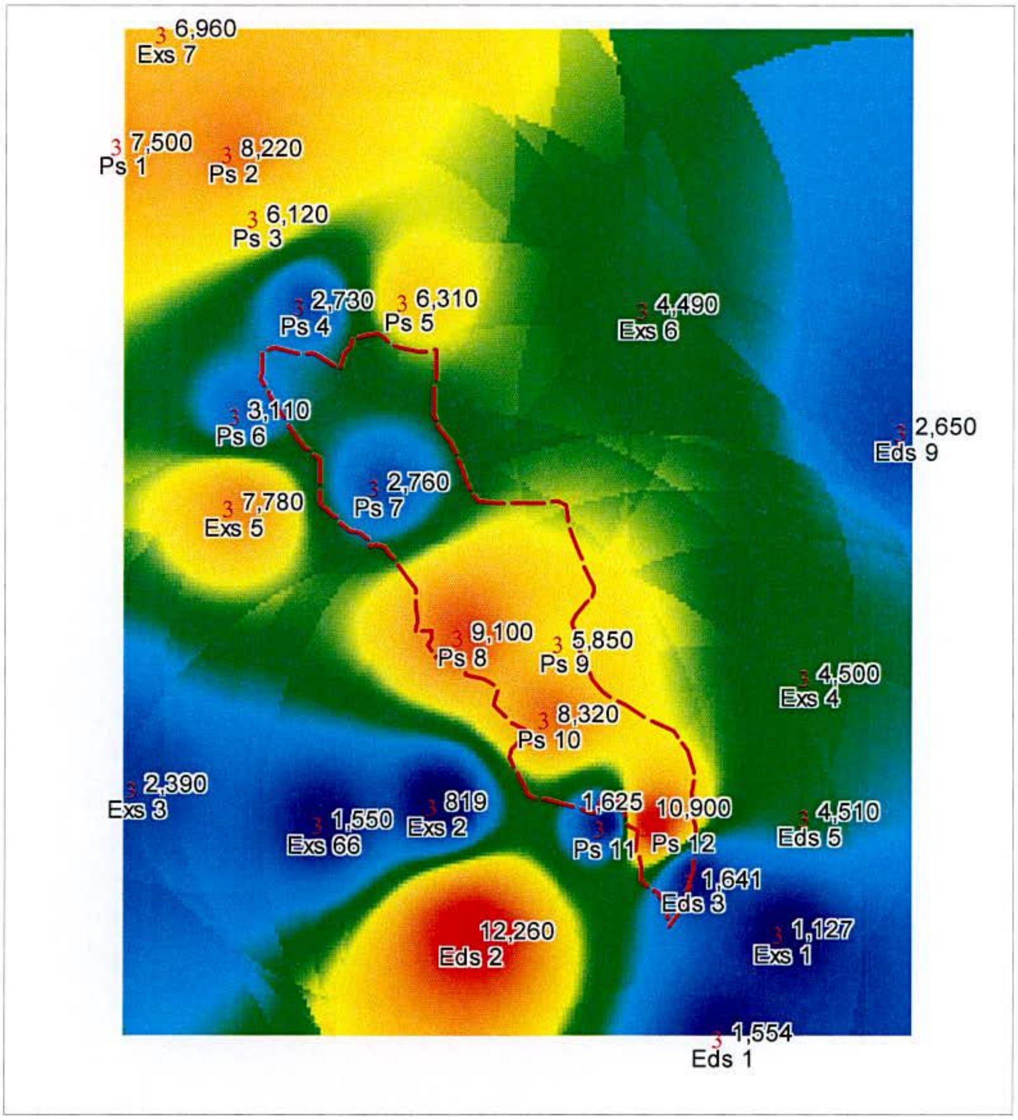


Figure 5-17 Conductivity Map after Monsoon in the Shallow Aquifer

During the dry season, rivers get brackish due to the fall of fresh water discharge and progression of sea water in the estuaries. This progression extends very far to the north. On 29/04/2004 conductivity was around 6000 µS/cm in Bairhab River at Noapara (border with Jessore district). However, the hypothesis of contamination of the shallow aquifer by river would have to explain how this process occurs. The upper shallow aquifer, which is in direct contact with river, should be contaminated first and show higher conductivity than the shallow aquifer, but this explanation is overruled. Moreover there is no evidence of higher conductivity in the vicinity of river. Finally, if infiltration from rivers were responsible for the salinity of the shallow aquifer, why would this salinity remain high all year round whilst the salinity of river falls down to 400 μS/cm in December (result from river monitoring at Rupshaghat Point)?

There is no geological evidence that could explain the salinity of the water in the shallow aquifer. No evaporates are found in the sediments that could explain high conductivity in the water.

A last hypothesis which could be given to explain the presence of salt considers that the water in the shallow aquifer is sea water which has been trapped during the Holocene period. In their study regarding arsenic contamination BGS and DPHE, (2001) report suggests that the time needed to renew the water of the aquifer, even with present abstraction, would take few thousand years. In the Faridpur aquifer, the time to flush out arsenic from the aquifer is estimated between 20,000 and 71,000 years. Similarly, it can be envisaged that if saline water was trapped 10,000 years ago (while the mangrove was covering the area), it has not been completely flushed yet. However, if 20,000 years are needed to flush out the salt under present gradient conditions, one may ask how much time was needed to flush out the fresh water already present in the aquifer between the low stand period (-18,000) and the Holocene period (-10,000).

Isotopic analysis could help to determine the reason for the saline water presence in the shallow aquifer. An attempt was made by Rus, J.S. (1985). Not surprisingly, no tritium activity was detected, but limited numbers of analysis were made to the other isotopes which also could not define the age of the water. Understanding the origin of salt in the aquifer might be considered as a scientific preoccupation. It has however practical consequences, if the water of the shallow aquifer is connate (trapped) water its salinity will go decreasing (although at very low speed) because of the areas of fresher water coincide with high transmissivity. In the contrary (proximity of a sea encroachment for instance) salinity might increase even more and threaten other fresh water resources.

5.1.2.6 Abstraction

The shallow aquifer is exploited for irrigation, domestic supply and industries. Mainly in the northern portion of the City (Moheswerpasha, Fulbabi Gate and Daulatpur) is totally depends on this aquifer. A total sum of 7250 numbers hand tube wells was installed in this aquifer by KCC throughout the City. At present there is no production tube well functioning in this aquifer. Available information did not allow distinguishing the abstraction in the shallow from the upper shallow aquifer. As a matter of fact many tube wells which are reaching the shallow aquifer do not properly isolate the upper shallow aquifer.

5.1.3 Deep Aquifer

The deep aquifer constitutes the main water supply source of Khulna. The main study regarding this aquifer, prior to the GWRHI project was lead by IWACO in the eighties (Rus, 1985). Mott MacDonald Ltd worked on the water distribution system of Khulna. Previous investigations however always focused on KCC area. The numerous tube wells drilled during the project (more than 73) have considerably extended the knowledge of the geological feature of this aquifer. From the lithological logs of these wells, 15 cross sections have been drawn and are presented in Appendix -3.

5.1.3.1 Aquifer Structure

The deep aquifer layer is made of sandy material from fine to coarse size. Its thickness varies from 20 to more than 150 m. It is found all over the study area. The cross sections elaborated reveal a particular structure:

- From north to south of the study area, the deep aquifer layer is increasing in thickness and gently sloping southward. A particularly productive zone seems to exist below Khulna City, with coarse material.

- From west to east of the study area, the thickness of the aquifer is dramatically increasing from a thin deep layer of 20 m thickness to a wide and shallower layer. This is linked to the variation in thickness of the clay layer which separates the shallow from the deep aquifer. On a rough approach, it can be said that west of the river Bairhab exists a massive layer of clay material, up to 260 m in thickness which acts as an aquiclude, while east of the river, the thickness of the clay decreases to a few meters and is to be considered as an aquitard. It is believed that on the eastern and southern border of the domain study, the clay layer which separates the shallow from the deep aquifer disappears, allowing mixing of the two aquifers.

The reason of the presence of the clay is not yet explained. According to the report of Rus, (1985), the clay could have been deposited in a subsiding lake. The conditions of such deposit are difficult to understand. Such sediments would have been deposited under very quiet conditions, which are not compatible with the deposit condition of the aquifer material. They would thus be deposited after the deposit of the fluvial material which constitutes the aquifer, and before the low stand period of erosion which levelled the upper part. Now the question arises, how could such a thickness be accumulated and why would it affect the thickness of the sand layer? Rather than a lake, this clay body could be the filling of a submarine trench by hemiplegic sedimentation of fine silt and clay conveyed into the sea by a nearby river confluence. The shape of the clay body which seems to be stretched along a north south axis and its swallowing towards the north could be compatible with this hypothesis. However, evidence of this marine sedimentation remains to be demonstrated.

Another hypothesis (Figure 5-18) would be that the massive clay is remain of an older (Miocene) deposit, slightly tilted westward by the post Miocene tectonic episodes and completely eroded on the eastern part. Therefore the deep aquifer layer would be composed of sand from different age and

Another hypothesis (Figure 5-18) would be that the massive clay is remain of an older (Miocene) deposit, slightly tilted westward by the post Miocene tectonic episodes and completely eroded on the eastern part. Therefore the deep aquifer layer would be composed of sand from different age and origin: marine Miocene sand conformably in place below the clay layer, of thin thickness (20 m), and Pliocene to Pleistocene fluvial sands occupying the eastern part of Khulna City and covered by finer sediments and clays.

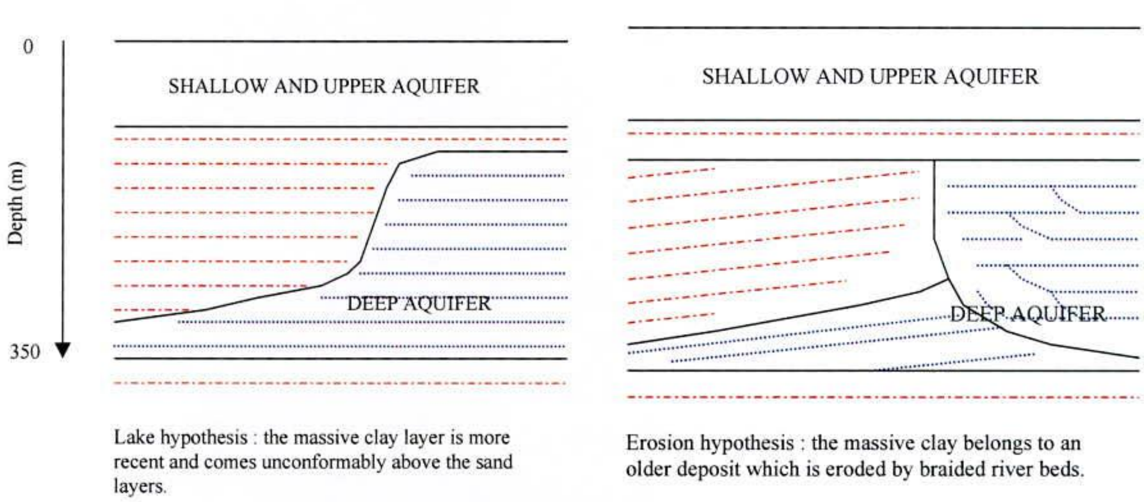


Figure 5-18 West - East Interpretative Cross Section

Whatever the origin of the clay sedimentation is, its presence on the east side of the domain study constitutes a major structure which can be delineated thanks to the analysis of new and old lithologs (about 170 tube wells). Thus the configuration of the domain study can be divided in three North-South strips following the Bairhab River:

1. Towards west, water is coming across 20 m thick layer (Cross Section CC) with low conductivity (<1000 µS/cm) in Figure 5-19 at a depth of about 280 m. In this area the depth of the thin aquifer layer becomes out of reach because exploration in that area became difficult without high capacity powered rig. It is observed that towards further west, the clay thickness decreases. The layer again appears at Katenga, extreme North-West of the study area, (Exd_17) at a depth of 300 m. On the other hand at Shahpur (Exd_18) a sandy layer has been appeared at

assumed and, in this case, this would confirm (but not explain) the "U" shape of the clay body.

To investigate below the clay layer at Shahpur High School, North of Dumuria Exd_18 is the first tube well in this area where discovered 77 m thick aquifer, is quite interesting and requires for further investigations in this area.

Nevertheless this part of the aquifer which is on the western border of the study area may belong to another system of aquifer connecting to the layers with further west. Potentially a symmetric aquifer structure could exist on the western side of the clay layer as similar to layer present in Khulna.

2. The central part is a narrow strip on the right bank of the Bairhab River of deep and thick aquifer layer, protected from the shallow aquifer by a still important clay thickness (100 to 50 m), most of KCC wells are located in this area.

The transmissivity of this area is high (2 to 4 $\times 10^{-2}$ m^2/s), partly because the aquifer thickness becomes important and partly because of an increase in grain size (from medium to coarse). The thickness of the is 170 m in Pd_09 and 200 m in KCC_26 which correspond to an increase of 10 times the thickness of the layer in the western and northern part of the aquifer. This central part is the only location of the study area where coarse sand has been identified below the depth of 250 m (example: the new KCC production well at PTI More). The substratum of the aquifer in this area is locally below 350 m, out of reach of hand dug tube well. The conductivity of water (EC) in most cases remains below 1000 µS/cm.

Below the southern area of Khulna City water levels during 2004 did not fully recover the level observed in 2003 (Figure 5-20). The

Below the southern area of Khulna City water levels during 2004 did not fully recover the level observed in 2003 (Figure 5-20). The amplitude of groundwater fluctuation seems less than in other parts of the deep aquifer (1.5 m).

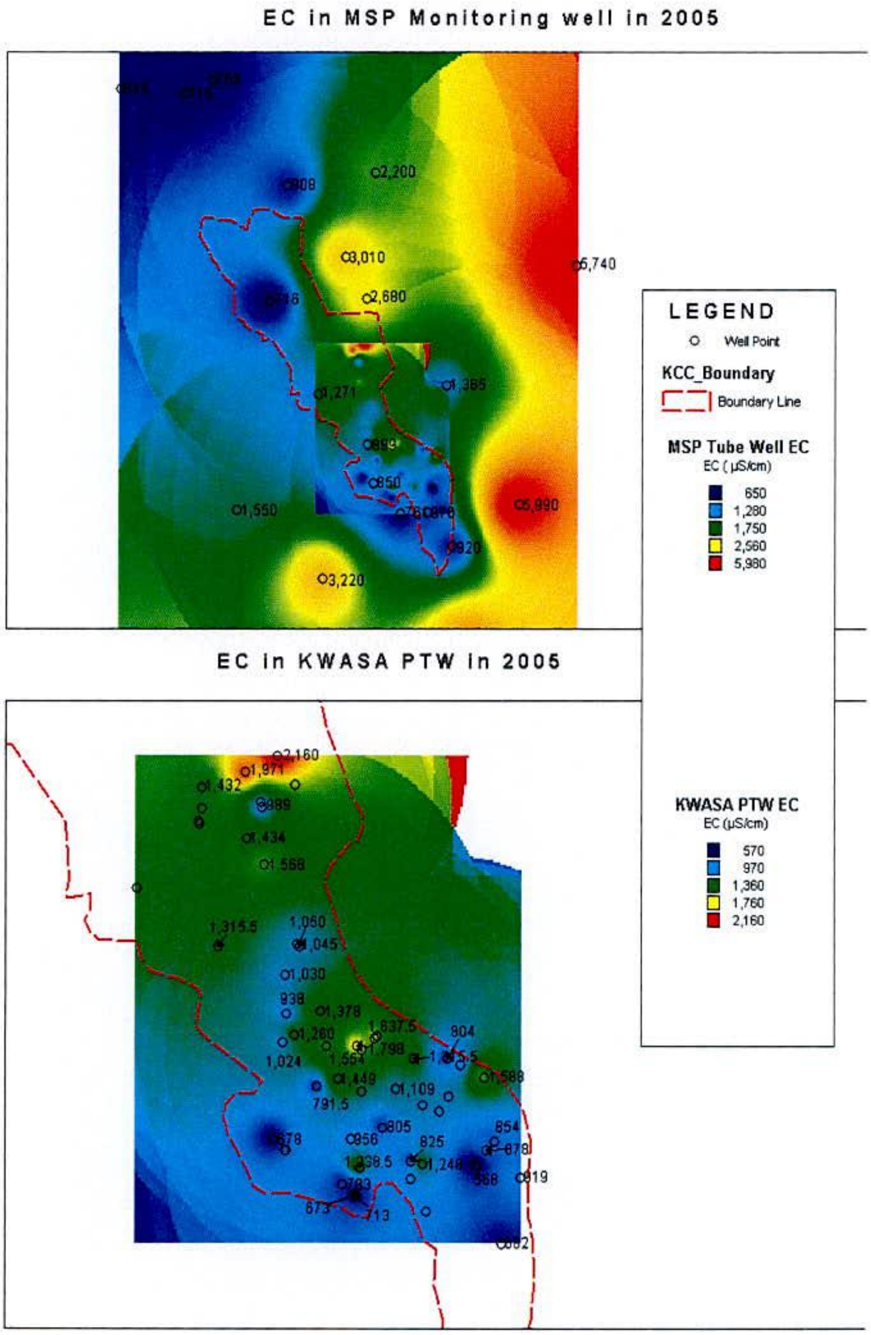


Figure 5-19 Conductivity Map of the Deep Aquifer in March 2005

3. In the Eastern part, as well as towards the North, the clay layer gets thinner and practically disappears (30 to less than 6 m). Other clay or silty layers appear at various depths. After monsoon, the water levels of 2004 recovered their maximum level of 2003 showing that a recharge takes place in the deep aquifer (Figure 5-21). This recharge could however be loaded with salt as this third strip is characterised by high conductivity values above 2000 µS/cm.

The amplitude of the groundwater fluctuation varies from place to place between 1.50 m in southern part and 3.60 m at Phultala in the northern part of the City.

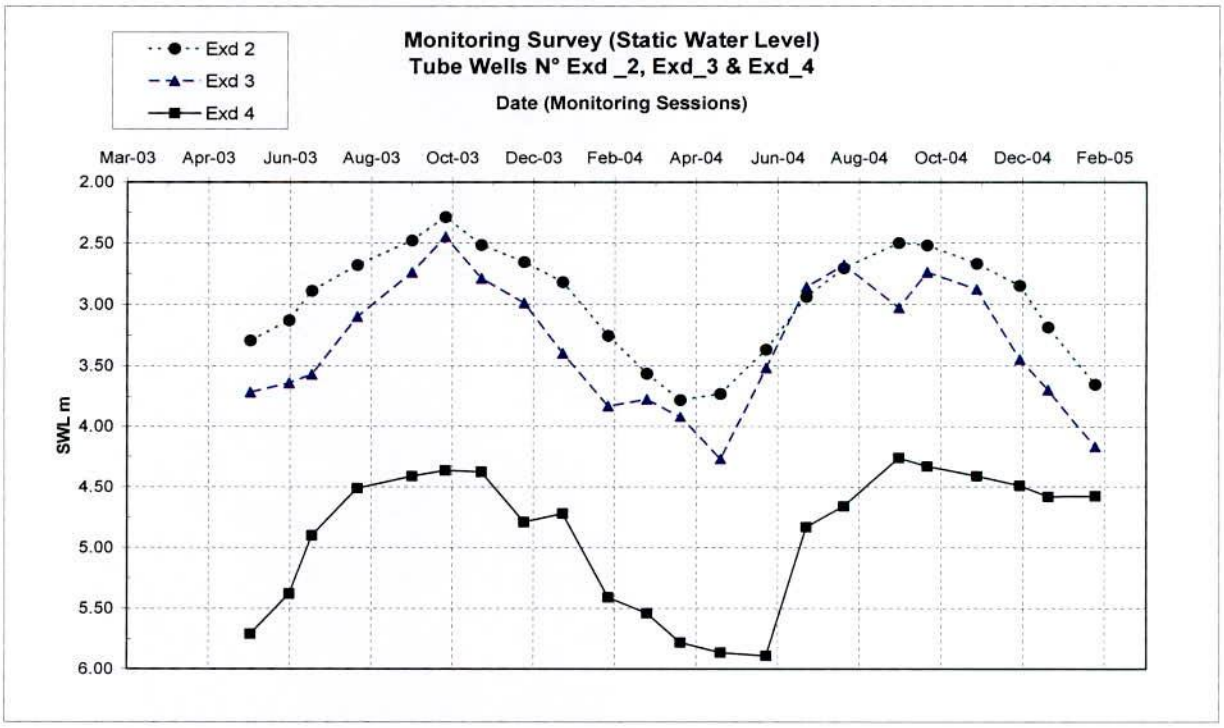


Figure 5-20 Water Level Depth on the Central Strip of the Deep Aquifer

The low salinity of the deep aquifer may be surprising. Considering the low elevation of the water table above sea level and the proximity of sea water, one might expect the presence of salt water below 160 to 200 m, as a result of density equilibrium between fresh and salt water.

The high transmissivity central strip where the lowest conductivity is observed despite the heavy pumping of KCC and some industrial wells, could be assimilated as a tube within which a fresh water flow coming from the North push sea water further South. Water level fluctuation proves, if needed, that recharge take place in the deep aquifer. However, flow velocities in groundwater are so slow that any groundwater flow cannot disrupt a hydrostatic equilibrium under natural conditions. The flow, even considering the high transmissivity of the area cannot push the salt water. Therefore, the absence of salt water in the deep aquifer needs to be explained by another mean.

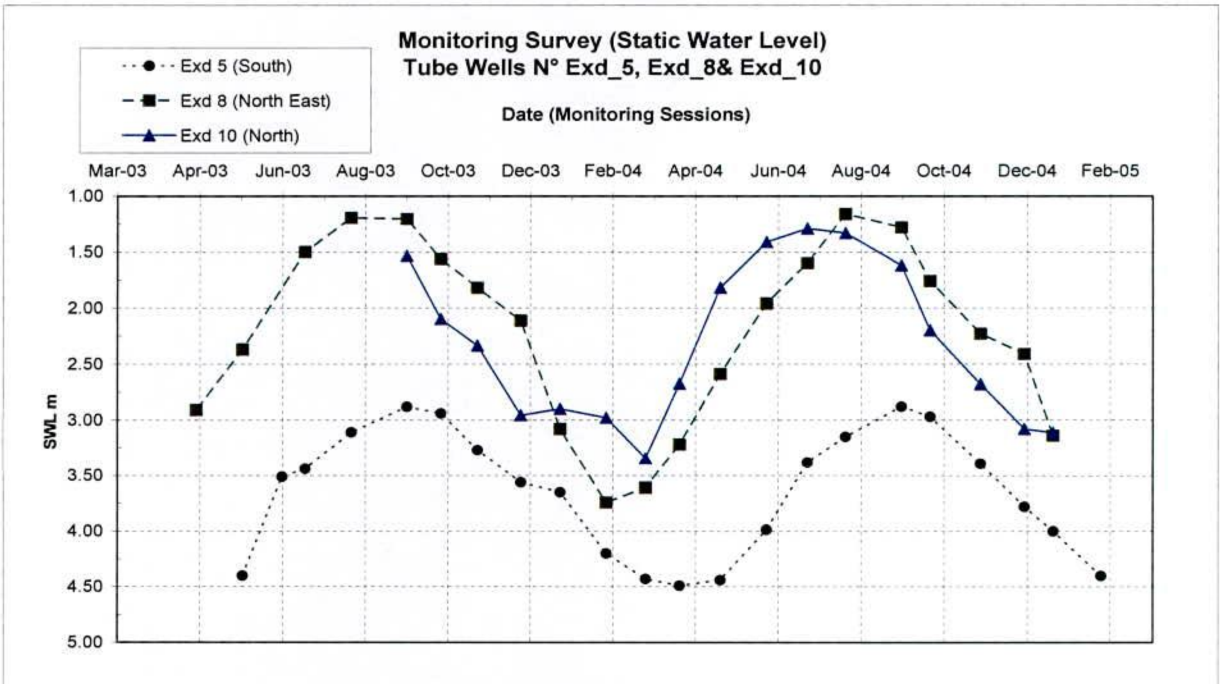


Figure 5-21 Water Level Fluctuation in Deep Aquifer, Eastern Strip

Considering the depth of the productive layer and its important variation in thickness it is believed that the contact with sea water if any is indirect and very far. Sea encroachment, although theoretically possible, might be blocked by some geological barrier. The observed higher values of conductivity could be linked to another origin than sea water encroachment such as contamination by a deeper, or a

5.1.3.2 Relation between Aquifers

The characteristics of the three aquifers become clear when conductivity is plotted against depth. After plotting the conductivity of water against the depth of the filter screen the result clearly shows that:

- the upper shallow aquifer is showing all ranges of conductivity,
- the shallow aquifer has very few points below 1000 μS/cm
- the deep aquifer is rarely above 3000 μS/cm.

Extreme points have been identified and at least two remarks can be derived:

- In January, the upper shallow aquifer shows conductivity higher than the shallow aquifer (Edu_04; Edu_02; Esu_05 are above 5000 μS/cm), whereas in October (after monsoon) this trend is opposite. This illustrates the sensitivity of the upper shallow aquifer to the monsoon recharge and its salinization during the dry season.
- It appears that the highest conductivity observed in the deep aquifer correspond to points that have a thickness of clay of less than 30 m (Exd_05; Exd_09; Exd_01; Exd_07; Pd_03). A relation was searched between clay thickness and conductivity (Figure 5-23). It showed without any possible ambiguity that, the highest conductivities are observed for the thinnest upper clay layer. This is a strong argument to advance that the salinity of the deep aquifer originates from the shallow aquifer above it, through the clay aquitard. As a matter of fact, the conductivity map of the deep aquifer show salinity contamination in the Northern, Eastern and Southern area where the clay layer is disappearing (Figure 5-19). One point (Exd_02) is an exception to this rule. The conductivity measured at Exd_02 is very high, (higher than in the shallow aquifer), despite almost 200 m of clay protecting the

rule. The conductivity measured at Exd_02 is very high, (higher than in the shallow aquifer), despite almost 200 m of clay protecting the aquifer. Therefore for this point the origin of salinity should be searched elsewhere.

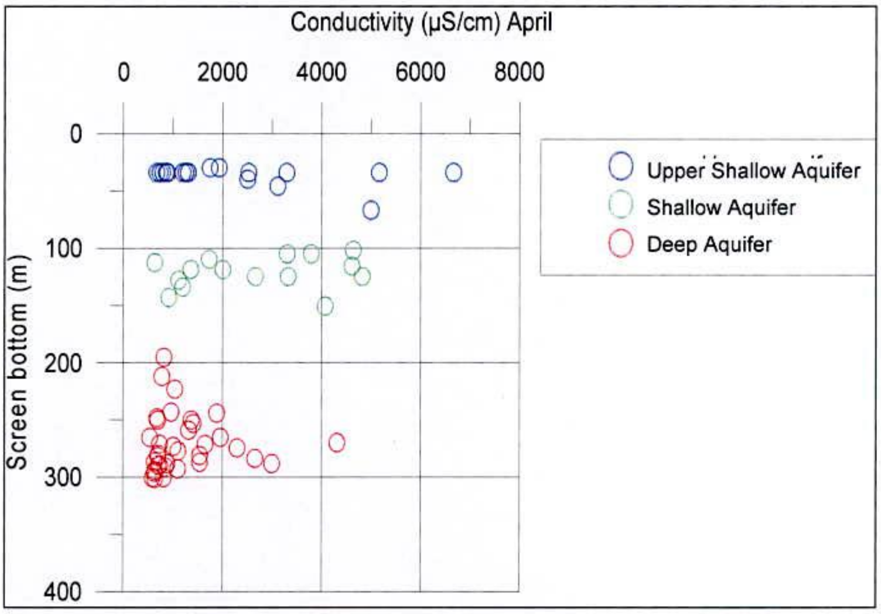


Figure 5-22 Conductivity versus Screen Depth (January 2005)

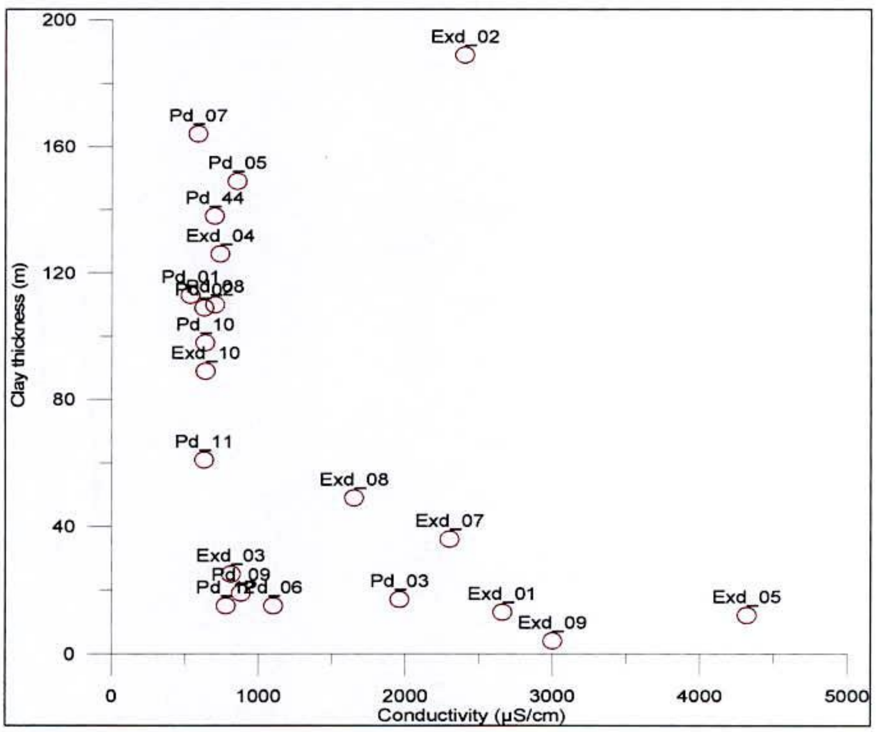


Figure 5-23 Conductivity versus Clay Aquitard Thickness in the Deep Aquifer

Following the above idea, the temperature was plotted against the screen depth. Abnormal temperature was described during the IWACO study without proper explanation. The abnormal temperature were as well observed during the previous studies and plotted in various progress reports, but everybody focused only high values. After plotting the geothermal (theoretical) gradient on the same graph (Figure 5-24) it is observed that, abnormal temperature appears on both sides of the theoretical line. There are few wells showing higher temperature than what is expected, but also there are some wells with lower temperature than expected. These lower temperatures could be explained by the contact with shallower water. For instance, Exd_09 is among the lowest temperature of the deep wells and its connection with the shallow aquifer makes no doubt.

In the shallow aquifer, two points are clearly hotter than they should be. These points are Exs_4 and Exs_6. The temperature of these two wells has been recorded a peak temperature 33°C in May 2005. These anomalies could indicate a connection with the deep aquifer. Considering their locations both wells are supposed to have a thin clay layer separated the shallow aquifer from the underneath deep aquifer.

In the deep aquifer, the highest temperatures are recorded on KCC production wells (Kcc_43, Kcc_25 and Kcc_10). On the contrary, in case of lowest temperature it is observed only in the project tube wells (including the above mentioned Exd_02). It can be assumed that, there might be a linkage between the use of the well and its temperature. This link could be natural (appealing of deeper water in pumping wells) or artificial (warming of the water – 1 or 2°C only – during its trip through the pumping pipe). It is necessary to indicate that the sampling tap is generally located close to the engine of the vertical axis pump. Therefore the artificial increase of temperature could explain local variations and local peaks. However, the hypothesis of deeper water appealed by pumping wells are also to be considered as the bottom of the aquifer remains unknown in some areas. This confirms the need to investigate the area with « extra-deep » drillings.

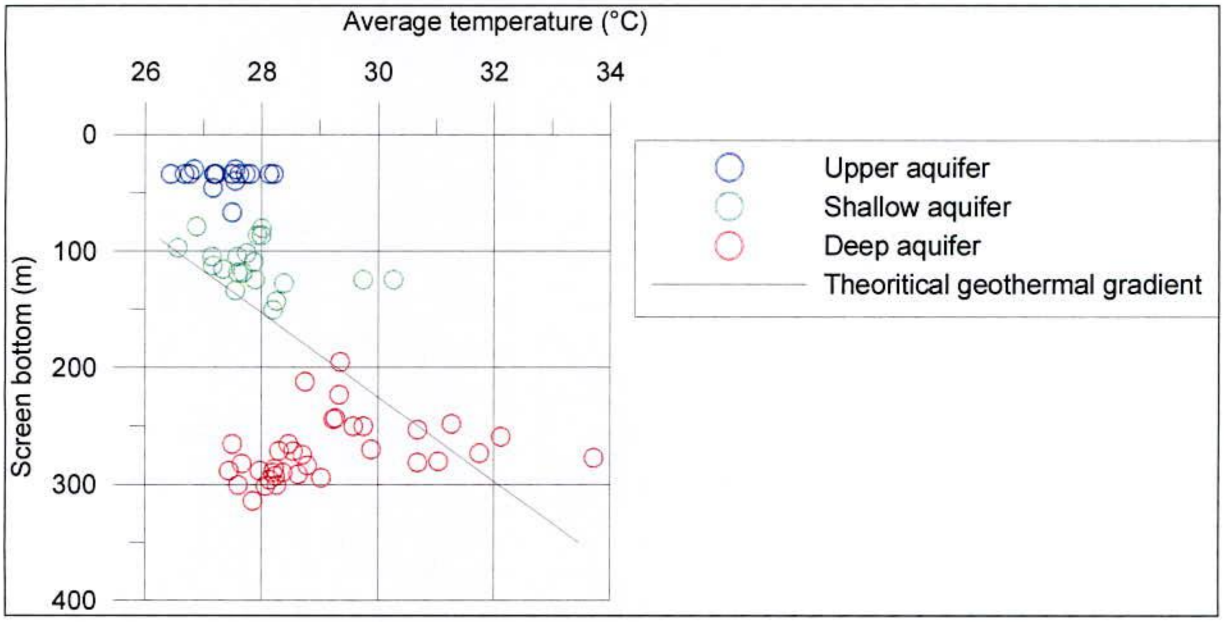


Figure 5-24 Temperature versus screen depth – January 2005.

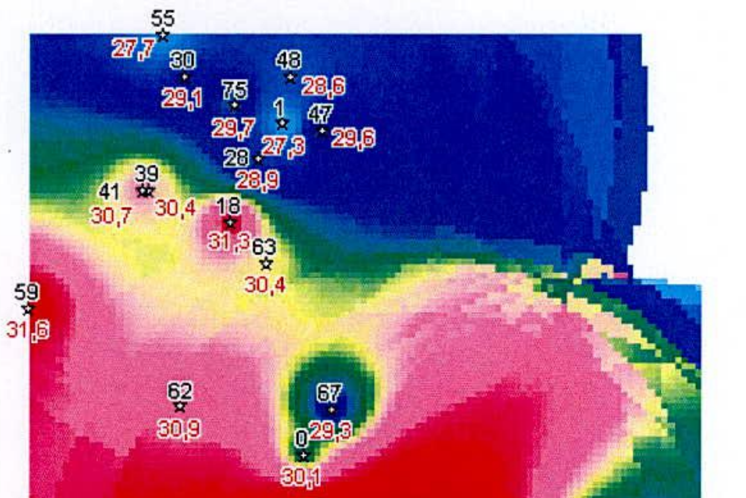


Figure 5-25 Temperature of the KCC production Tube Wells

Figure 5-26 reports on a map two criteria to compare aquifers: water table elevation and conductivity. It can be seen that in the central region a depleted zone takes place in the deep aquifer. The elevation of the water table of the deep aquifer has become lowered by several tens of years of abstraction and the piezometric surface is under constant influence. The shape of the zone clearly shows the direction of highest permeability along a north-south axis. On the eastern side, the difference between water table elevations tends toward zero.

Electrical conductivity is also compared. While it is not meaningful to pay attention to the absolute values, it is interesting to note the inversion of trend when going from west to east. In the west side of the Bhairhab River, the shallow aquifer has a higher conductivity and do not mix with the deep aquifer. On the contrary on the eastern side, because of the decrease in thickness of the clay layer separating the two aquifers, the shallow and deep aquifers are in connection. Thus the salinity could follow a normal pattern with a density differentiation, the highest salinity being at the lower part of the aquifer system.

Another assumption is that the lower salinity observed in the shallow aquifer in the eastern part is due to the freshening of its water by connection with the upper shallow aquifer. In order to validate this assumption, the upper shallow and shallow aquifers are compared in Figure 5-27.

The comparison on Figure 5-27 shows that the upper shallow water table is in many points identical to the shallow water table, it seems to absence of upper shallow aquifer, and almost everywhere the upper shallow water table observed above the shallow water table. Thus, if the communication exists, it is from the upper shallow aquifer towards the shallow aquifer. Secondly, the upper shallow aquifer towards the Eastern area of Khulna is fresher than the shallow aquifer on the other hand it is opposite towards the Western area of Khulna. Thus, as per the previous assumption if there is communication it will tend to dilute the shallow aquifer salinity. This might be the probable cause of observing low salinity in the shallow aquifer towards the Eastern area of Khulna than the salinity in the deep aquifer as well.

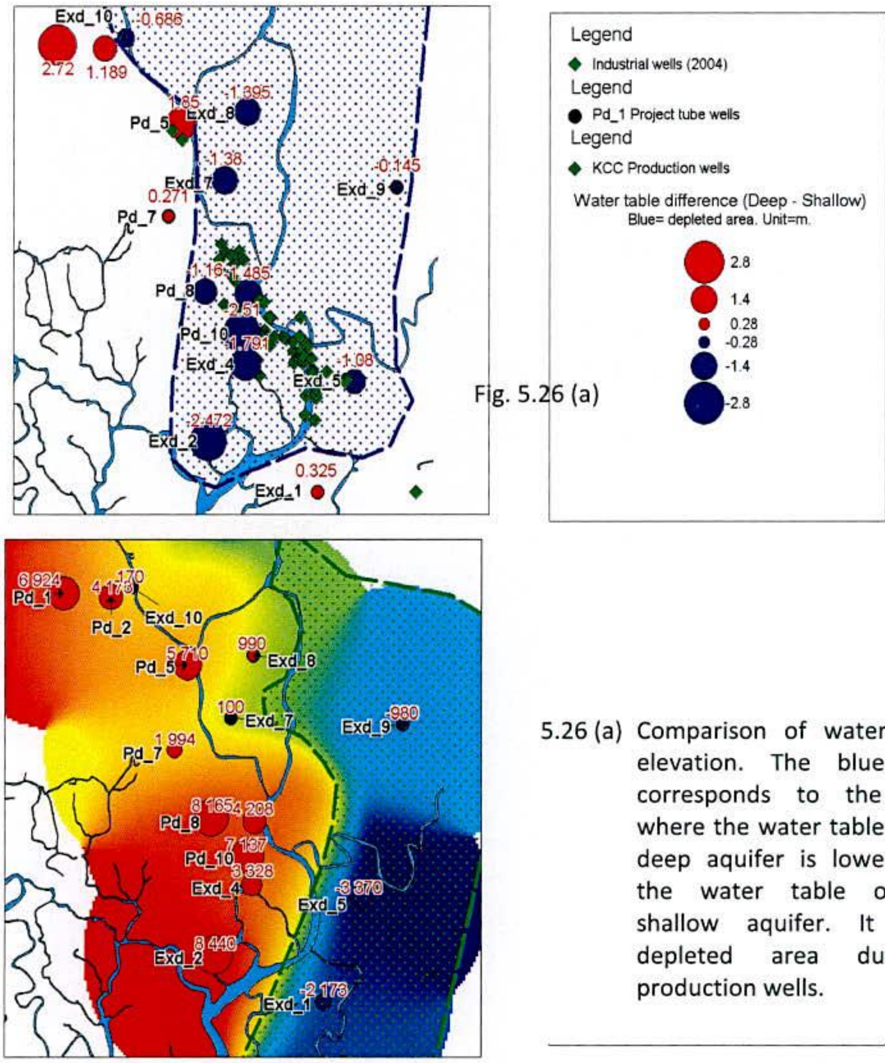


Fig. 5.26 (a)

5.26 (a) Comparison of water table elevation. The blue area corresponds to the zone where the water table of the deep aquifer is lower than the water table of the shallow aquifer. It is a depleted area due to production wells.

Fig. 5.26 (b)

5.26 (b) Comparison of Electrical conductivity. The green area corresponds to the zone where the deep aquifer is more saline than the shallow aquifer.

Figure 5-26 Comparison of Deep and Shallow Aquifer Water Level and Conductivity

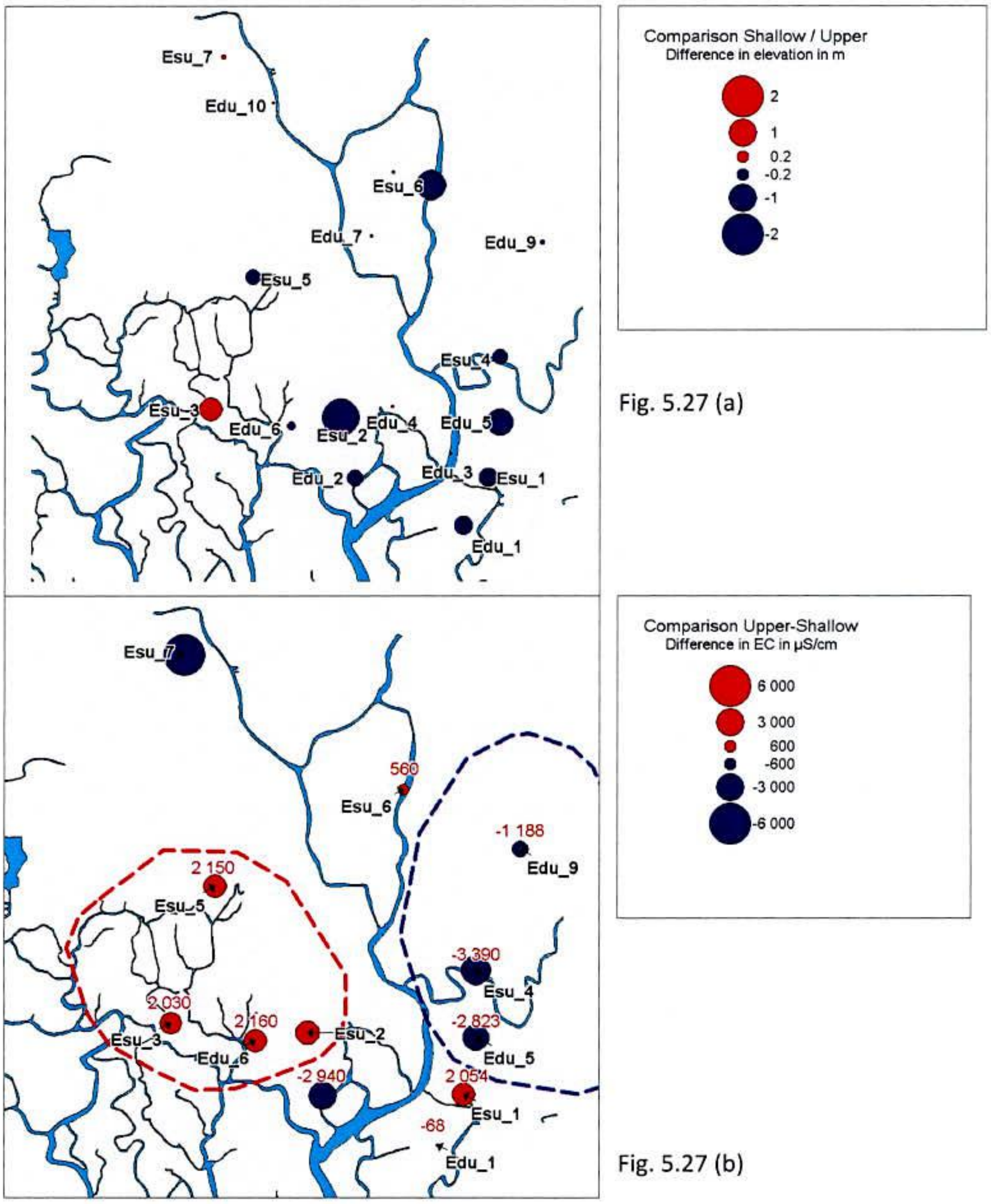


Fig. 5.27 (a) Comparison of water table elevation.
The water table of the upper aquifer is above the water table of the shallow aquifer.

Fig. 5.27 (b) Comparison of electrical conductivity. Two regions can be delineated;
Towards the East of Khulna the upper aquifer is fresher than the shallow one.
Towards the West of Khulna the upper aquifer is more saline than the shallow one.

Figure 5-27 Comparison of Upper shallow and Shallow Aquifer Water Level and Conductivity

It can be concluded that, the deep aquifer will have to take into account a thick aquiclude on the western side, the variation of thickness of the central strip and the leaking properties of the aquitard in the eastern strip. Concerning the boundary conditions, the presence of fresh water in the north and west borders and brackish water in the south and east border should be considered. The presence of brackish water has become threatening to the fresh water for Khulna Water Supply both qualitative and quantitative point due to the depletion cone created by the abstraction in the Khulna City area.

A summary of the conceptual model is given in Figure 5-28 – 5-31 and the following illustrations.

Substratum Depth (m)	Thick. (m)	Hydrogeological Unit		Nature of sediments	Main Features
6 to 20 m	6 to 20 m		Upper aquitard	Clayey and silty sediments	-
40 to 50 m	Max. 40m		Upper aquifer	Very fine sediments	Low permeability; composite aquifer low water quality high seasonal quality variation
~50 m	~10 m		Shallow aquitard	Clayey silt	
~125 m	45 to 65m		Shallow aquifer	Fine to Medium sands	High permeability; Continuous and relatively homogeneous aquifer; High salinity. Not suitable for water supply.
130 to >300m	5 to 260m		Deep aquiclude and aquitard	Clay and clayey silt	Aquiclude west of Bhairab river. Aquitard east and south of the river.
25 to >320m	20 to 150m		Deep aquifer	Fine, Medium and locally coarse sands	High permeability; Variable thickness increasing from North to South and West to East. Continuous aquifer; Relatively low salinity except East and South. Already highly exploited
320 to 350m	?		Deep basement	Clay	Locally (East and South), out of reach without a power rig.

Figure 5-28 Summary of the Conceptual Model Sketch

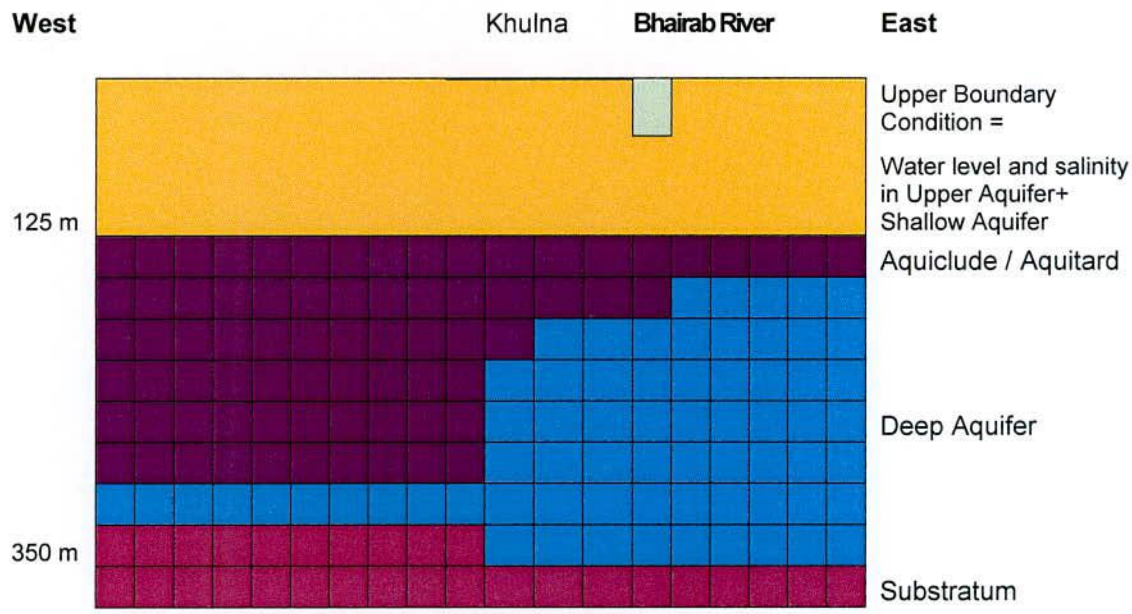


Figure 5-29 Vertical West-East Cross -Section of the Conceptual Model

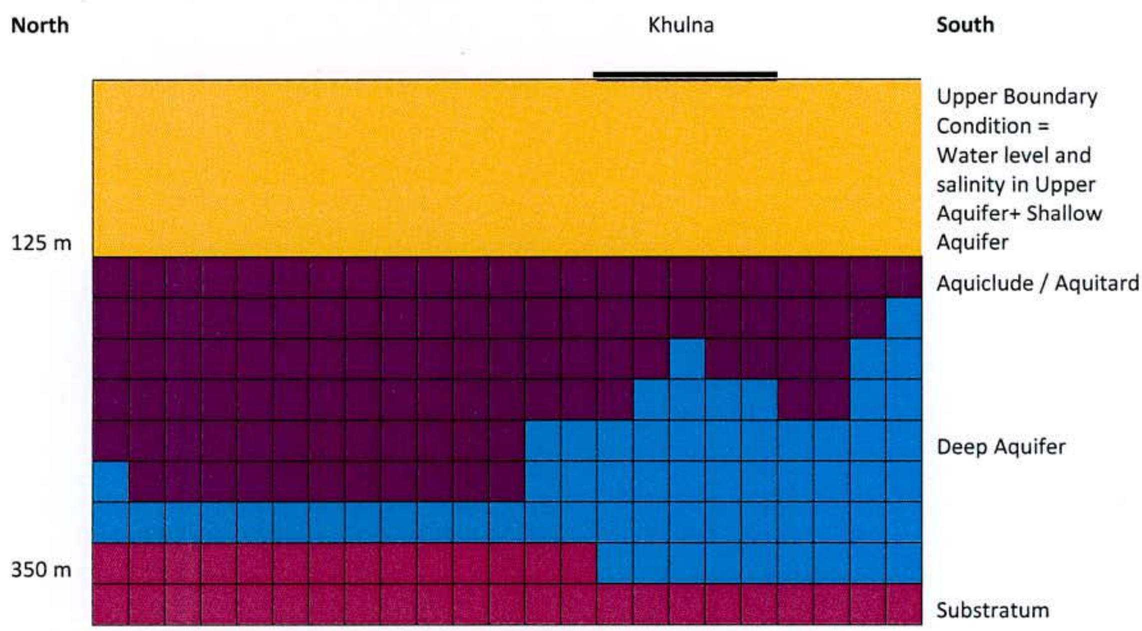


Figure 5-30 Vertical North South Cross- Section of the Conceptual Model

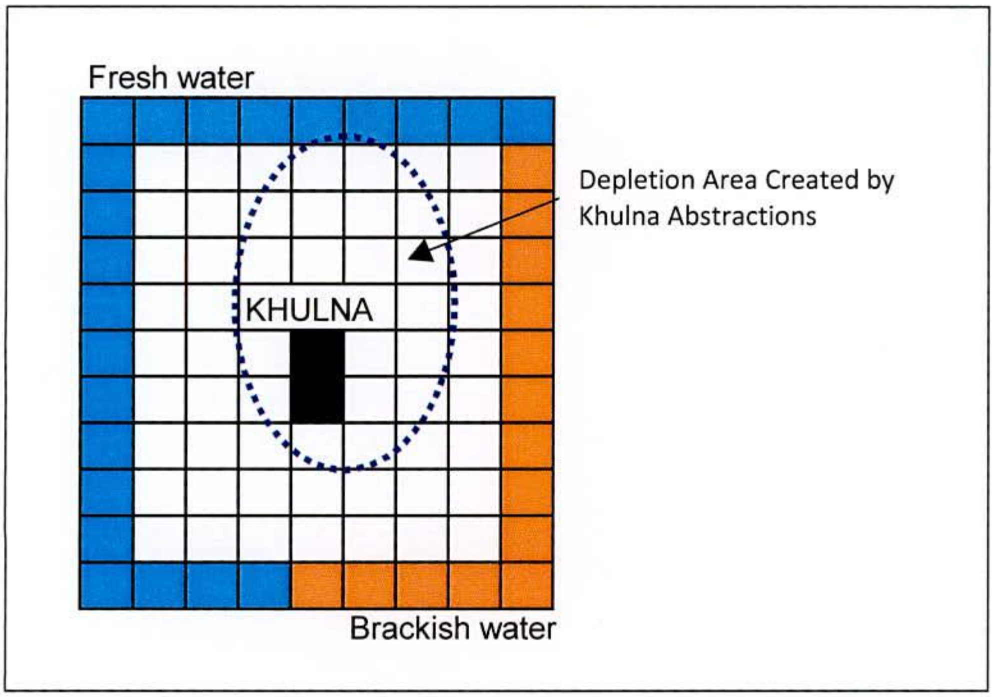


Figure 5-31 Boundary Conditions for the Deep Aquifer Layer

5.2 Estimation of the Renewable Recharge

By the study of the groundwater hydrographs of 21 wells in deep aquifer, starting from April 2003 to Mach 2005 (two special monitoring sessions conducted in May and October 2009), fluctuations of the water level upon time are observed in each observation wells in the entire area. This fluctuation is the indication of the groundwater recharge, which is clear from all the monitoring wells. The quality analysis further confirms that the deep aquifer still contains freshwater in the City and nearby areas. However, all the graphs of static water level versus time indicated that the recharges are following its usual annual cycles. The observed average calculated fluctuating height for the entire study area in 2005 and 2009 are 2.286m and 1.93 m respectively. It can be mention here that the average height in 2009 may not real representative value for 2009 because only two (2) monitoring sessions may not sufficient for this purpose (one in the pre-monsoon and the other is in the post-monsoon). Highest fluctuating water height is observed at Pd_44 in both 2005 and 2009 is 3.61m and 2.48m, respectively in Phultala, Khulna. The location of this tube well is far away (roughly 18 km north) from Khulna City Corporation (KCC) abstraction area. The lowest fluctuating water height is observed in 2005 in Exd_2 that is 1.33m, located at Jalma Chakrakhali in Bhatiaghata Upazila of Khulna but in 2009 the lowest water fluctuation is observed at Exd_3 is 1.29m at Asia sea Food, Lobonchara. Both tube wells are located in the southern part of the KWASA abstraction. In most of the cases it is observed that low static water level occurs at dry season in the month of April and after that water level starts to rise, up to the month of October, post monsoon. Then water level starts to fall again. It is also observed from the comparison of 2003-04, 2004-05 and 2009 graphs that fluctuating heights are almost same. The graphs also explain that the recharge in the northern area of KCC is higher than the southern area. It is known that there is another abstraction zone exists in Phultala area.

5.3 Groundwater Flow Analysis Using Iso-Piezometric Maps

It has been observed that the high and low static water levels prevail in the months of October and April, respectively, almost in all the wells of the deep aquifer except only in few occasions.

Upon consideration of high static water level occurs in September, 2004 for all monitoring wells, an iso-piezometric thematic map has been prepared as shown in Figure 5-32. This map shows the flow direction of the study area during high static water level situation. It shows that the main depression of the static water levels is near the KCC area due to the concentrated abstraction. Using iso-piezometric lines in Figure 5-32, flow lines are constructed as a separate map as shown in Figure 5-34.

It has been observed that the lowest static water level condition prevails in the month of April 2009 in all deep aquifer wells. An iso-piezometric thematic map is prepared for this low static water level which is shown in Figure 5-33. It also shows that the main depression location is near the KCC area where the concentrated abstraction occurs. Iso-pizometric lines and flow lines have been drawn in Figure 5-27 with a superimposition of April 2004 electrical conductivities. This is to be noted that more saline contaminated area is lying under low static water level situation than high static water level situation. Another abstraction area is observed near Phultala that has influenced the iso-piezometric lines in the study area.

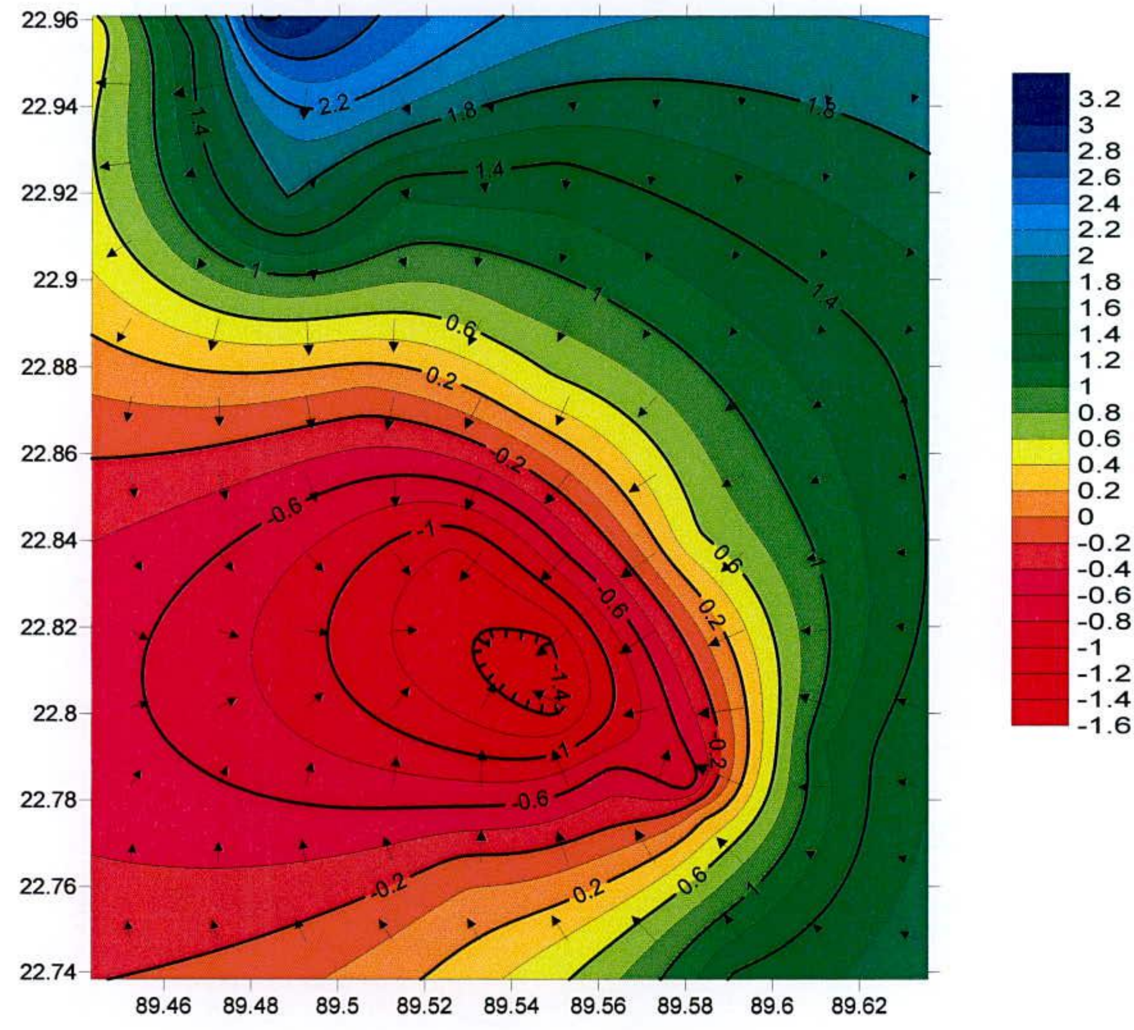


Figure 5-32 Iso-piezometric thematic map of SWL for September, 2004 for the Deep Aquifer

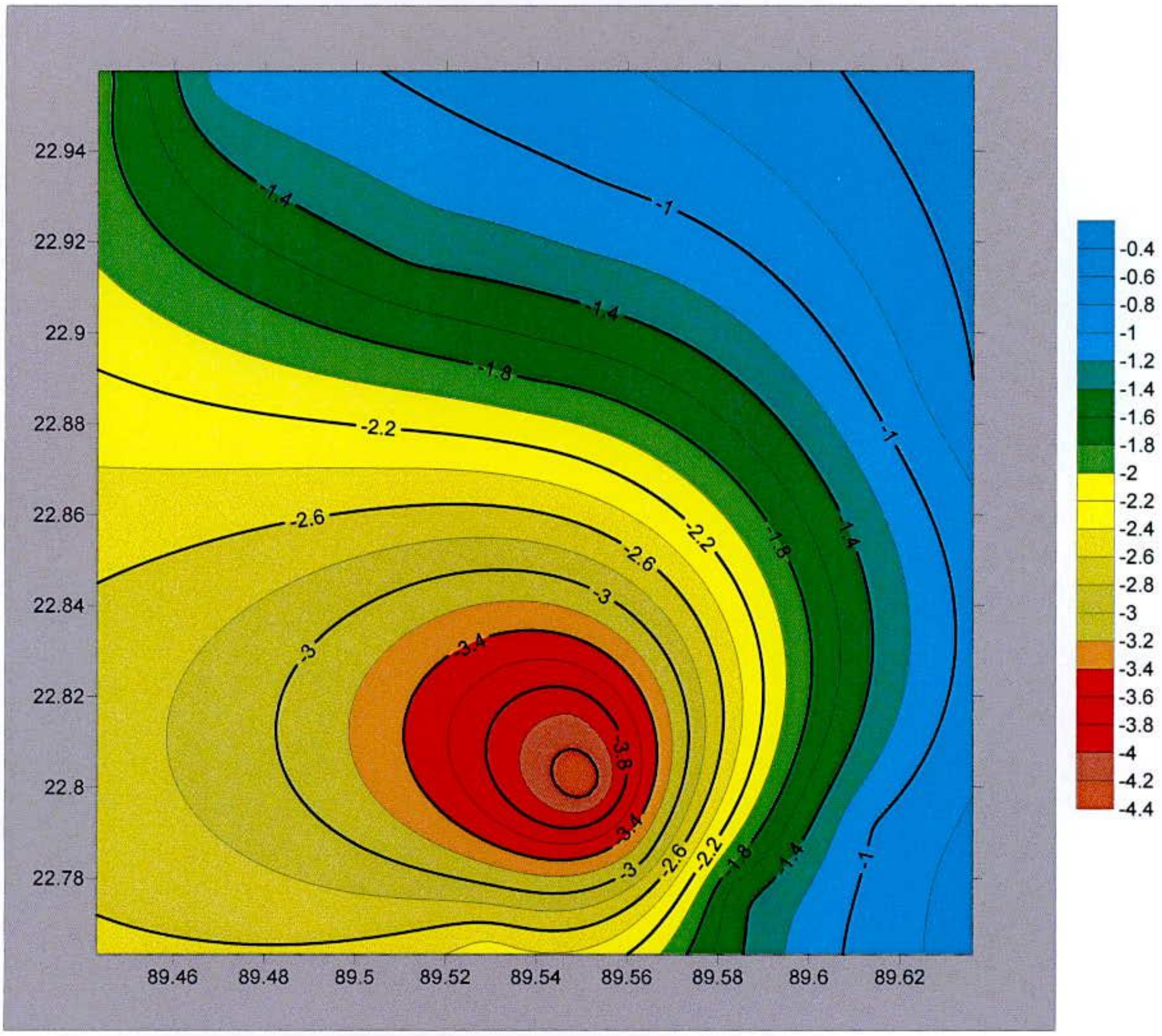


Figure 5-33 Iso-Piezometric thematic Map of SWL for April, 2009 for the Deep Aquifer

Iso-piezometric Lines and Flow Lines High Static Water at Level Condition

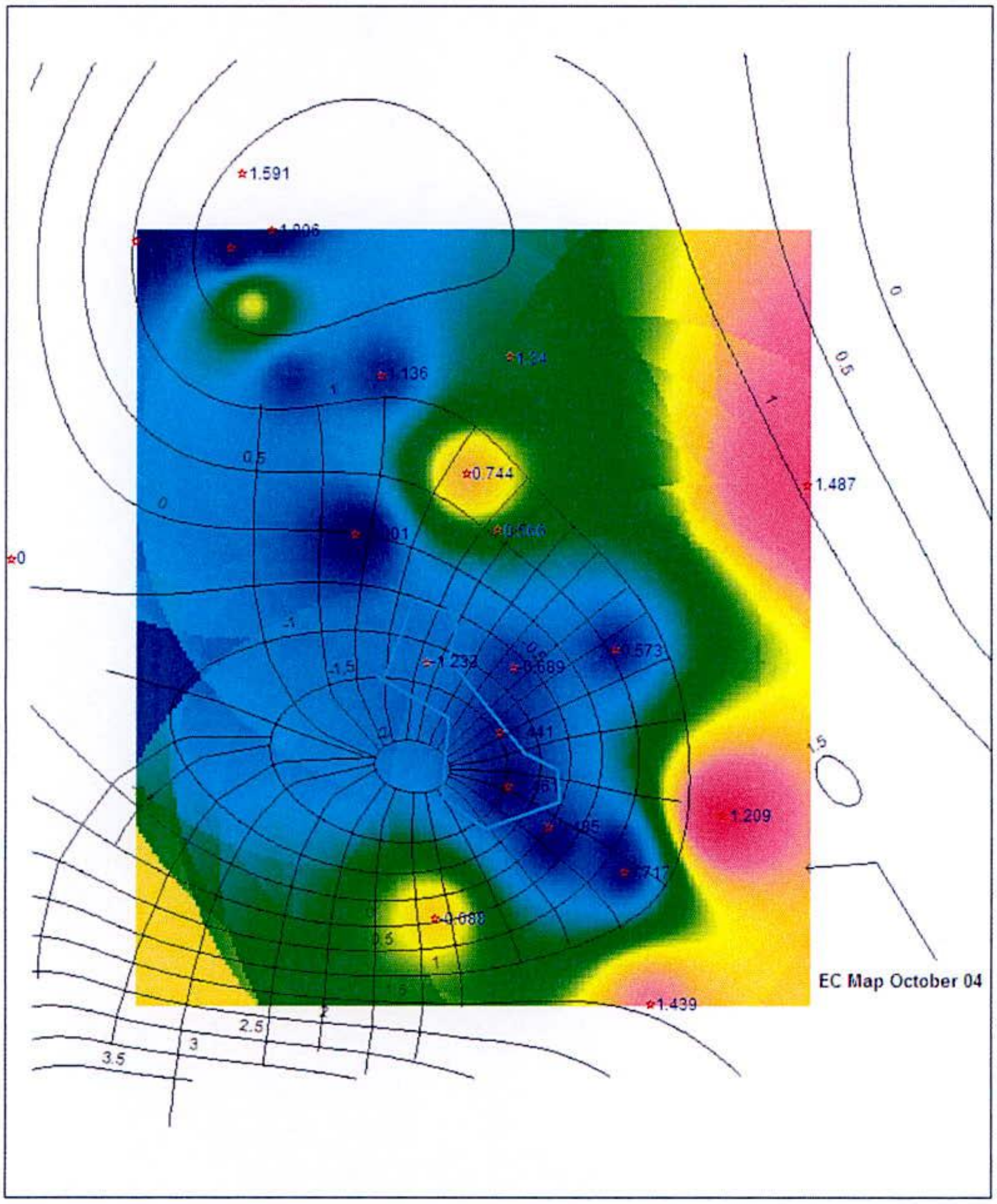


Figure 5-34 Iso-piezometric Flow Lines for October, 2004

A comparison of water levels of a specified time in different years (e.g., April 2003, April 2004, March 2005 and in April – May, 2009) are shown in Figure 5-41 to describe the pre-monsoon situations in the study area. This exercise will illustrate the trend of changes of the static water level with time. The Figure explains the situation of the study area. It appears that in every year the lowest static water level is declining significantly. The static water level in April 2003, April 2004, March 2005 and April –

May, 2009 is -2.5m, -3.2m, -3.4m and -4.40m respectively. It is seen that. However, all the hydrographs (in Appendix-2) show that the highest static water levels in the month of October recover to the original positions, i.e., the whole aquifer becomes fully recharged.

5.4 Tidal Effect

The tidal fluctuation of the Bhairab River has been measured for continuous 30 days in 2003 and presented in Figure 5-35. The effect of tidal fluctuation on deep and shallow aquifer has also investigated in 2003 in Figure 5-36 shows the tidal effect in Pd_09 and Ps_09.

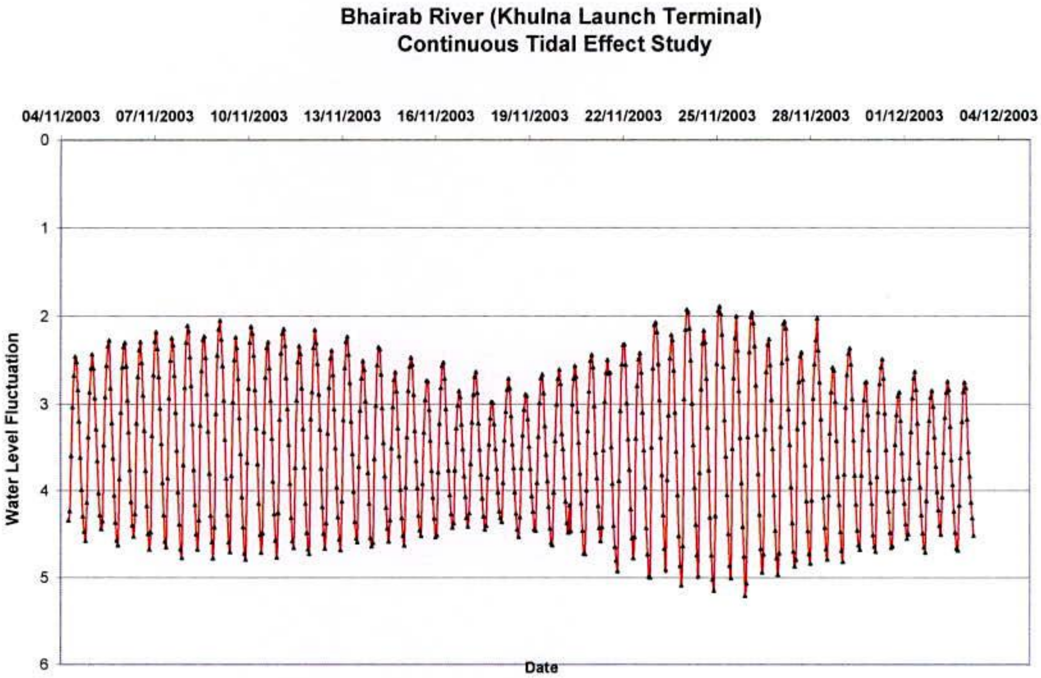


Figure 5-35 Tidal Fluctuation Observed for Bhairab River in 2003.

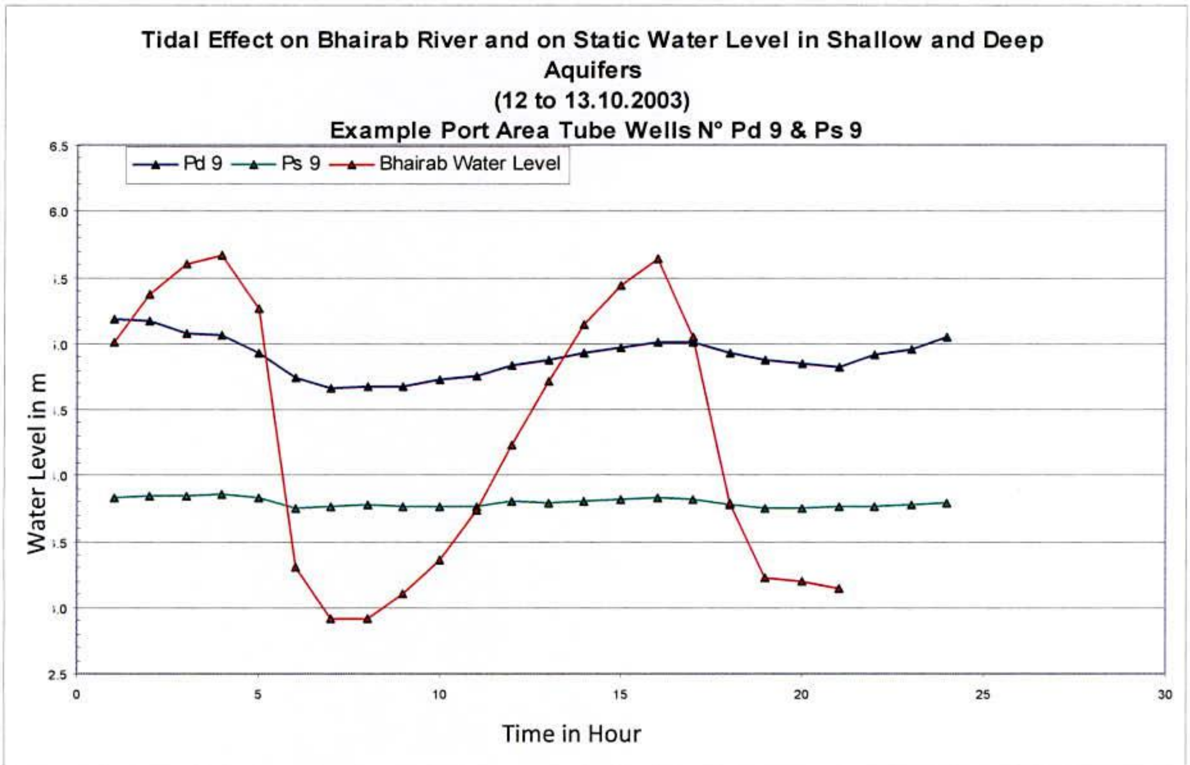


Figure 5-36 Tidal Effect on Ground water Table observed for Bhairab River in 2003.

5.5 Estimation of the Aquifer Parameters

From water quality point of view, as upper shallow aquifer is highly contaminated by the arsenic (Figure 5-39) and also water from the shallow aquifer has not considered for public water supply due to high concentration of arsenic and saline, these two aquifers has discarded for farther investigation for the aquifer parameters during the project period. Only the deep aquifer has been considered to estimate its transmissivity and storativity. The pumping tests have been conducted in the months of March-April, 2005 due to the past experience of observing the lowest static water level in that period. This can be mention here that, in order to get critical values from the hydrodynamic tests, general practice, the period of lowest static water level for the aquifer is chosen as the suitable period as. The locations of hydrodynamic test are presented in Table 5.3 and the location map of the test wells are shown in Figure 5-43. Using 10 numbers pumping test data these hydrodynamic parameters are estimated. The field data of 11 aquifer tests on 10 locations of the KCC area has been presented in Appendix-4.

The drawdown versus time (on semi-log paper) graphs for each pumping tests are shown in Appendix-4. A representative graph on well KCC J at Arambag area of KCC is shown in Figure 5-42 & 5-43, incorporating tidal corrections into its raw pumping test data. Transmissivity has been calculated from these graphs. Storativity has been calculated from those locations where observation wells are available. The results of the pumping tests are shown in Table 5.5. The table shows that transmissivity values are in between 1.36×10^{-4} m^2/s to 7.12×10^{-2} m^2/s while the storativity values are in between 9.54×10^{-4} to 4.73×10^{-3}. The corresponding averages of transmissivity and storativity are 3.4×10^{-2} m^2/s (2940 m^2/day) and 2.2×10^{-3} respectively.

Table 5-1 Locations of the Wells for Pumping Tests in Deep Aquifers

Serial No.	Longitude (Degree)	Latitude (Degree)	Name of the Well
1	89.544	22.849	Khalishpur KCC Office (New)
2	89.568	22.793	Tootpara Well Field
3	89.546	22.856	Khalishpur TV Centre
4	89.526	22.838	Rayer Mahal
5	89.568	22.808	PTI Mor
6	89.572	22.809	KCC Rest House
7	89.553	22.821	KDA Staff Quarter
8	89.548	22.802	Arambagh - 2
9	89.535	22.849	Mujgunni well field 4
10	89.520	22.908	Cable Factory

5.6 Estimation of Usable Recharge

Usable recharge in the study area can be estimated, using contour map of groundwater potentials around a group of wells having concentrated abstractions in the area concerned (i.e., forming closed contours). The corresponding flow lines are being created on to the closed contours to form curvilinear square flownets to use steady-state formula, in order to obtain the recharge into or discharge from the closed contour area. Since the fluctuation of water table is a slow process, a single representative flownet is enough to estimate recharge of a particular period. The usable recharge has been calculated assuming prevailing flow is under a steady-state condition. Under the steady-state situation the volume of abstraction (discharge) should be equal to the volume of recharge. In fact, there is a lowering of water level in the average order of 2.13m (Table 5.2), occurring in a total hydrological year, which is equivalent to 5.84 mm lowering of water level per day. Assuming the process as steady-state condition, volume of shortfall water responsible for declining of water level 5.84 mm per day has been neglected. The shortfall amount that has been neglected can be estimated as follows:

Recharge volume neglected in the above steady-state estimation

= area in the closed contour (from Figure 5-40 and 5-41) x storativity×5.84mm

$= 60\times10^6\,m^2 \times 0.0022\times 0.00584 m/day \approx 770\ m^3/day$

It is worthy to note that both the recharge and abstraction volumes should demonstrate their seasonal fluctuations. As such two extreme situations, one in the month of April and the other in the month of October, are taken to estimate daily recharges into the area concerned. These daily recharges for two specified months should be equivalent to the corresponding daily abstractions for drinking, industrial and other uses in the area.

High static water level situation (October), usable recharge, $R = mhT/n$

$= 27\times0.5m\times2940m^2/day$

$\approx 39{,}700\ m^3/day$

Low static water level situation (April), useable recharge, $R = mhT/n$

$= 24\times0.5m \times2940m^2/day$

$\approx 35{,}300\ m^3/day$

It shows that in the month of April the area has less recharge volume per day compared to the recharge in the month of October. It may be due to the fact that in October the surrounding area's water levels are higher than in the month of April , which drives more flow in the month of October towards the concentric area for an almost same amount of abstractions in both months. It is to be noted that if the recharge volume 770 m^3/day is added to the above recharge volumes of October and April, it stands to provide the total amount of recharges occurring. So, the recharge volumes per day become:

Recharge volume in October = 39,700 + 770 = 40,470 m^3/day

Recharge volume in April = 35,300 + 770 = 36,070 m^3/day

To assess the present groundwater abstraction rate in 2004, the following information has been collected from LGED (2005)

KCC production for drinking supply = 25,000 m3/day

Industrial, institutional and others supply = 15,000 m3/day

So the total abstraction in and around KCC is 40,000 m^3/day. This abstraction volume is an average value, which should have some variation on the basis of seasons. However, these types of seasonal abstraction data are not available. The recharge volume in the month of April is substantially less than the average abstraction rate 40,000 m^3/day. This observation gives an important indication why the lowest static water levels are lowering more than its previous years' lowest static water levels as mentioned in Section 5.5.

5.7 Comparison with Previous Study

Modelling was done by LGED (2005) to simulate the impact of future groundwater development scenarios on groundwater levels. For this three different scenarios have been taken that are based on different projections on future growth in water demand due to increased population, industrial and commercial uses and other activities foreseen in the region. The scenarios that have been projected in 2030 are:

Scenario 1: As per the Khulna Development Authority (KDA) Master Plan

1	Population	KCC	2.59 millions	
		District	5.49 millions	
2	Abstraction	KCC	98,000 m^3/day	Present abstraction is 25,000 m^3/day; considering a 4% growth rate of KCC abstraction; considering 120 l/c/d for the population who gets KCC piped connection and for the remaining unconnected population considered as 50 l/c/d
		Industrial	40,000 m^3/day	Present demand is 15,000 m^3/day and

			considering growth rate 3% for existing industries and 1 new industry for each year that requires 110 m^3/day.

***Result on scenario 1*:** Static water level will be -28m (MSL) in 2030

Scenario 2: As per trend of last 10 years

1 Population	KCC	1.24 millions	
	District	3.72 millions	
2 Abstraction	KCC	59,000 m^3/day	Present abstraction is 25,000m^3/day; considering the similar growth rate of KCC abstraction with last 10 years. considering 110 l/c/d for the population who gets KCC piped connection and for the remaining unconnected population considered as 50 l/c/d.
	Industrial	30,000 m^3/day	Present demand is 15,000 m^3/day and considering growth rate 2% for existing industries and one new industry for each two year that requires 110 m^3/day

Result on scenario 2: Static water level will be -12 m (MSL) in 2030

Scenario 3: Total abstraction should remain the same, but at the end of 2005 only the newly constructed 10 wells would be connected to the system; i.e., total abstraction would be 40,000 + 6,000 = 46,000 m^3/day

Result on scenario 3: Static water level will be -4.5 m (MSL) in 2030

For different scenarios (1, 2 and 3), recharges have been calculated using iso-piezometric maps (shown in Figure 5-46) generated from modelling exercise. A closed contour water level adjacent to the City centre has been taken for the estimation. The flow lines have been drawn on to the iso-piezometric maps in order to obtain the number of flow tubes. The numbers of flow tubes obtained are 23, 28 and 28 for respective scenarios. So the usable recharges for different scenarios under lowest static water level conditions are:

Usable recharge in Scenario 1: $R_1 = \frac{mTh}{n}$

$= 23 \times 2940m2/day \times 2m$

$\approx 135{,}200$ m3/day

Usable recharge in Scenario 2: $R_2 = 28 \times 2940 m^2/day \times 1m$

$\approx 82{,}300\ m^3/day$

Usable recharge in Scenario 3: $R_3 = 28 \times 2940 m^2/day \times 0.5m$

$\approx 42{,}600\ m^3/day$

It can be seen that the amount of recharge is below than the amount of water abstracted. As such water levels are receding rapidly to undesirable levels and giving rise to higher salinity. It can be said that the situation of Scenario 3 of the modelling exercise has been recommended by the LGED (2005) to be implemented in the KCC area, otherwise consequences will be bad. Water level in dry season (March 2005) near KCC has been calculated -3.4m (MSL). If 10 additional tube wells are added to the withdrawal, then the simulated groundwater level in 2030 would be near to -4.5m (MSL). This is due to the addition of 10 production wells (6,000 m^3/day) in KCC network in 2005.

Electrical Conductivity in March & October 2004,

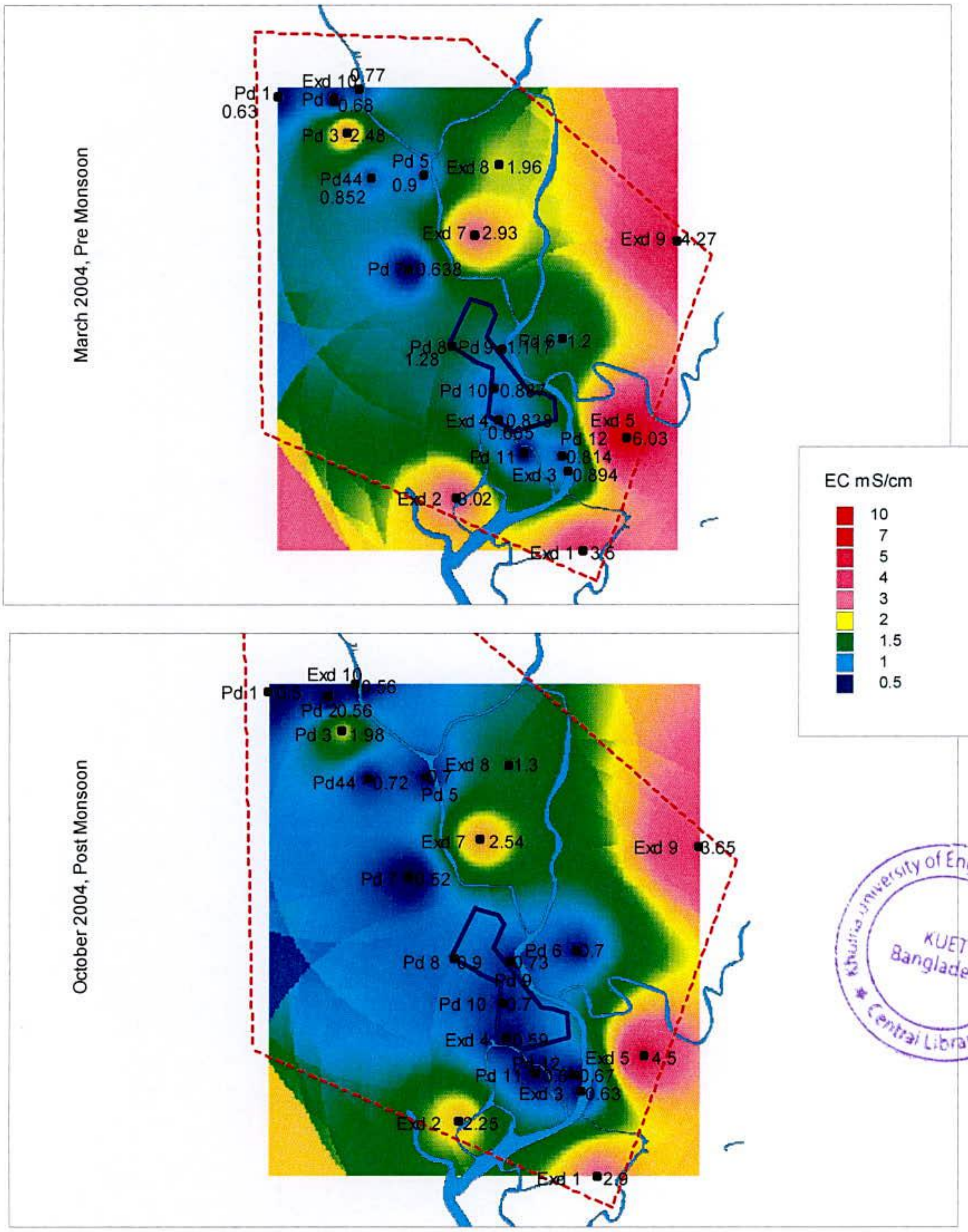


Figure 5-37 Comparison of EC in Pre-monsoon and Post-monsoon Situation, Deep Aquifer

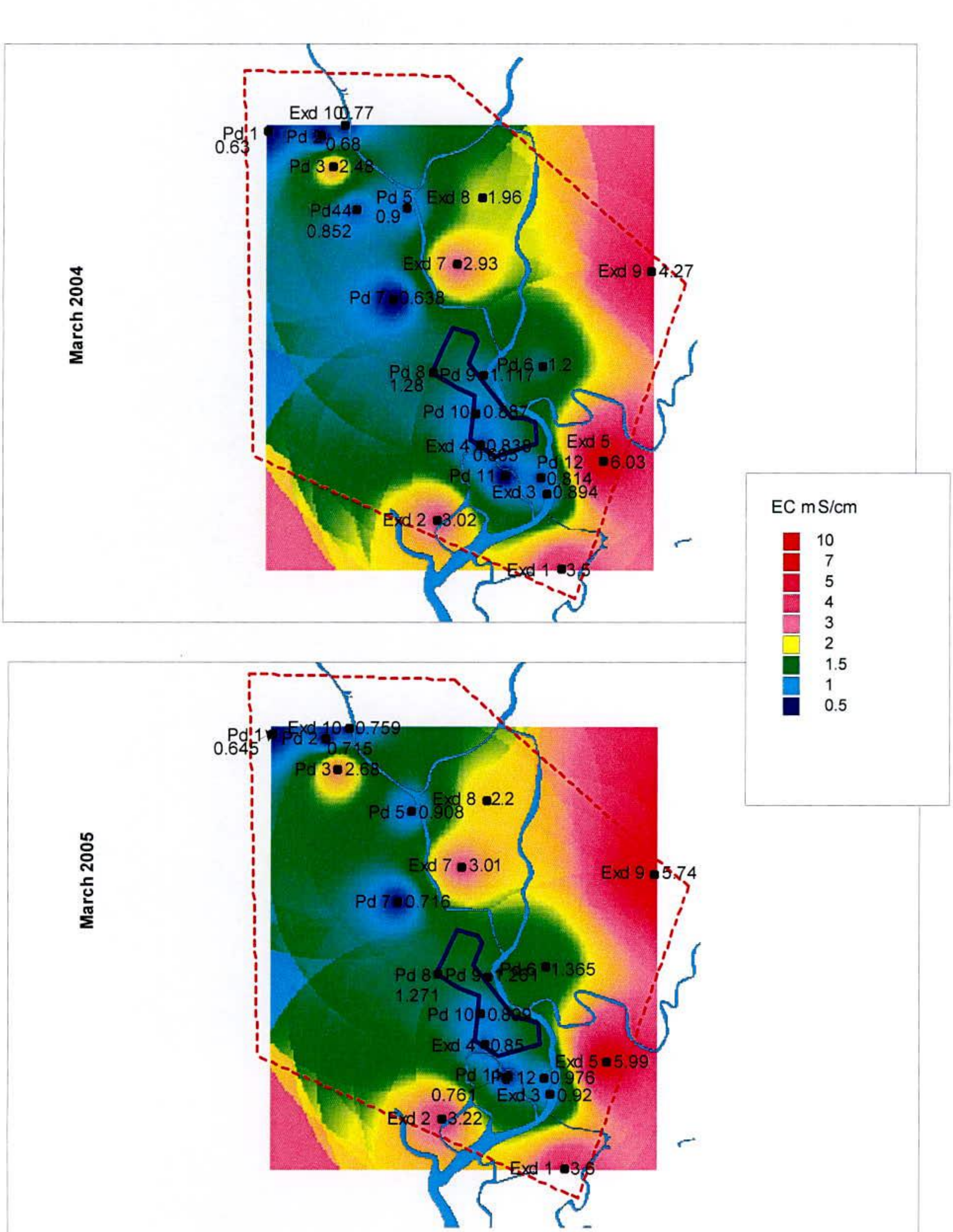


Figure 5-38 Comparison of EC in March 2004 and March 2005, Deep Aquifer

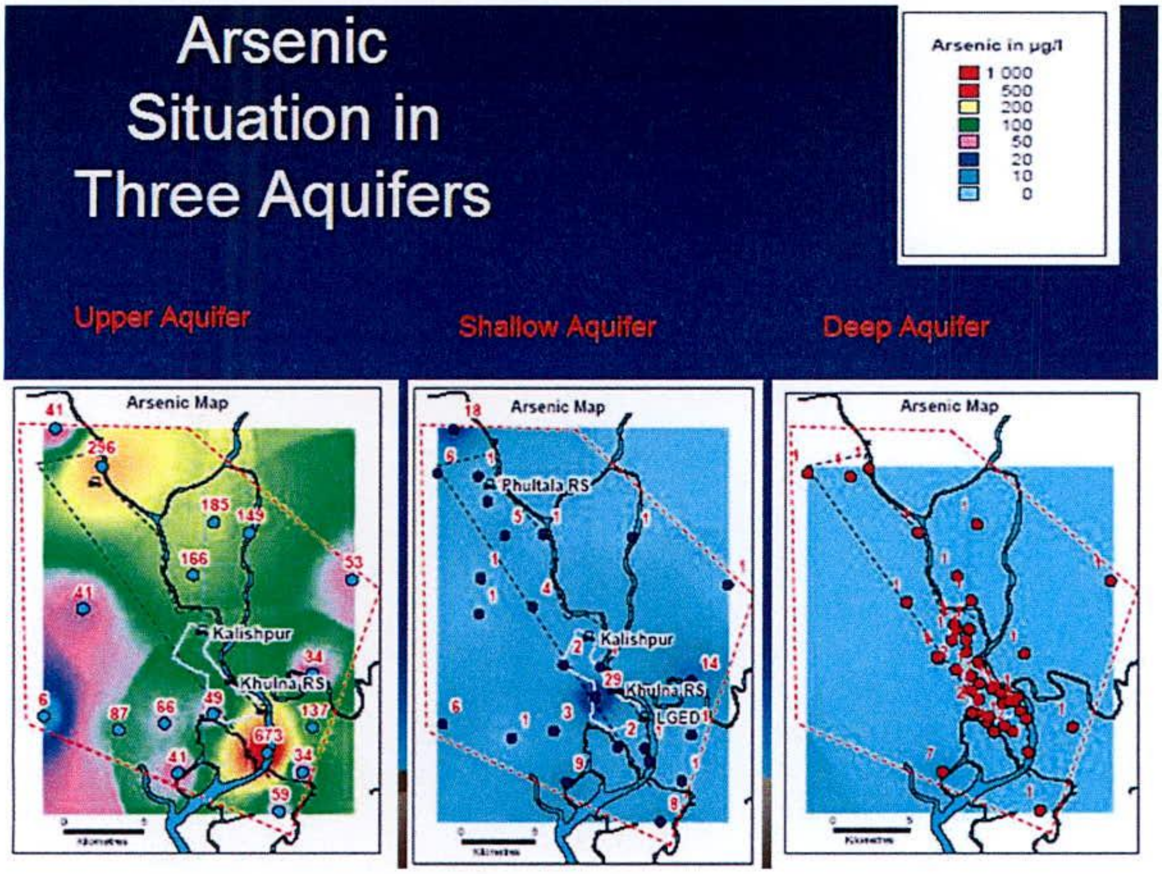


Figure 5-39 Arsenic Status in Three Aquifers

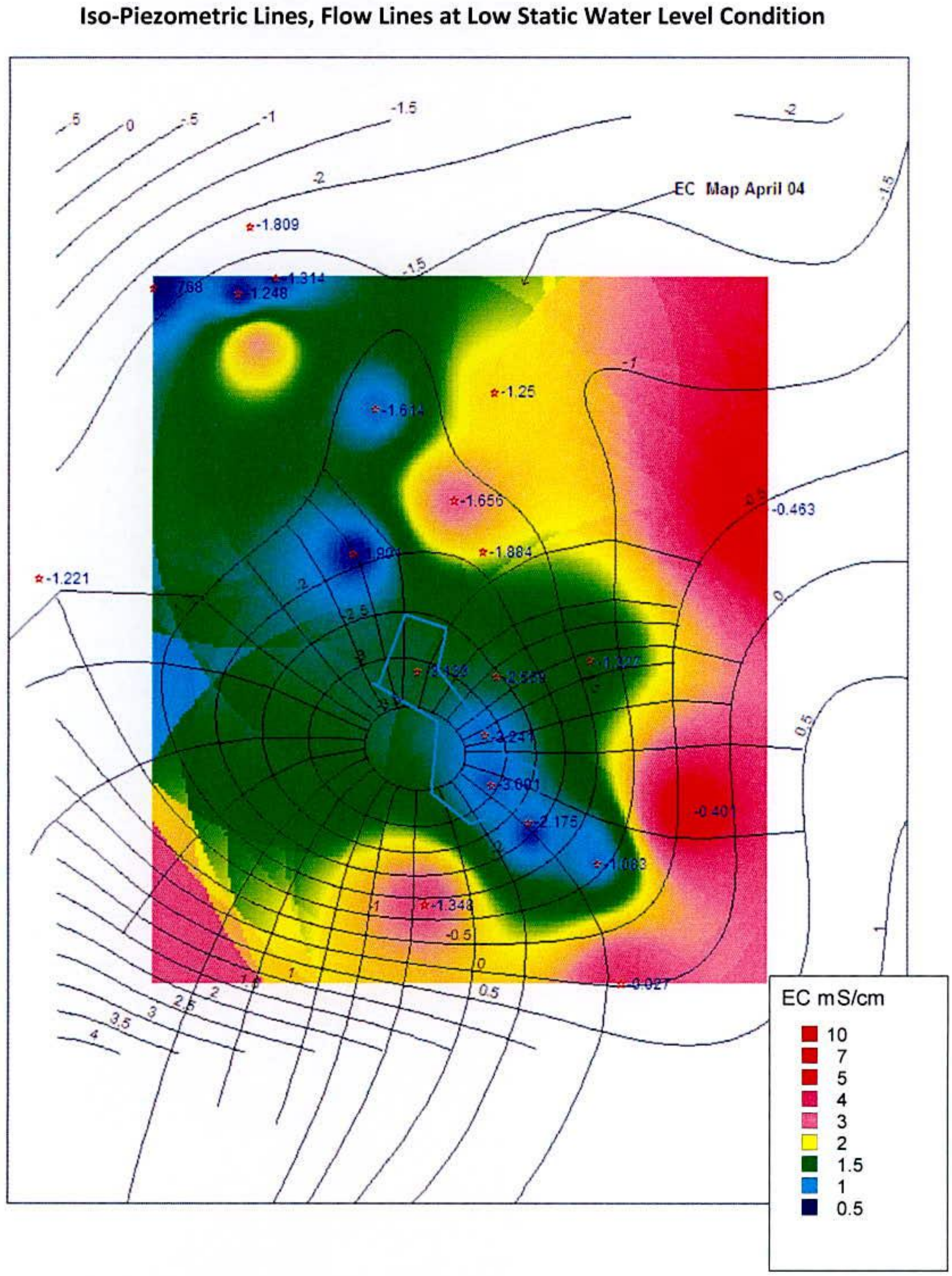


Figure 5-40 Iso-Piezometric Lines, Flow Lines and EC Curve of April, 2004

Iso-Piezometric Lines, Flow Lines at High Static Water Level Condition

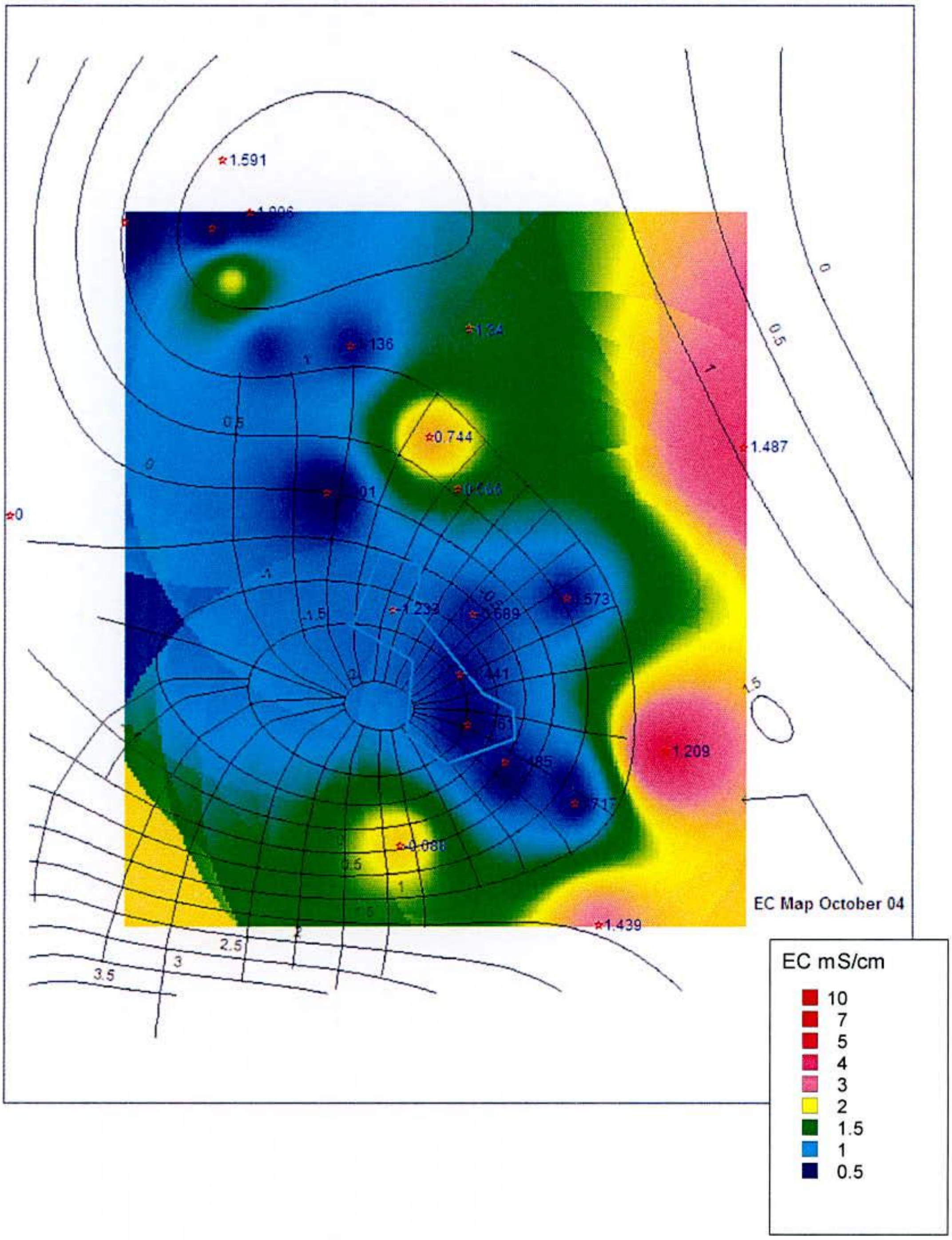


Figure 5-41 Iso-Piezometric Lines, Flow Lines and EC Curve of October, 2004

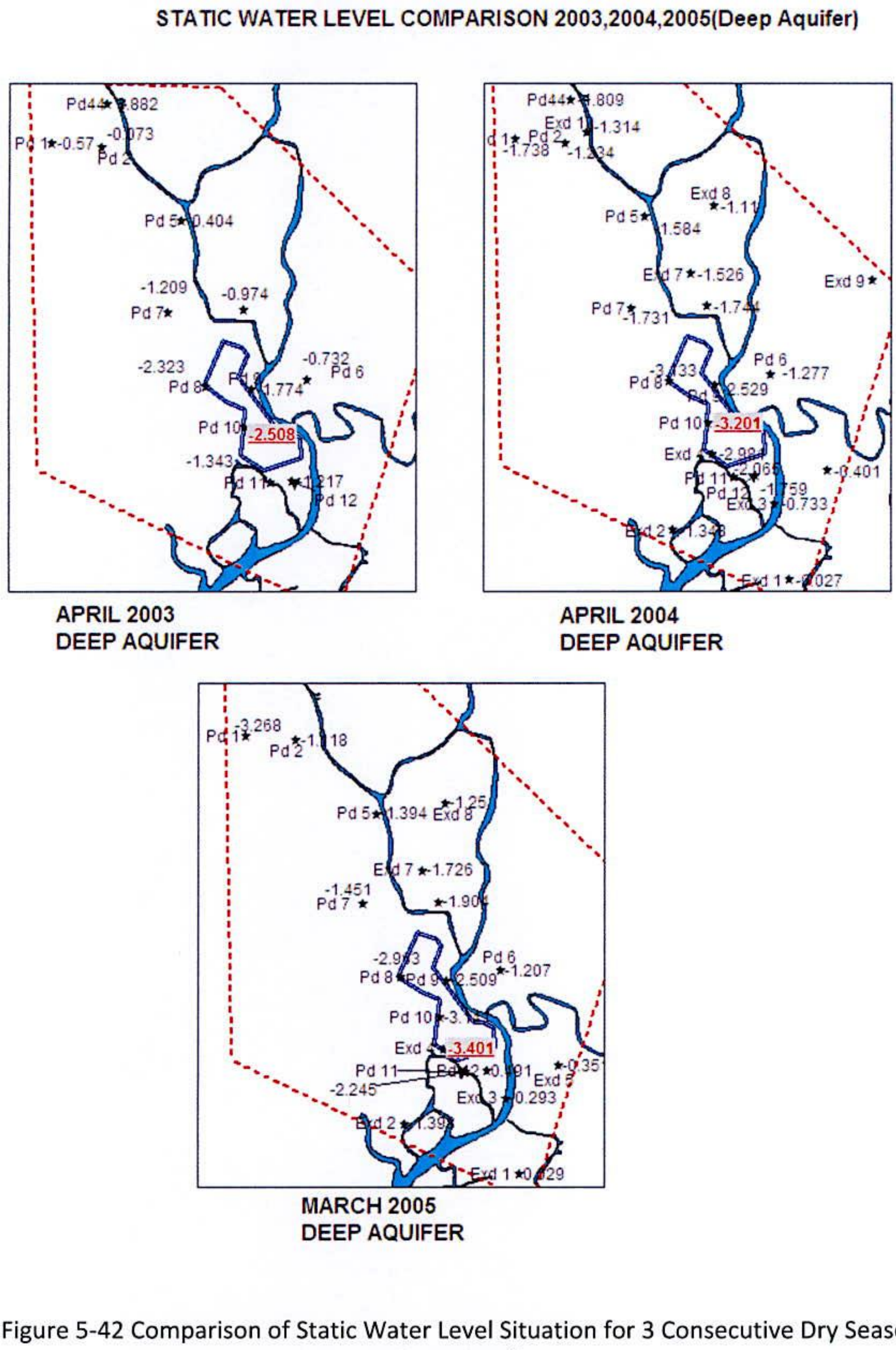


Figure 5-42 Comparison of Static Water Level Situation for 3 Consecutive Dry Seasons, Deep Aquifer

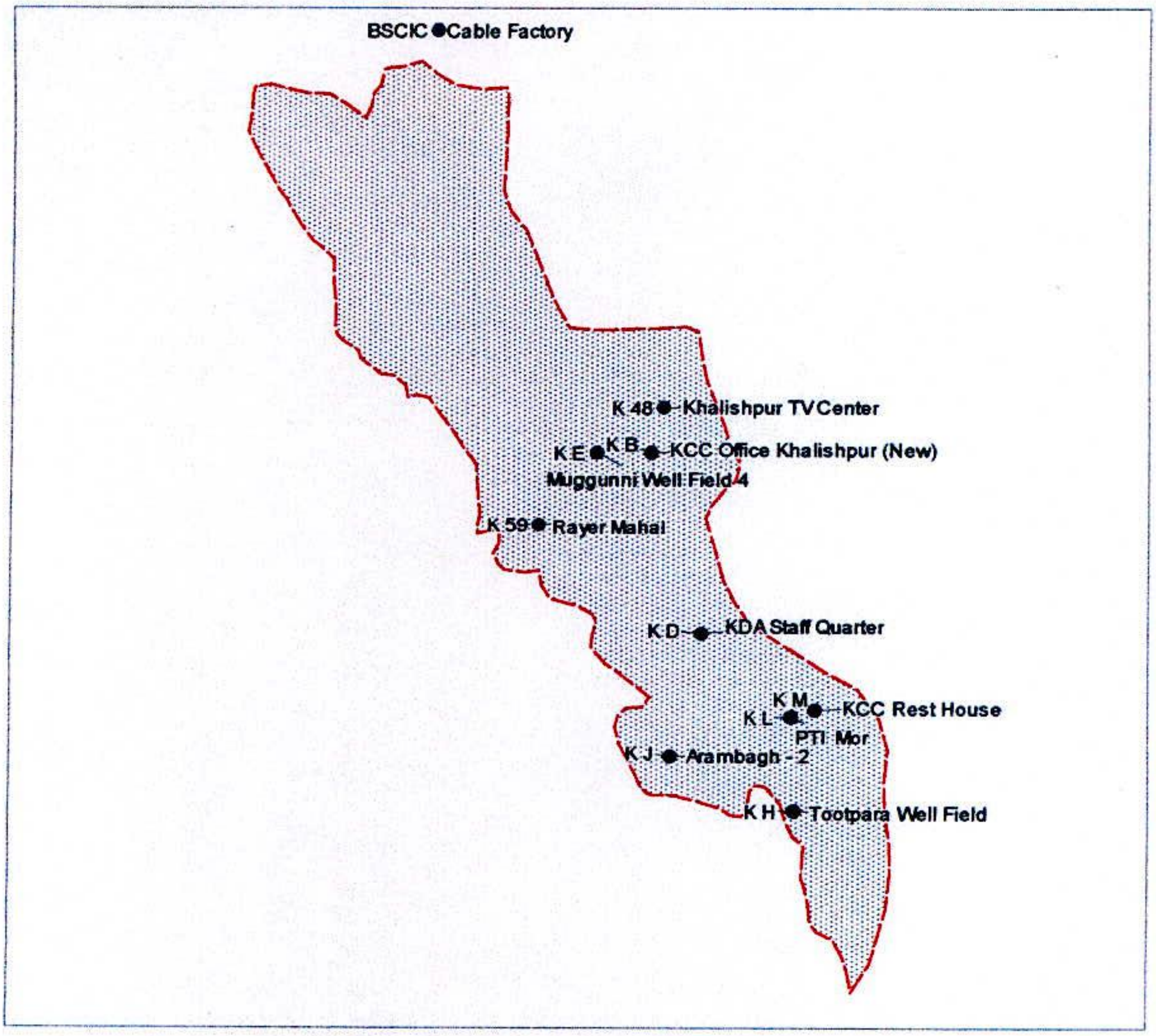


Figure 5-43 Location of wells for Pumping Tests

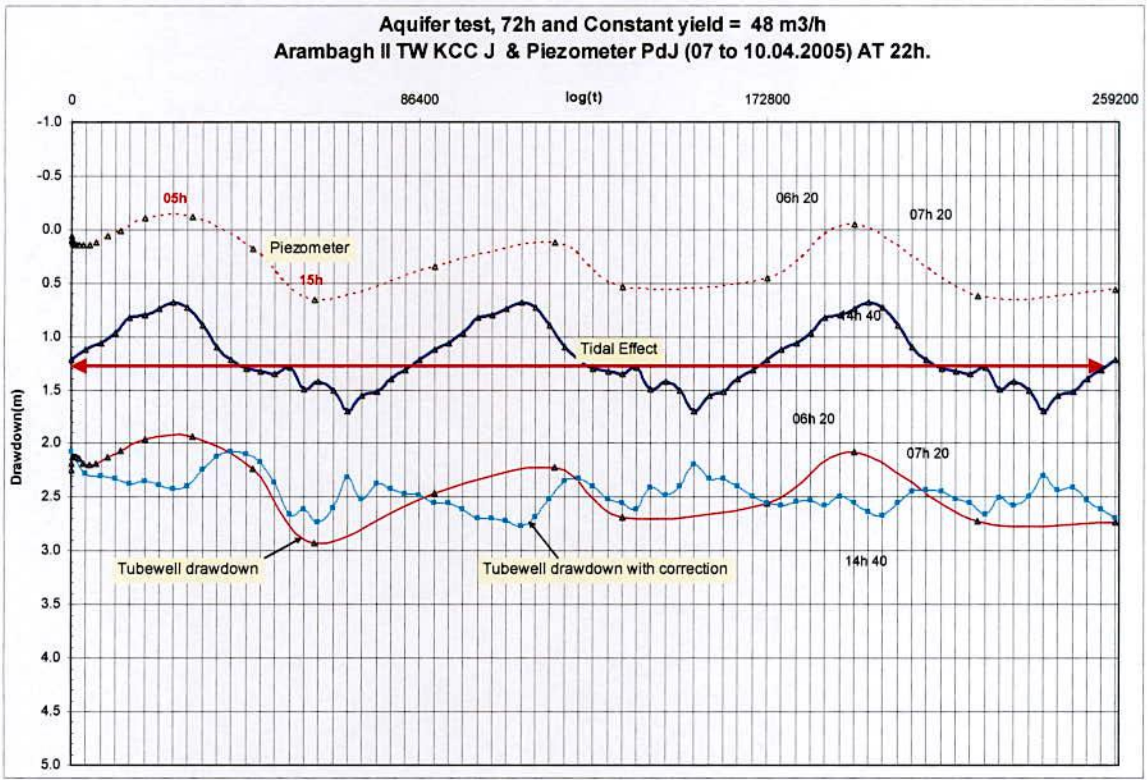


Figure 5-44 (a) Normal Graph of the Sample Pumping Tests on the Well KCC - J (Arambag)

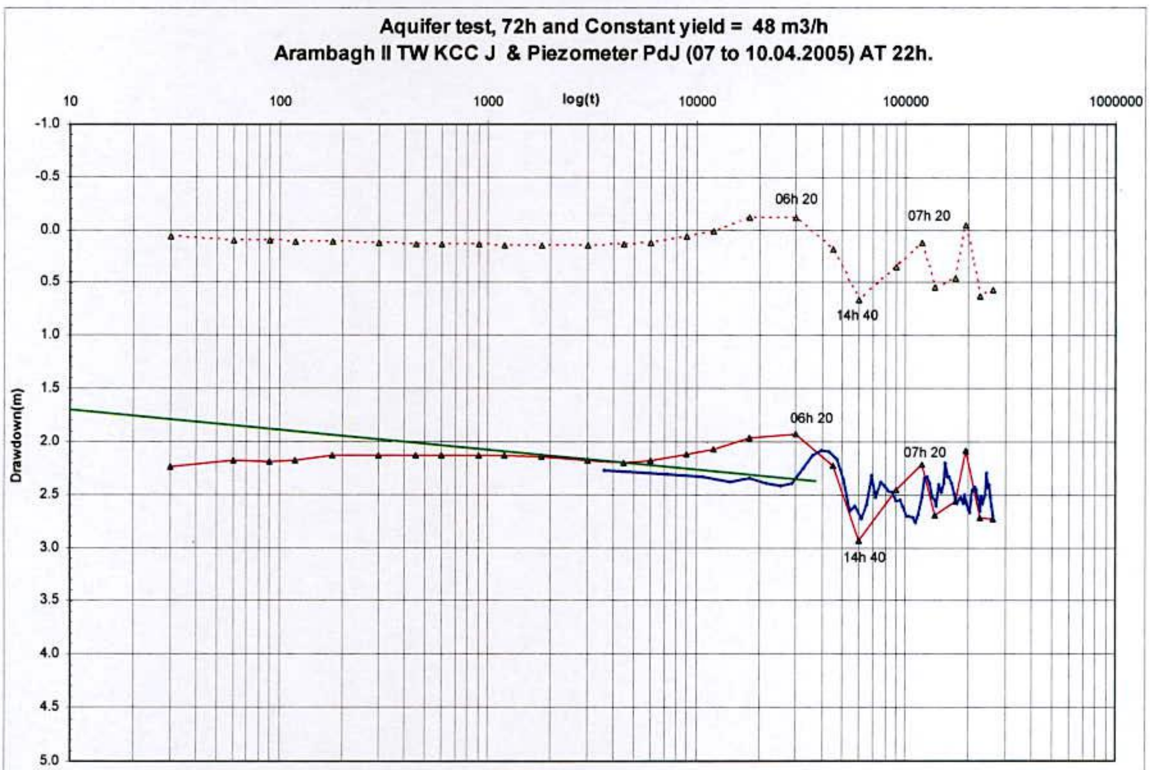


Figure 5-45 (b) Semi-Log Graph of the Sample Pumping Tests on the Well KCC - J (Arambag)

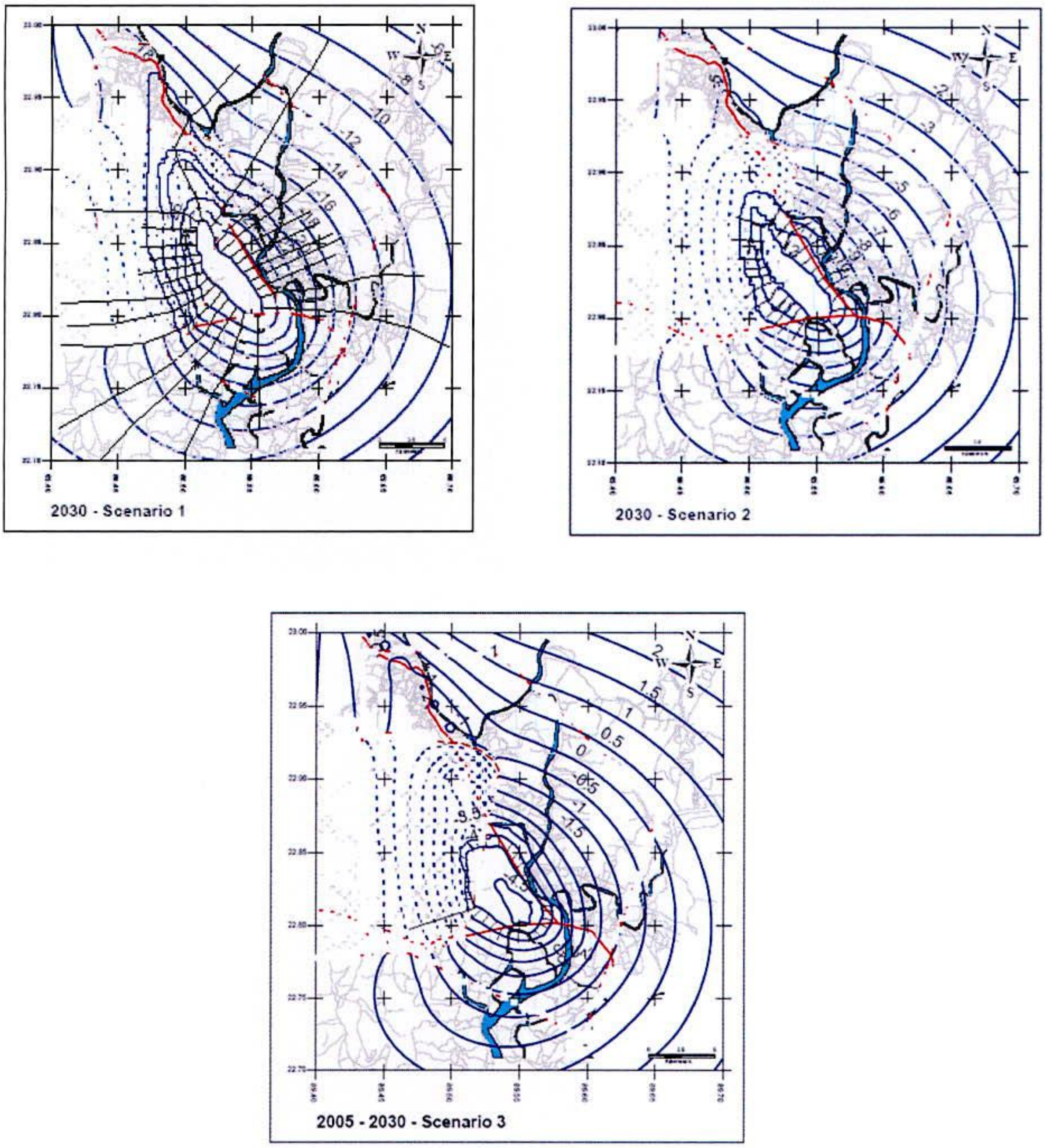


Figure 5-46 BRGM-ANTEA-ARMCO Modelling Scenario 1, 2 and 3

Table 5-2 Fluctuating Water Height Calculation for Deep Aquifer

Well No.	Longitude (Degree)	Latitude (Degree)	High static water level from well top (m)	Low static water level from well top (m)	Fluctuating water height (m)	Area under Thiessen Polygon (sq. km)	Col6*Col7	Average fluctuating water height in the study area (m)
1	2	3	4	5	6	7	8	9
Pd_1	89.4433	22.9575	1.50	4.30	2.80	22.55	63.14	**2.13**
Pd _2	89.4703	22.9556	1.00	3.95	2.95	16.62	49.03	
Pd _3	89.5472	22.8747	4.00	6.45	2.45	19.71	48.29	
Pd _44	89.4736	22.9769	2.80	6.20	3.40	8.60	29.24	
Pd _5	89.5136	22.9192	2.25	5.00	2.75	27.86	76.62	
Pd _6	89.5811	22.8403	2.80	4.70	1.90	31.47	59.79	
Pd _7	89.5064	22.8736	2.30	4.20	1.90	63.35	120.37	
Pd _8	89.5269	22.8369	3.40	5.30	1.90	41.57	78.98	
Pd _9	89.5517	22.8353	5.13	7.00	1.87	8.84	16.53	
Pd _10	89.5481	22.8167	4.30	6.10	1.80	8.56	15.41	
Pd _11	89.5619	22.7894	2.96	4.65	1.69	7.19	12.15	
Pd _12	89.5733	22.79	2.70	4.60	1.90	8.14	15.47	
Exd_ 1	89.5911	22.7383	2.14	3.61	1.47	12.91	18.93	
Exd _2	89.5291	22.7633	2.52	3.78	1.26	33.74	42.51	
Exd _3	89.5836	22.7763	2.47	4.27	1.80	13.13	23.63	
Exd _4	89.5502	22.8011	4.26	5.89	1.63	10.25	16.71	
Exd _5	89.6119	22.7927	2.88	4.49	1.61	19.18	30.88	
Exd _7	89.5383	22.8908	3.18	5.58	2.40	11.74	28.18	
Exd _8	89.5508	22.9244	1.16	3.75	2.59	42.57	110.26	
Exd _9	89.6358	22.8875	0.95	2.90	1.95	33.24	64.82	
Exd _10	89.4822	22.9608	1.65	4.77	3.12	20.83	64.99	
Total					**45.14**	**462.05**	**985.91**	

Table 5-3 Results of Transmissivity and Storativity

Name and Number of wells	Transmissivity	Storativity	Remarks
1.Cable Factory Duration:24 h Constant yield: $17m^3/h$ Distance to obs. well: Start at: 22h Month: 22-23 April 05	$1.36x\ 10^{-4}\ m^2/s$	-	Piezometric well information is missing
2.i) Arambag Duration:72 h Constant yield: $48m^3/h$ Distance to obs. well: Start at: 22h Month: 07-10 April 05	$8.13x10^{-3}\ m^2/s$	$9.75x10^{-4}$	Tidal correction is considered to measure T and S
ii) Arambag Duration:12 h Constant yield: $118m^3/h$ Distance to obs. well: 13.7m Start at: 6-30h Month: 05 April 05	$1.2x10^{-2}\ m^2/s$	$1.20x10^{-3}$	
3.ii) Rayer Mahal Duration:72 h Constant yield: $38m^3/h$ Distance to obs. well: 167m Start at: 6-30h Month: 30-02 Mar-April 05	$4.83x10^{-2}\ m^2/s$	-	Fluctuation of EC indicates that the Deep & Shallow are hydraulically connected due to lack of isolation of aquifer during construction
4. KCC Rest House Duration:10 h Constant yield: $72m^3/h$ Distance to obs. well: 18.4m Start at: 22h Month: 18-19 March 05	$7.12x10^{-2}\ m^2/s$	$4.73x10^{-3}$	

Name and Number of wells	Transmissivity	Storativity	Remarks
5. PTI More Duration:10 h Constant yield: 122m^3/h Distance to obs. well: 9.1m Start at: 22h40m Month: 19-20 March 05	4.13x10^{-2} m^2/s	3.37x10^{-3}	
6. Tootpara well field Duration:10 h Constant yield: 111m^3/h Distance to obs. well: 13.3m Start at: 22h45m Month: 20-21 March 05	3.76x10^{-2} m^2/s	1.3x10^{-3}	
7. KDA new market Duration:10 h Constant yield: 116m^3/h Distance to obs. well: Start at: 22h20m Month: 21-22 March 05	2.82x10^{-2} m^2/s	-	Co-ordinate of observation well is missing
8. Mujguni Duration:12 h Constant yield: 125m^3/h Distance to obs. well: Start at: 7h Month: 24-25 March 05	4.34x10^{-4} m^2/s	-	Co-ordinate of observation well is missing
9. TV centre Duration:10 h Constant yield: 20 m^3/h Distance to obs. well: 3m Start at: 08h23m Month: 28 March 05	5.08x10^{-4} m^2/s	1.9110^{-3}	
10. Khalishpur KCC Branch office Duration:10 h Constant yield: 100m3/h Distance to obs. well: 9.8m Start at: 10h20m Month: 27 March 05	1.2710^{-2} m^2/s	2.97x10^{-3}	Due to high tidal effect while starting the test, the t_0 cannot be calculated, it is assumed 10 sec

CHAPTER – SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

a) Based upon the geological, hydro-geological and water quality analysis, it is found that, Khulna City has three aquifers the first one is Upper Shallow Aquifer which is within 50 m from the surface and spread over most of the study area; the second one is Shallow Aquifer which is more significant and extended up to 150 m from the surface the thickness of this aquifer is about 60 – 80 m; and finally the third one is the Deep Aquifer which starts from 200m even somewhere from 300 m. The thickness of deep aquifer is about 100 m in South-East area and 20 m at North-West area of the City. From south to north and from east to west, the deep aquifer's thickness is decreasing.

b) The direction of flow in three aquifer has been clearly identified as follows:

   i. Upper Shallow Aquifer: The recharge of the upper shallow aquifer starts through surface water during the pre-monsoon period and it occurs through the low permeability of the first layers during monsoon. The directions of water flow are towards the depression area from the recharge area. The depression is created in those areas where more water is being abstracted from this aquifer.

   ii. Shallow Aquifer: The recharge of the shallow aquifer is being occurred from the North-Western area, near Phultala, where no upper shallow aquifer has been identified, and in the south eastern area, where the upper shallow and the shallow aquifer joints together. The direction of water flow towards the depression area (City area) through the north, north-east and from the south-east area where recharge is being occurred.

   iii. Deep Aquifer: There is a big depression in the abstraction area (central and southern area of the city where all the wells of KWASA are being located) of the city. Recharge comes through the northern and north-west narrow channel towards the city. In the southern part of the city presumably deep aquifer linked with the shallow aquifer due to massive thickness of the deep aquifer. There might have flow towards north from the south due to the presence of a massive depression in the City centre.

c) The water quality of the upper shallow aquifer is totally unacceptable due to high concentration of arsenic and saline. The water of the shallow aquifers is also high concentration of saline, in most of the area, but arsenic contamination is within the range. So that, under the study, both aquifers didn't not considered as suitable sources of water for the Khulna city. The water of the deep aquifer, fortunately for the city area, has good quality water in respect to all water quality parameters. In the south and south-east area of the city the presence of high concentration of saline has been detected.

d) The findings of the special ground water monitoring session conducted in 2009 is that, there is no indication of increase of average temperature neither in KWASA production well nor in MSP monitoring well since 2005. But at PTW_58 (Shonadanga_2) the difference of temperature observed is 5^0C which is the maximum single point increase among all wells. It is also observed that the average temperature of KWASA production wells in the central part of the city is much higher than those in other part of the study area. There is no increase in the average EC value for the MSP monitoring wells since 2005. The average SWL in the project area in 2005 and 2009 is - 1.42 m from mean sea level (MSL) and - 2.06 m from MSL respectively, thus the net average annual declination of SWL becomes 0.63 m. Nevertheless the net single point maximum declination of SWL recorded is 1.00 m (Exd_04). This mass of declination of the SWL has affected neither EC nor Temperature though the average temperature is higher than the normal range. This can be noted that, there is no indication of any increase of the EC value at the well observing highest augmented temperature (PTW_58, Shonadange_2). This observation may refer as the cause of high temperature is gas leakage instead of mining water hypothesis. However "deep drilling" in the City centre can answer this question.

e) In order to estimate fluctuating water heights from the monitoring wells of deep, shallow and upper aquifers in the study area, weighted average method has been applied using Thiessen polygons. It has been observed that all the three aquifers have fluctuating water levels and the average water heights of deep, shallow and upper aquifers are 2.13 m, 2.26 m and 1.97 m, respectively.

f) Transmissivity and storativity have been evaluated in the study area from the collected pumping test data. It has been observed that the transmissivity values vary between 1.3×10^{-3} m^2/sec to 7.1×10^{-2} m^2/sec and the storage coefficient varies from 9.7×10^{-4} to 4.7×10^{-3}. The corresponding averages of transmissivity and storativity are 3.4×10^{-2} m^2/s (2940 m^2/day) and 2.2×10^{-3} respectively.

g) For highest static water level, in the month of October, the usable recharge has been obtained 40,470 m^3/day which is slightly more than the average abstraction rating (40,000 m^3/day). While for lowest static water level, in the month of April, usable recharge has been obtained 36,070 m^3/day. This amount is much less than the KCC average abstraction. As such, under existing rate of abstraction the lowest static water levels are further declining every year. Comparing with the modelling study done by LGED in 2005, it can be concluded that concerning the declination of static water level their prediction (LGED) becomes true but on the quality aspect it is not like their prediction. The observation in 2009, total average declination of SWL in last four (4) years (0.63 m) didn't affect the total average salinity of the deep aquifer, which indicates the potentiality of the aquifer for farther room of some possible additional abstraction. It is true that the complete dependency on ground water for Khulna city may not sustainable for long with the present aquifer system, alternative solution should be find out in near future.

6.2 Recommendations

a) It is recommended for very deep drilling (up to 600 m) to answer some unresolved issues like i) causes of high temperature in the central part of the city and ii) presence of farther deep aquifer and potentially of such aquifer to meet the demand of the city. Asian Development Bank (ADB) is going to finance for the very deep drilling because it might be the cheapest possible solution among the alternatives of the city water supply.

b) In order to prepare long term planning for farther additional abstraction total abstractions through KWASA production wells, private hand tube wells and private industrial production wells is needed to be quantified.

c) Khulna Water Supply and Sewerage Authority (KWASA) should continue regular groundwater monitoring activity for SWL and the water quality due to the vulnerable situation for the presence of saline font very near to the city.

d) Since the fresh water resource of the deep aquifer is limited and cannot sustain substantial increase in abstraction rates, an additional volume of drinking water may be derived from blending of water of different sources. The electrical conductivity (EC) of the deep aquifer near and south of the city centre is very low. There might have few solutions to mitigate the water crisis of the city; i) if this water is mixed with a small quantity of moderately mineralised water from the shallow aquifer, the overall quality will be acceptable and the overall water production can be increased. It is reminded that, since the water from the shallow aquifer is arsenic free it might be acceptable for municipal water supply if the iron could be removed by simple aeration then filtration. ii) preserve and restrict the abstraction from deep aquifer water for the period of low salinity in the surface water (7-8 months' time in the Bhairab- Rupsha River) and supply the ground water for the period of high saline in the surface water (February – June). iii) under WASA Act1996, KWASA can impose control over the industrial abstraction from the deep aquifer. In order to restrict abstraction from deep aquifer, for industrial use, KWASA can provide them alternate water through the surface water sources throughout the year.

Appendix – 1

MSP and KWASA Monitoring Network with GPS Coordinates

1. MSP Monitoring Network Location with GPS Coordinates

Sl. No.	Inv. Bh	Village	Upazilla	Coordinates (Degree)		Depth (m)	Z GL (msl) (m).	Parapet Height (m).	Z HP (msl) (m).
				X	Y				
1	Pd_ 1	Benapukur Uttar Para	Phultala	89.4433	22.9575	317	2.114	0.418	2.532
2	Pd_ 2	Damodar Purba Para	Phultala	89.4703	22.9556	305	2.367	0.335	2.702
3	Pd _3	Senhati	Dighalia	89.5472	22.8747	284	4.291	0.275	4.566
4	Pd_ 5	Gilatala Dakkhin Para	Phultala	89.5136	22.9192	305	3.218	0.168	3.386
5	Pd _6	Shirgati	Rupsha	89.5811	22.8403	305	3.106	0.267	3.373
6	Pd _7	Aarong Ghata	Dighalia	89.5064	22.8736	311	2.025	0.274	2.299
7	Pd _8	Rayer Mahal	Khulna	89.5269	22.8369	305	1.822	0.345	2.167
8	Pd _9	Khulna Port Area	Khulna	89.5517	22.8353	305	4.045	0.396	4.441
9	Pd _10	Sonadanga	Khulna	89.5481	22.8167	305	2.509	0.35	2.859
10	Pd _11	Horintana Mosque	Batiaghata	89.5619	22.7894	295	2.033	0.442	2.475
11	Pd _12	Loban Chara Bazar	Khulna	89.5733	22.7900	287	3.052	-0.566	2.486
12	Pd_44	Phultala M M College	Phultala	89.4736	22.9769	341	4.135	0.256	4.391
13	Exd_ 1	Nijgram Madrasa	Batiaghata	89.5911	22.7383	305	3.284	0.295	3.579
14	Exd _2	Jalma chakrakhali	Khulna	89.5291	22.7633	317	2.155	0.277	2.432
15	Exd _3	Lobanchara, Asia Sea Food	Khulna sadar	89.5836	22.7763	311	2.817	0.37	3.187
16	Exd _4	Sher -e-Bangla Road	Rupsha	89.5502	22.8011	299	2.537	0.262	2.799
17	Exd _5	Elaipur	Batiaghata	89.6119	22.7927	305	3.793	0.296	4.089
18	Eds _66	Kayabazar	Batiaghata	89.4928	22.7908	317	2.401	0.315	2.716
19	Exd _7	Dighalia Thana Complex	Dighalia	89.5383	22.8908	305	3.546	0.378	3.924
20	Exd _8	lakhohati School	Dighalia	89.5508	22.9244	305	2.178	0.322	2.500
21	Exd _9	Sreepur	Terokhada	89.6358	22.8875	293	2.251	0.186	2.437
22	Exd _10	Damodar	Phultala	89.4822	22.9608	305	4.456	0.327	4.783

2. KWASA Monitoring Network Location with GPS Coordinates

Serial No.	Name of Well	Location	Well No.	Longitude	Latitude
1	Gollamari	Nirala Kacha Bazar / Habalibag	10	89.5572	22.8033
2	Baikali R & H	Divisional Stadium	18	89.5419	22.845
3	Khulna Cirkit House (Mini)	Khulna Cirkit House	22	89.5733	22.8136
4	Ferry Ghat 3	KCC Central Garage Caompound	23	89.5608	22.8172
5	Pallimongol	Pallimongol / Hazi Bari	25	89.5536	22.8161
6	Khalishpur office	KCC Branch Office	26	89.5439	22.85
7	Khalishpur 5	Khalishpur ward N° 10 Nayabati	30	89.5381	22.8564
8	Nirala Well Field 1	UPHCP, Nirala R / A	34	89.5581	22.7956
9	Nirala Well Field 3	UPHCP, Nirala R / A	36	89.5578	22.7958
10	Tutpara Well Field 3	Tutpara	38	89.5678	22.8
11	Muggunni Well Field 1	Comissioner Office W# 9	39	89.5347	22.8475
12	Muggunni Well Field 3	Comissioner Office W# 9	41	89.535	22.8472
13	Sonadanga 1	South Herald School , Sonadanga R/A	43	89.5489	22.8178
14	Arambag	Gollamari Bus Stand More	44	89.5458	22.8033
15	Tarer Pukur	United Nessions Shishu Park	45	89.5639	22.8103
16	Khalishpur Road N° 12	Khalishpur Road N° 12	47	89.5489	22.8525
17	Khalishpur TV Center	Khalishpur TV center	48	89.5464	22.8564
18	Rupsha DPHE 3	DPHE Office	49	89.5783	22.8031
19	Nur Nagar 1 (Mini)	Opposite Side of Fire Service	50	89.5494	22.8303
20	Zila School	Khulna Zila School	51	89.5769	22.8119
21	Islamabad Community Center	Gobor Chaka	52	89.5553	22.8117
22	Purba Bania Khamar	Khademul Islam Madrasha	53	89.5661	22.8003
23	Ferry Ghat 2 (Mini)	KCC Central Garage Caompound	54	89.5611	22.8175
24	Khalishpur Durber Shangha (Mini)	Nayabati Goal Park Chattar, Road # 24	55	89.5367	22.8594

Serial No.	Name of Well	Location	Well No.	Longitude	Latitude
25	Hazi Malek College	Molla Para	57	89.5794	22.7389
26	Sonadanga 2	Sonadanga Bowbazar	58	89.5472	22.8167
27	Rayir Mohol	Rayir Mohol Gov. Primary School	59	89.5258	22.8381
28	Shekhpara Bazar 3	Shekhpara Main Road, Fish Market	60	89.5581	22.8161
29	Bagmara 2	Bagmara 3rd Lane	61	89.5586	22.7994
30	250 beds Hospital	Comissioner Office W # 16	62	89.5378	22.83
31	Boyra Com. Center	Boykali CSD Road	63	89.5444	22.8414
32	Collegiete Girls School	Darogapara	64	89.5772	22.8019
33	Darul Ulum Madrasa	Musalman Para Main road	65	89.5619	22.805
34	Nur Nagar Fire Service	Fire Service Compound	67	89.5497	22.83
35	Rupsha Koshai Khana	Rupsha Stand Road	69	89.5822	22.7981
36	Sonadanga KCC park	Sonadanga R/A	70	89.5478	22.8206
37	DC Office Compound	DC Office Compound	72	89.5714	22.8144
38	Tutpara Taltala 2	Tutpara Hospital	73	89.5758	22.7997
39	Sir Iqbal Road Shisu Park	UPHCP, Diabatic Hospital	74	89.5664	22.8144
40	Khalishpur Jhil Pukur	Khalishpur Jhil Pukur	75	89.5417	22.8542
41	Boyra Main Road Modina Masjid	Boyra Main Road	76	89.5475	22.8261
42	Mistri Para	Mistri Para	77	89.5475	22.8019
43	Nirala KCC Park	Nirala R/A	78	89.5561	22.7972
44	Babu Khan Road	Babu Khan Road	79	89.5703	22.8072
45	Boshupara Koborkhana	Boshupara Graveyeard	82	89.5522	22.8106
46	Mujgunni Labutala	Goalkhali Bus Stand	83	89.5353	22.8522
47	Mujgunni Bottala	Behind Navy Colony	84	89.5353	22.8492
48	KCC Office Khalishpur (New)	KCC Branch Office	85	89.5442	22.8494
49	Purba Baniakhamar Madrasha	Near Baitunnajat Mosque	86	89.5661	22.7978
50	KDA Approach Road	KDA Approach Road	87	89.5528	22.8211

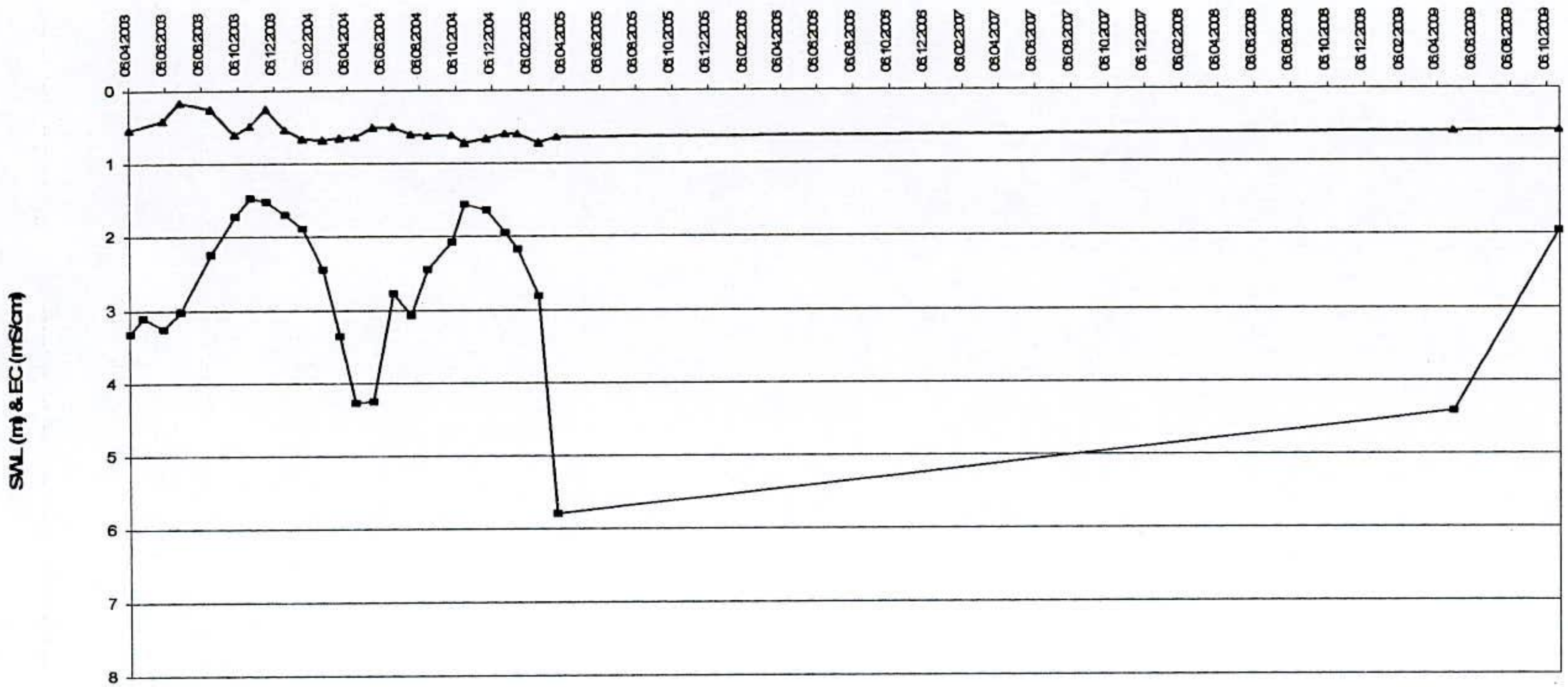
Serial No.	Name of Well	Location	Well No.	Longitude	Latitude
51	Sher-E-Bangla Road KCC Park	Near KCC Park	88	89.5589	22.8100
52	Tootpara Primari School	West Tootpara High School	89	89.5683	22.7933
53	PTI More	PTI More	90	89.5678	22.8081
54	KCC Rest House	Hazi Mohshin Road	91	89.5717	22.8092
55	Shekhpara Bazar Mosque	Astana Jame Mosque	92	89.5589	22.8156
56	Arambagh - 2 (Old Gallamari Rd)	Behind Lions School	93	89.5478	22.8019

Appendix - 2

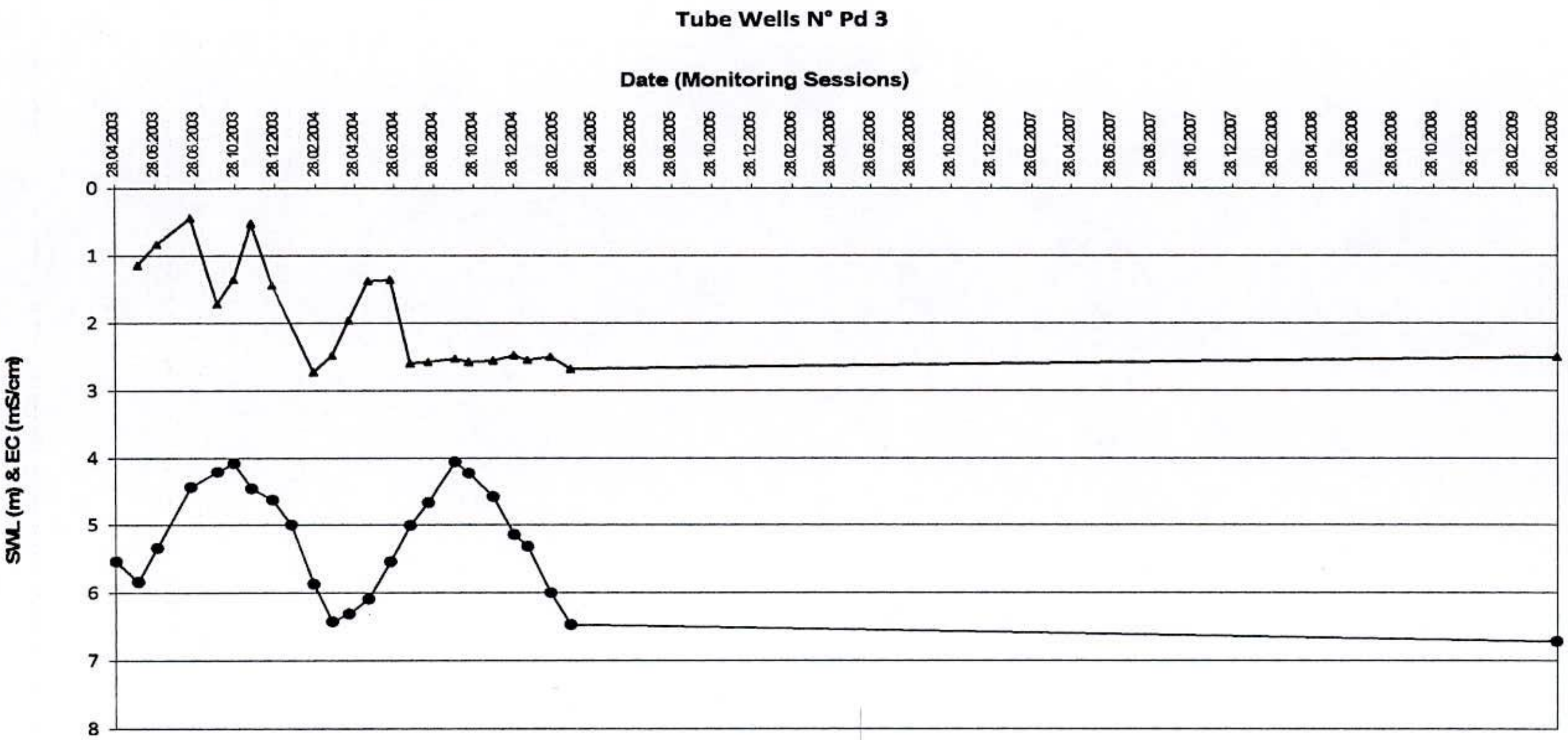
Groundwater Hydrographs with Water Quality of Deep Aquifer

Tube Wells N° Pd 1

Date (Monitoring Sessions)

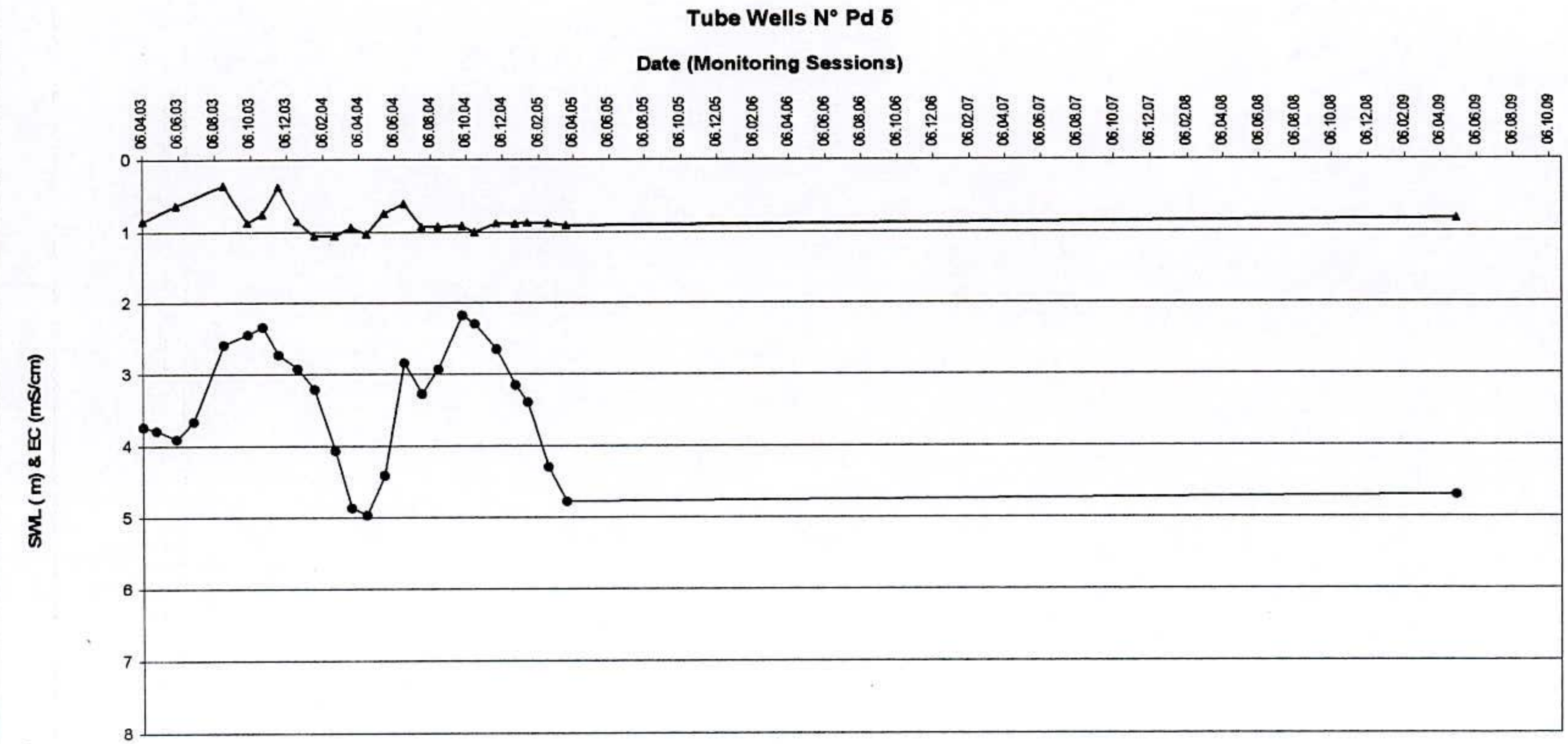


	06.04. 2003	28.04. 2003	01.06. 2003	30.06. 2003	17.07. 2003	20.08. 2003	30.09. 2003	25.10. 2003	21.11. 2003	23.12. 2003	21.01. 2004	24.02. 2004	23.03. 2004	18.04. 2004	18.05. 2004	21.06. 2004	21.07. 2004	18.08. 2004	28.09. 2004	19.10. 2004	25.11. 2004	27.12. 2004	17.01. 2005	21.02. 2005	24.03. 2005	02.05. 2009	25.10. 2009
SWL	3.321	3.102	3.252	3.020		2.250	1.725	1.474	1.520	1.700	1.890	2.450	3.354	4.270	4.250	2.780	3.070	2.450	2.080	1.560	1.640	1.954	2.180	2.820	5.800	4.420	1.96
EC mS/cm	0.536		0.407	0.169		0.256	0.606	0.478	0.259	0.529	0.667	0.683	0.655	0.646	0.506	0.498	0.605	0.621	0.614	0.726	0.667	0.596	0.600	0.726	0.645	0.593	0.581

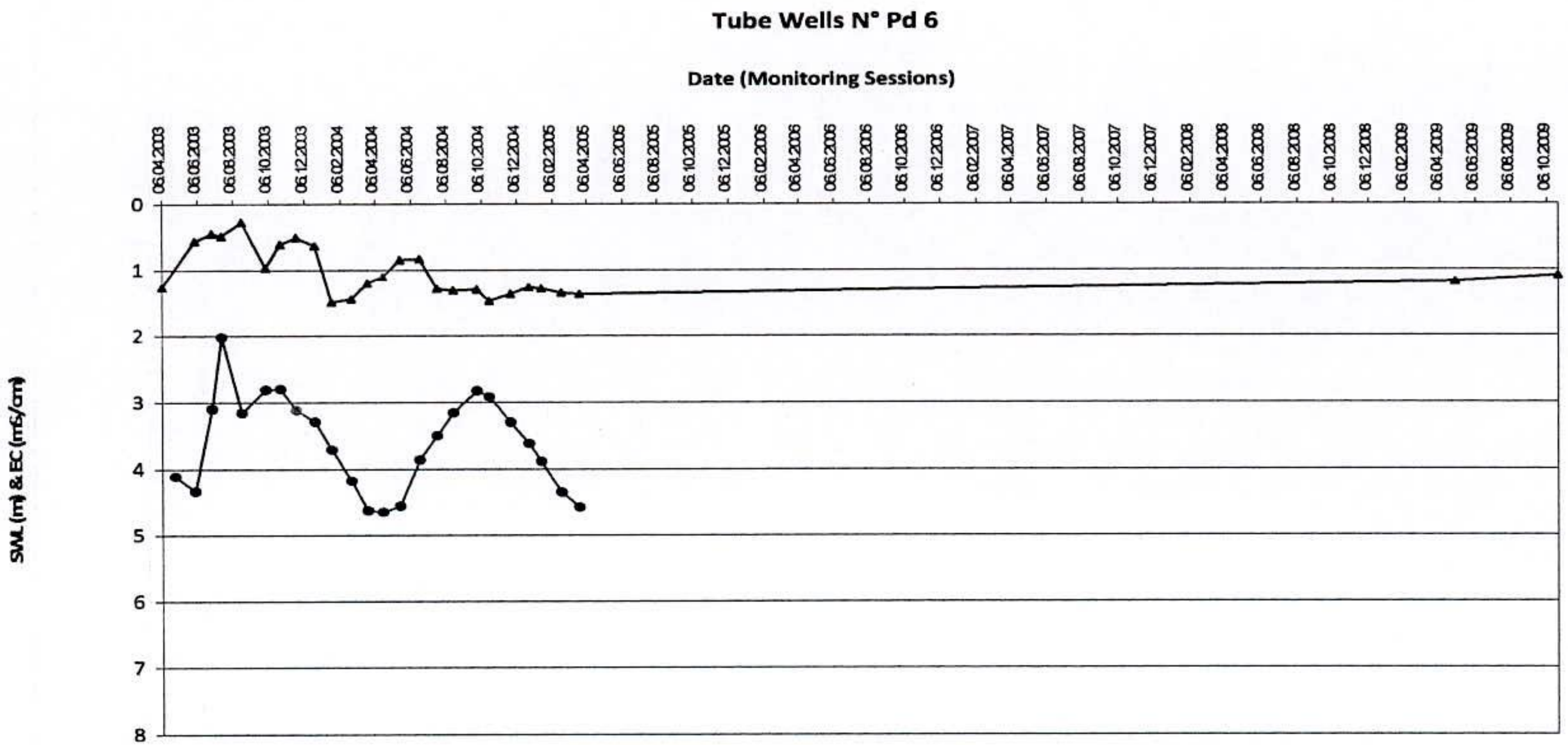


	28.04.2003	01.06.2003	30.06.2003	17.07.2003	20.08.2003	30.09.2003	25.10.2003	21.11.2003	23.12.2003	21.01.2004	24.02.2004	23.03.2004
SWL	5.54	5.84	5.34		4.44	4.21	4.08	4.460	4.630	5.000	5.870	6.426
EC mS/cm		1.140	0.825		0.442	1.721	1.353	0.520	1.443		2.730	2.480

	18.04.2004	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009
SWL	6.310	6.094	5.546	5.010	4.670	4.060	4.230	4.580	5.144	5.320	6.000	6.470	6.72
EC mS/cm	1.960	1.378	1.355	2.600	2.580	2.530	2.580	2.560	2.480	2.550	2.500	2.680	2.5

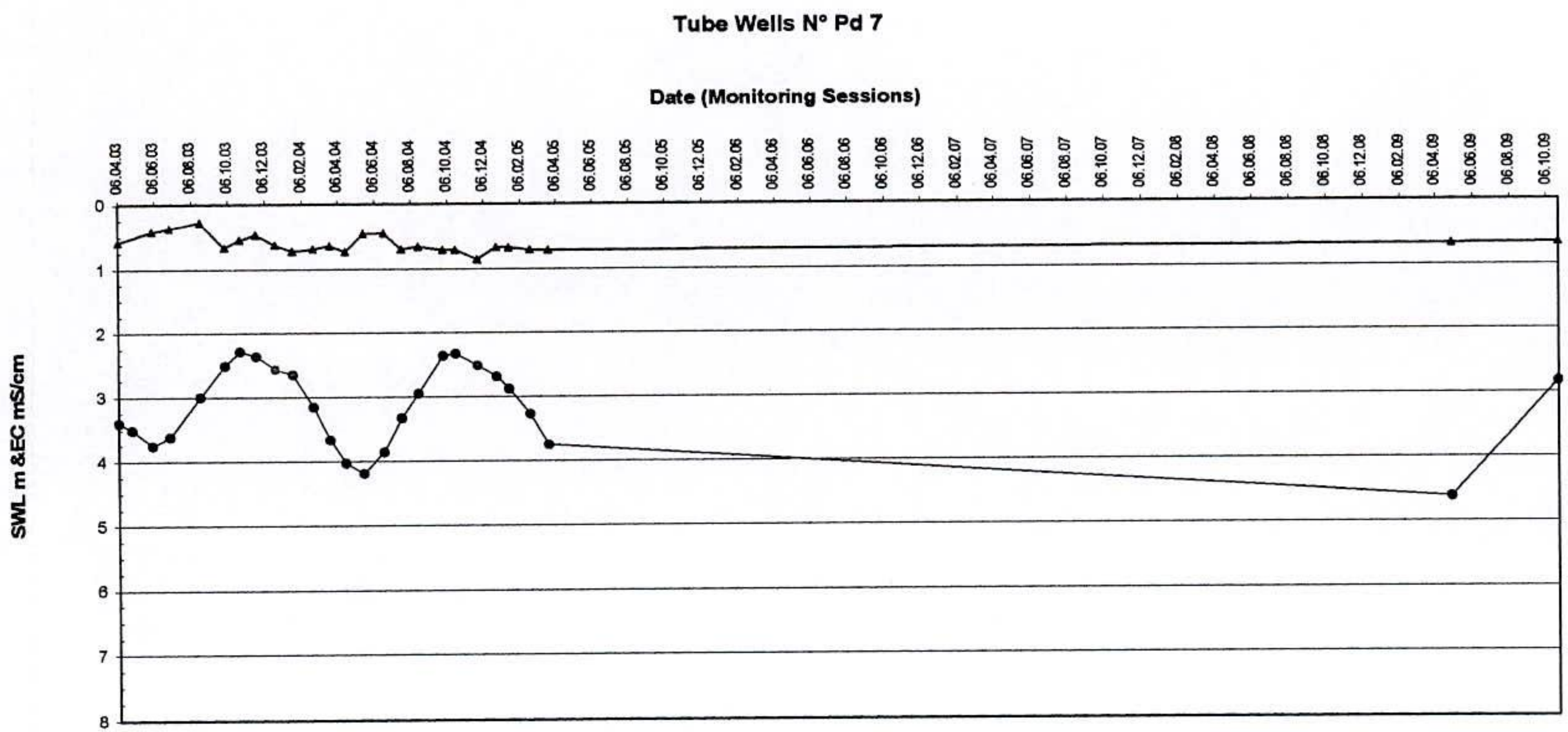


	06.04.2 003	28.04.2 003	01.06.2 003	30.06.2 003	17.07.2 003	20.08.2 003	30.09.2 003	25.10.2 003	21.11.2 003	23.12.2 003	21.01.2 004	24.02.2 004	23.03.2 004	18.04.2 004	18.05.2 004	21.06.2 004	21.07.2 004	18.08.2 004	28.09.2 004	19.10.2 004	25.11.2 004	27.12.2 004	17.01.2 005	21.02.2 005	24.03.2 005	02.05.2 009	25.10.2 009
SWL	3.740	3.790	3.910	3.660		2.590	2.445	2.336	2.726	2.920	3.210	4.070	4.870	4.970	4.416	2.840	3.270	2.930	2.170	2.290	2.650	3.150	3.390	4.300	4.780	4.7	
EC mS/cm	0.850		0.631			0.361	0.871	0.754	0.381	0.850	1.060	1.060	0.933	1.031	0.740	0.608	0.927	0.924	0.913	1.000	0.880	0.882	0.870	0.880	0.908	0.824	



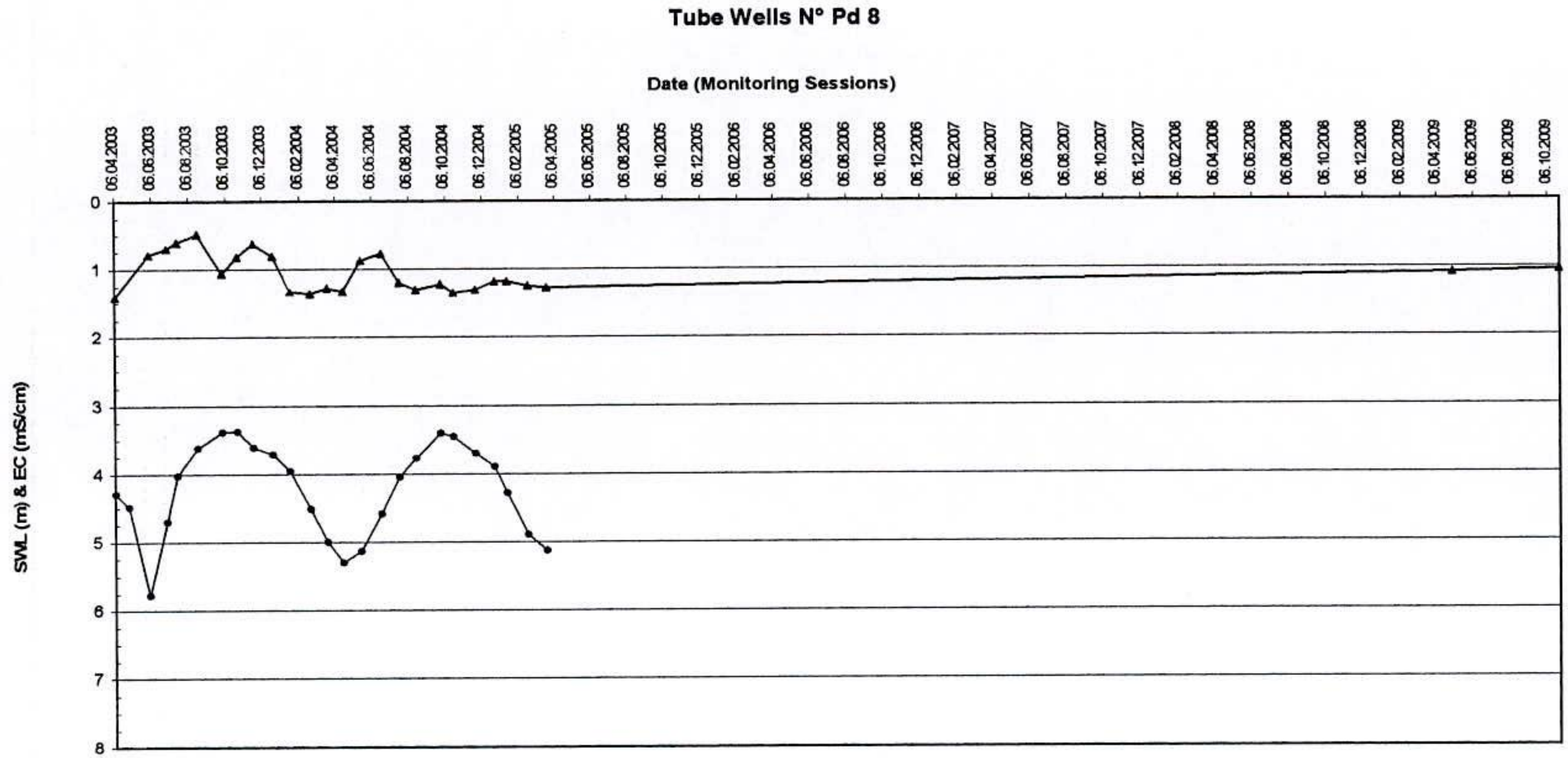
	06.04. 2003	28.04. 2003	01.06. 2003	30.06. 2003	17.07. 2003	20.08. 2003	30.09. 2003	25.10. 2003	21.11. 2003	23.12. 2003	21.01. 2004	24.02. 2004	23.03. 2004
SWL		4.11	4.34	3.10	2.02	3.16	2.81	2.8	3.120	3.290	3.716	4.180	4.630
EC mS/cm	1.260		0.557	0.441	0.482	0.271	0.96	0.606	0.506	0.626	1.490	1.440	1.200

	18.04. 2004	18.05. 2004	21.06. 2004	21.07. 2004	18.08. 2004	28.09. 2004	19.10. 2004	25.11. 2004	27.12. 2004	17.01. 2005	21.02. 2005	24.03. 2005	02.05. 2009	25.10. 2009
SWL	4.650	4.562	3.870	3.500	3.160	2.830	2.920	3.300	3.624	3.894	4.360	4.580		
EC mS/cm	1.100	0.843	0.830	1.285	1.314	1.296	1.469	1.364	1.262	1.283	1.345	1.365	1.186	1.091



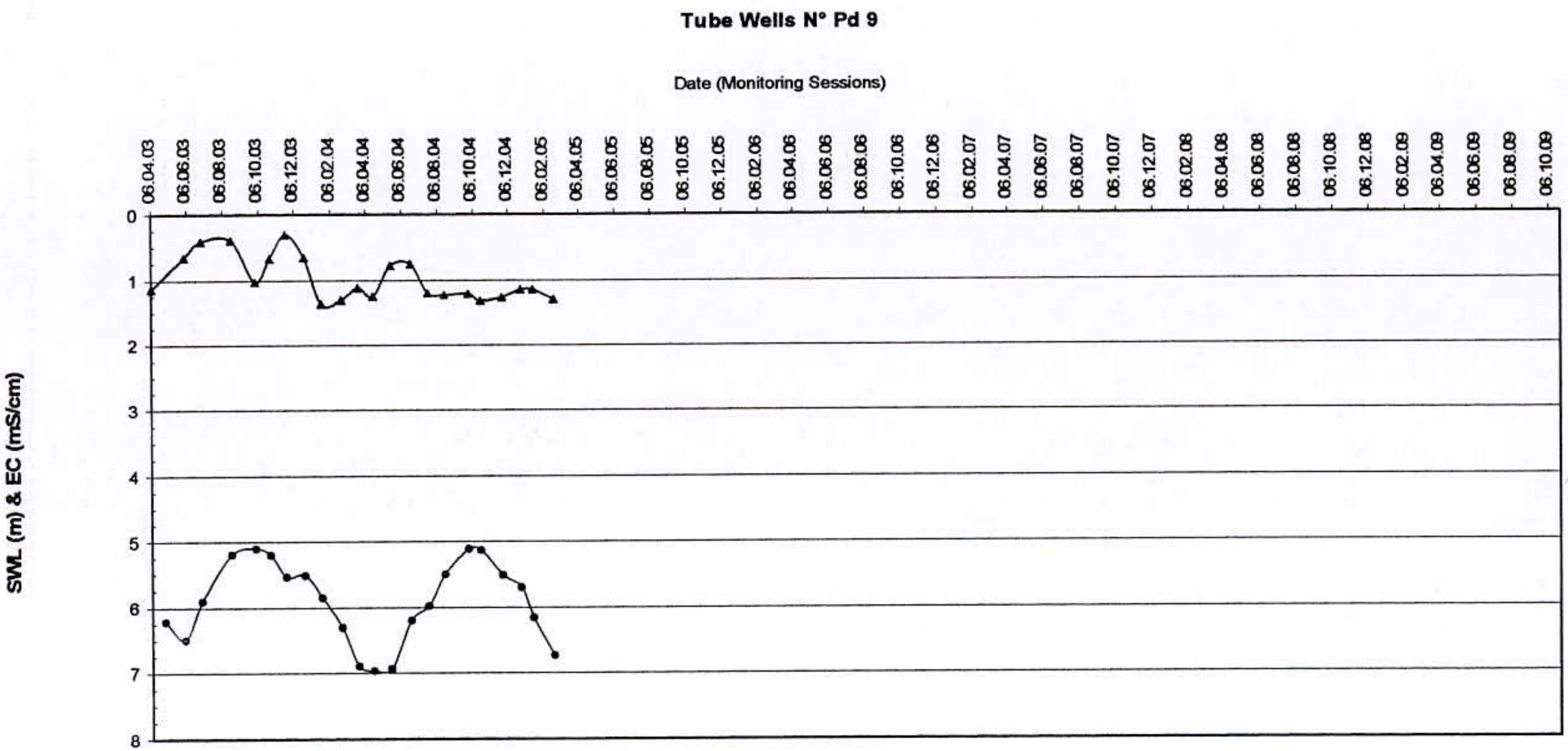
	06.04.2003	28.04.2003	01.06.2003	30.06.2003	17.07.2003	20.08.2003	30.09.2003	25.10.2003	21.11.2003	23.12.2003	21.01.2004	24.02.2004	23.03.2004	18.04.2004
SWL	3.400	3.508	3.754	3.614		3.000	2.510	2.286	2.366	2.570	2.656	3.156	3.664	4.030
EC mS/cm	0.580		0.413	0.365		0.276	0.659	0.541	0.462	0.620	0.722	0.690	0.638	0.728

	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009	25.10.2009
SWL	4.190	3.860	3.330	2.950	2.364	2.330	2.520	2.690	2.880	3.274	3.750	4.62	2.83
EC mS/cm	0.450	0.444	0.693	0.654	0.709	0.703	0.858	0.664	0.670	0.706	0.7	0.671	0.657

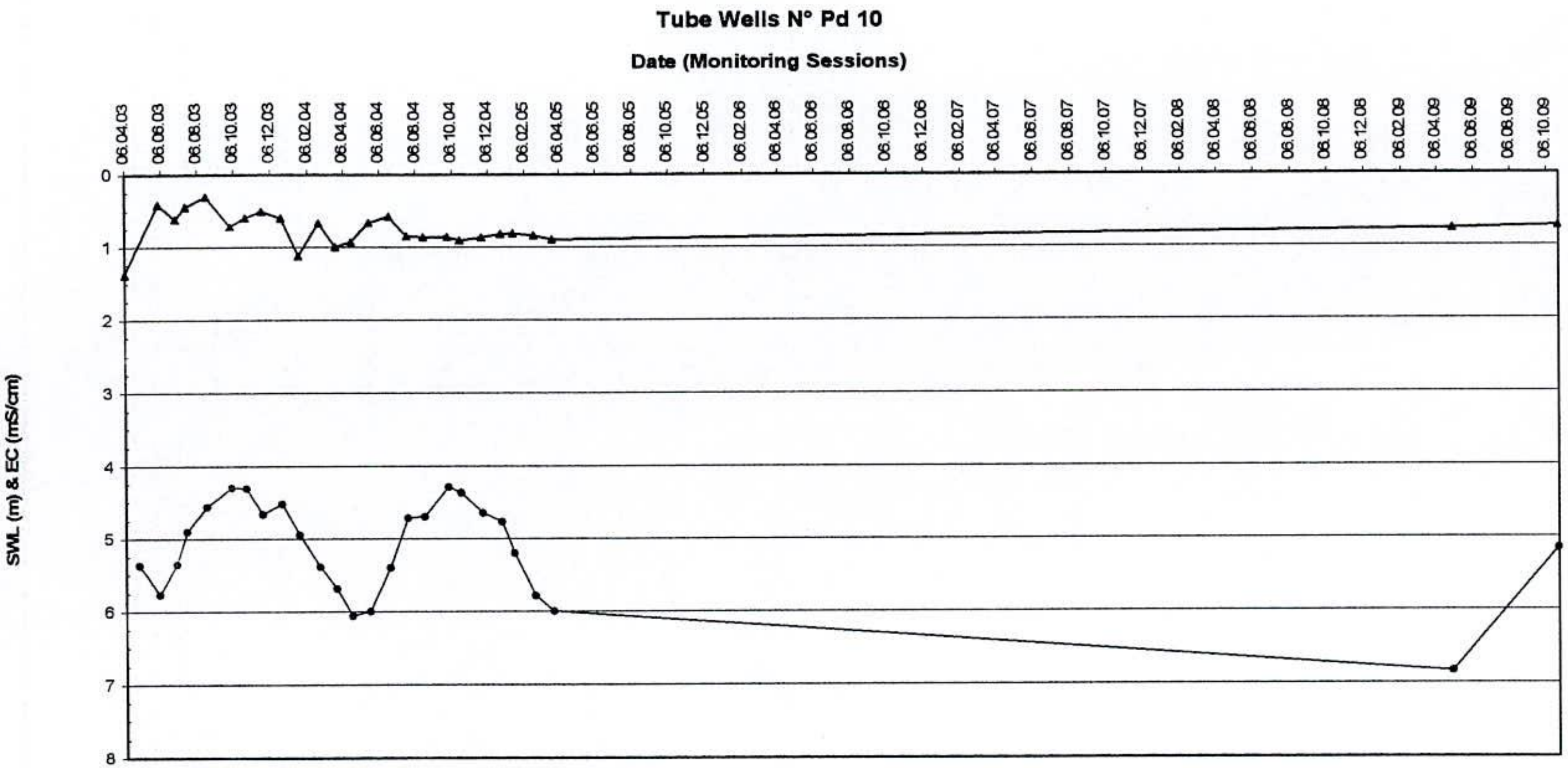


	06.04.2003	28.04.2003	01.06.2003	30.06.2003	17.07.2003	20.08.2003	30.09.2003	25.10.2003	21.11.2003	23.12.2003	21.01.2004	24.02.2004	23.03.2004	18.04.2004
SWL	4.294	4.490	5.780	4.700	4.030	3.620	3.390	3.380	3.610	3.710	3.956	4.520	5.000	5.300
EC mS/cm	1.410		0.788	0.695	0.604	0.485	1.064	0.818	0.623	0.812	1.330	1.360	1.280	1.325

	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009	25.10.2009
SWL	5.136	4.590	4.050	3.770	3.410	3.460	3.700	3.900	4.286	4.900	5.130		
EC mS/cm	0.874	0.769	1.196	1.304	1.223	1.349	1.305	1.185	1.184	1.245	1.271	1.082	1.045

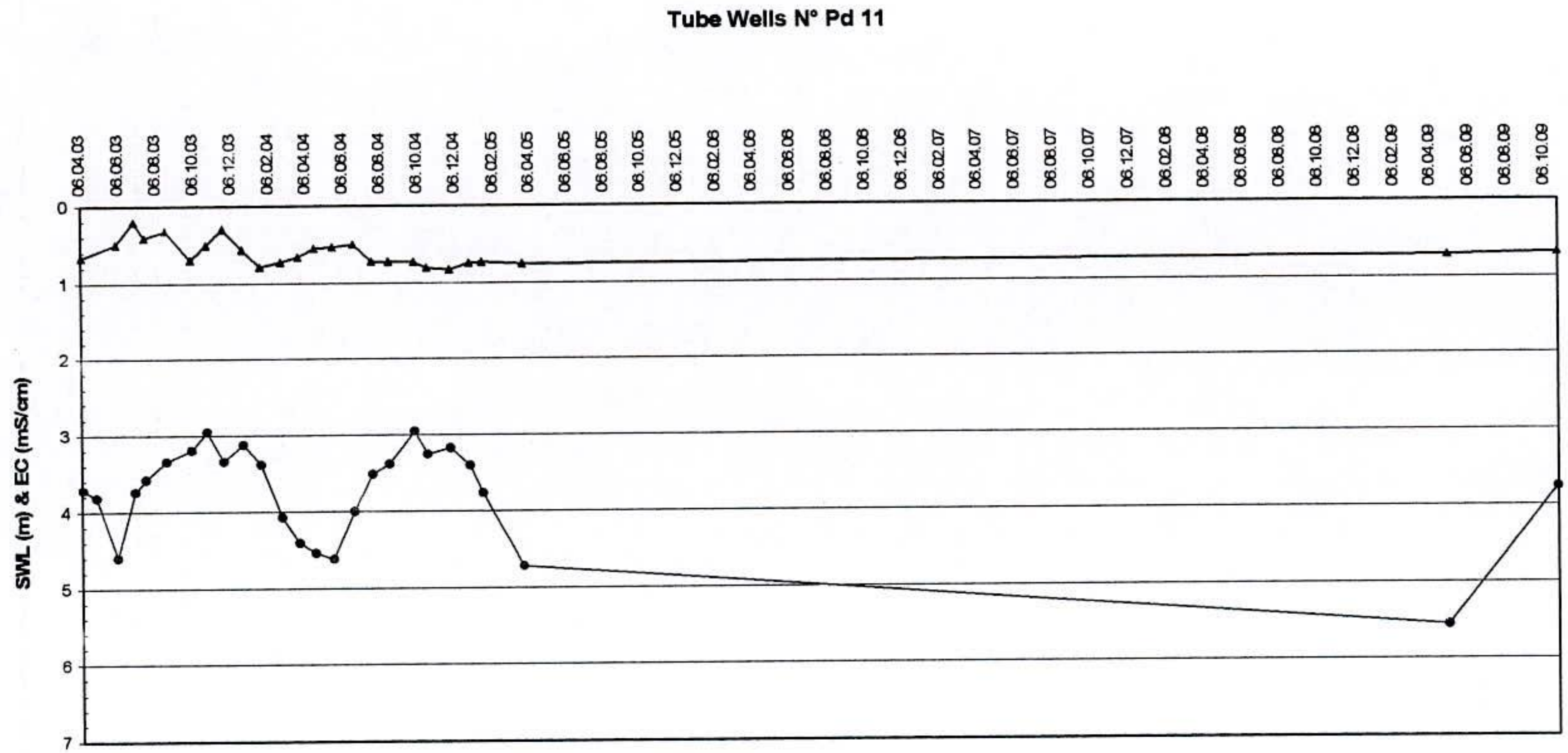


	06.04 .2003	28.04 .2003	01.06 .2003	30.06 .2003	17.07 .2003	20.08 .2003	30.09 .2003	25.10 .2003	21.11 .2003	23.12 .2003	21.01 .2004	24.02 .2004	23.03 .2004	18.04 .2004	18.05 .2004	21.06 .2004	21.07 .2004	18.08 .2004	28.09 .2004	19.10 .2004	25.11 .2004	27.12 .2004	17.01 .2005	21.02 .2005	24.03 .2005	02.05 .2009	25.10 .2009
SWL		6.215	6.494	5.900		5.190	5.100	5.200	5.534	5.510	5.850	6.310	6.900	6.970	6.940	6.200	5.980	5.500	5.110	5.130	5.510	5.700	6.160	6.740			
EC mS/cm	1.135		0.652	0.407		0.388	1.023	0.673	0.301	0.652	1.370	1.310	1.117	1.252	0.780	0.752	1.204	1.230	1.214	1.323	1.270	1.149	1.146	1.302			



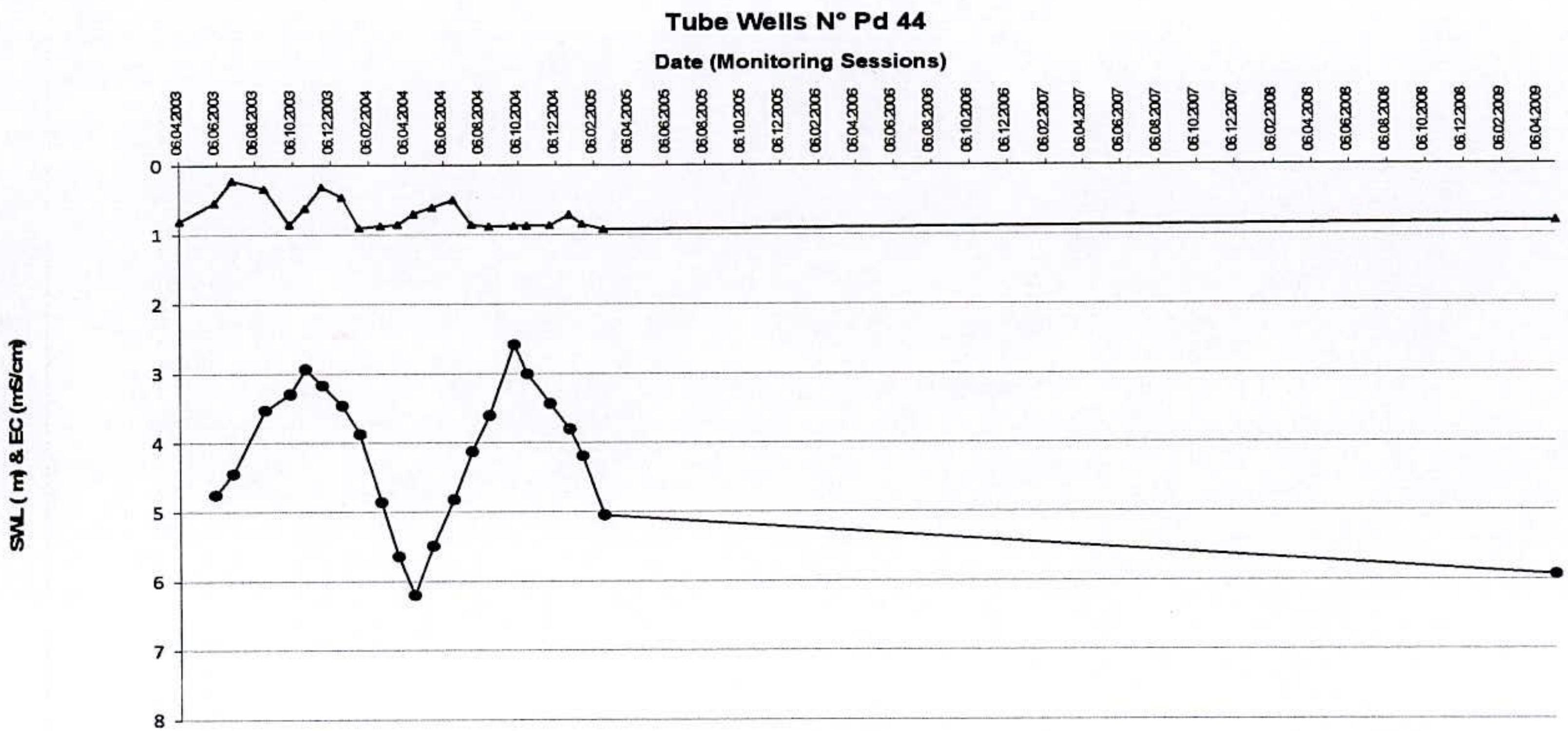
	06.04.2003	28.04.2003	01.06.2003	30.06.2003	17.07.2003	20.08.2003	30.09.2003	25.10.2003	21.11.2003	23.12.2003	21.01.2004	24.02.2004	23.03.2004	18.04.2004
SWL		5.367	5.770	5.350	4.904	4.560	4.300	4.310	4.666	4.520	4.950	5.386	5.690	6.060
EC mS/cm	1.378		0.411	0.615	0.443	0.303	0.715	0.595	0.509	0.598	1.120	0.668	1.000	0.930

	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009	25.10.2009
SWL	6.000	5.400	4.720	4.700	4.290	4.370	4.650	4.770	5.200	5.790	6.000	6.84	5.16
EC mS/cm	0.661	0.579	0.854	0.862	0.860	0.910	0.868	0.822	0.815	0.843	0.899	0.766	0.728



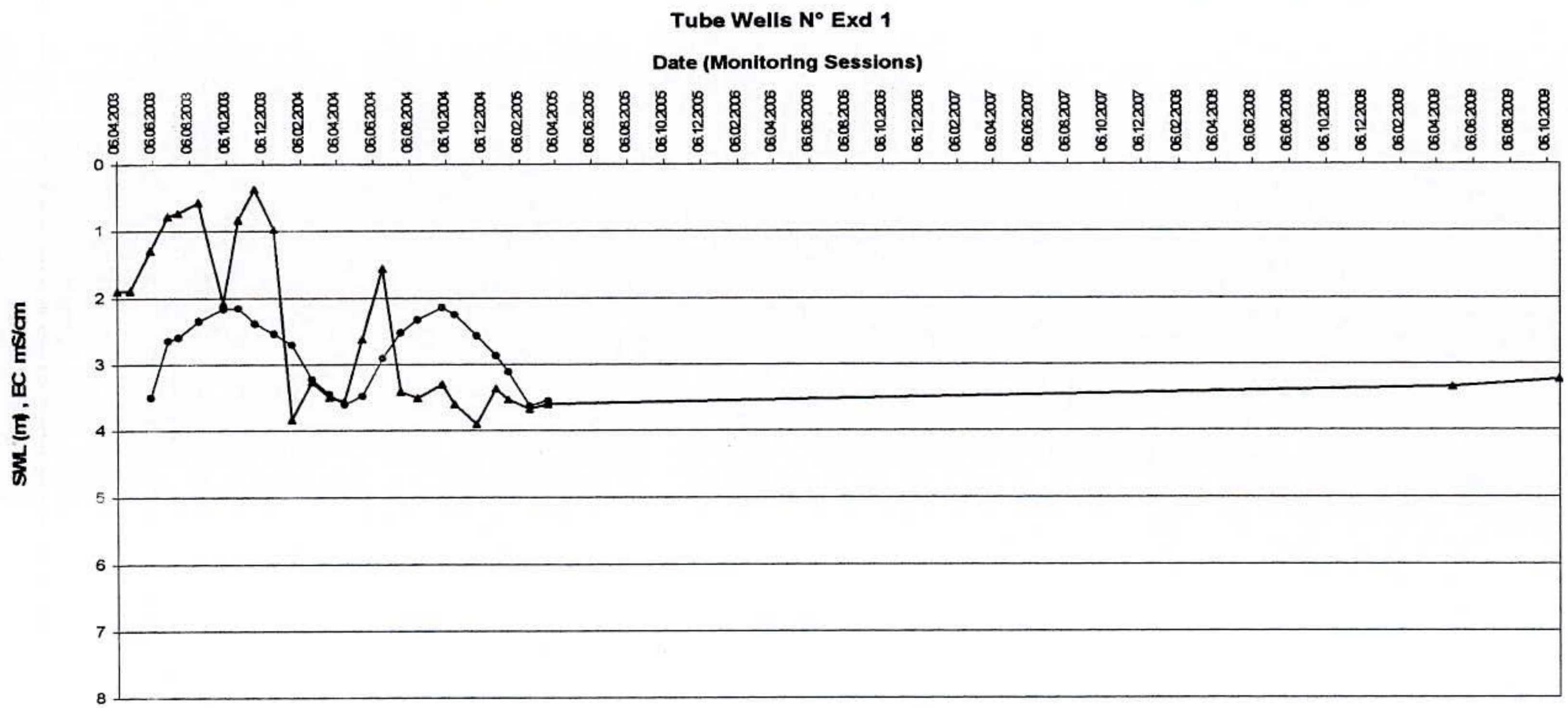
	06.04.2003	28.04.2003	01.06.2003	30.06.2003	17.07.2003	20.08.2003	30.09.2003	25.10.2003	21.11.2003	23.12.2003	21.01.2004	24.02.2004	23.03.2004
SWL	3.714	3.818	4.6	3.744	3.58	3.35	3.2	2.96	3.350	3.128	3.390	4.070	4.410
EC mS/cm	0.667		0.498	0.202	0.410	0.319	0.697	0.507	0.300	0.565	0.790	0.730	0.665

	18.04.2004	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009	25.10.2009
SWL	4.540	4.616	4.000	3.520	3.390	2.960	3.260	3.180	3.410	3.770		4.720	5.56	3.76
EC mS/cm	0.551	0.536	0.501	0.725	0.728	0.733	0.811	0.833	0.754	0.736		0.761	0.715	0.686



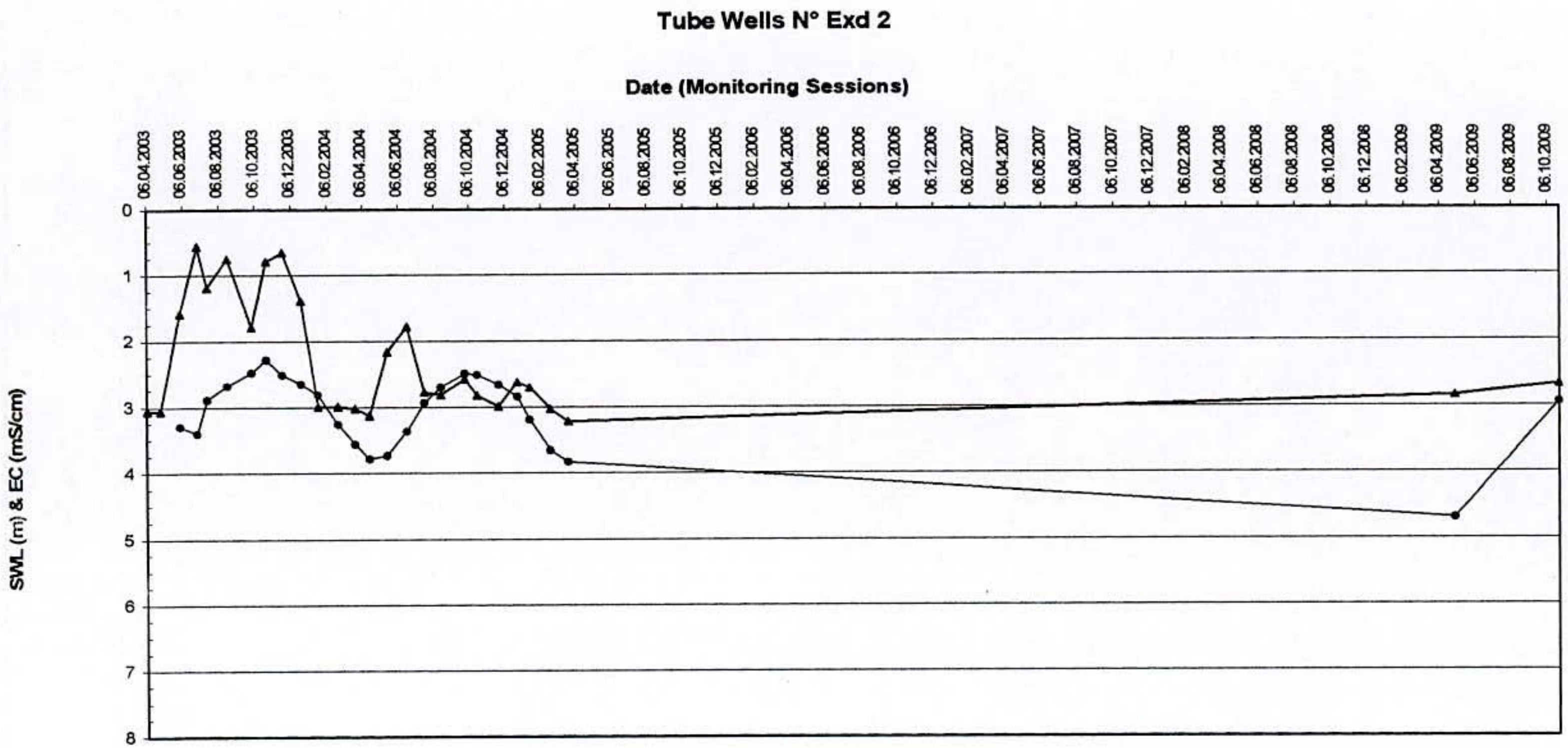
	06.04. 2003	28.04. 2003	01.06. 2003	30.06. 2003	17.07. 2003	20.08. 2003	30.09. 2003	25.10. 2003	21.11. 2003	23.12. 2003	21.01. 2004	24.02. 2004	23.03. 2004	18.04. 2004
SWL			4.75	4.45		3.530	3.300	2.934	3.176	3.466	3.880	4.860	5.642	6.200
EC mS/cm	0.800		0.543	0.216		0.333	0.848	0.616	0.310	0.457	0.900	0.870	0.852	0.698

	18.05. 2004	21.06. 2004	21.07. 2004	18.08. 2004	28.09. 2004	19.10. 2004	25.11. 2004	27.12. 2004	17.01. 2005	21.02. 2005	24.03. 2005	02.05. 2009
SWL	5.490	4.820	4.130	3.610	2.590	3.010	3.440	3.810	4.190	5.050		5.93
EC mS/cm	0.605	0.500	0.853	0.880	0.867	0.867	0.865	0.713	0.843	0.923		0.819



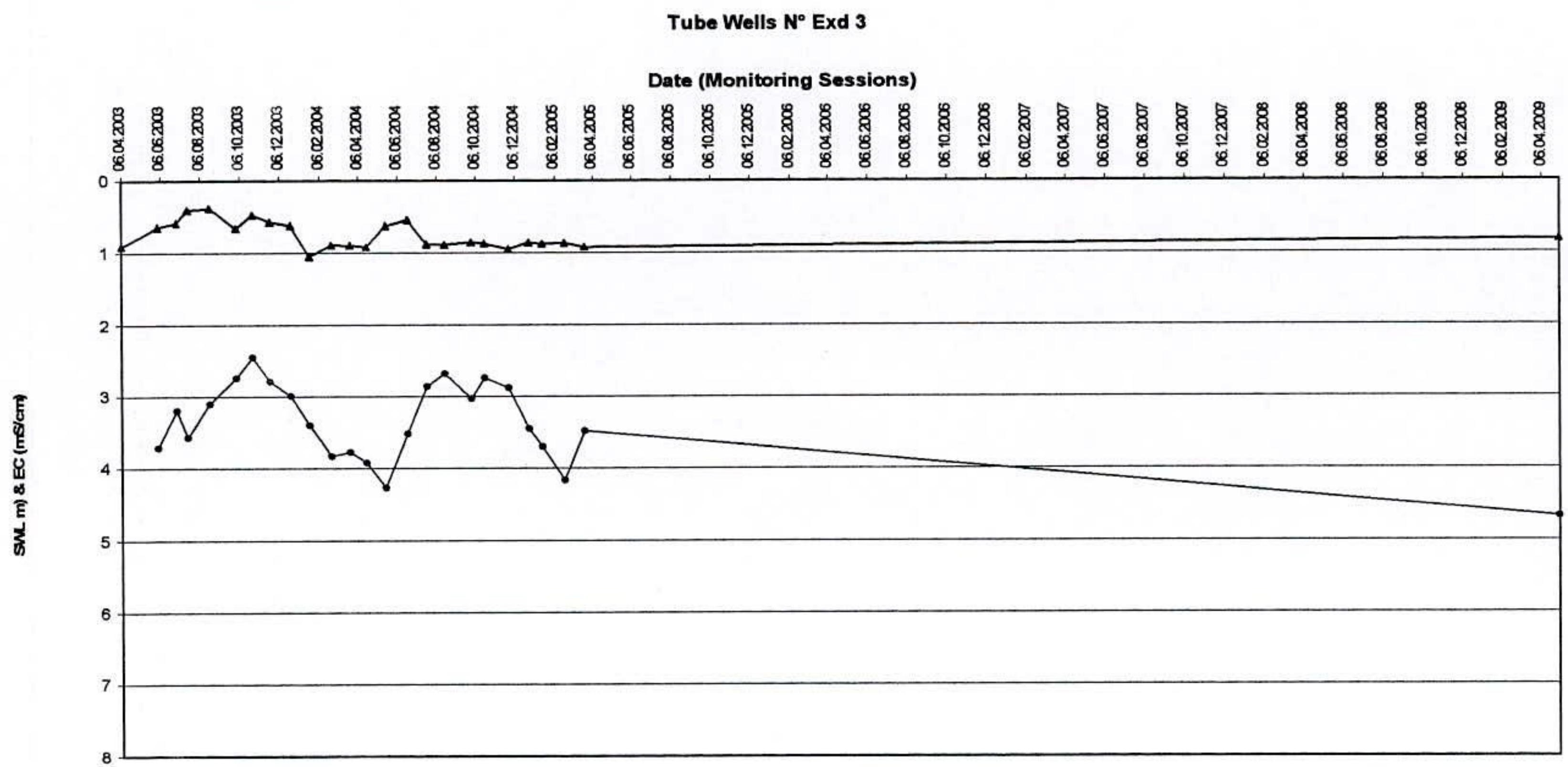
	06.04.2003	28.04.2003	01.06.2003	30.06.2003	17.07.2003	20.08.2003	30.09.2003	25.10.2003	21.11.2003	23.12.2003	21.01.2004	24.02.2004	24.03.2004	18.04.2004
SWL			3.500	2.640	2.590	2.350	2.160	2.150	2.386	2.536	2.700	3.224	3.454	3.606
EC mS/cm	1.890	1.890	1.290	0.780	0.735	0.576	2.080	0.830	0.374	0.973	3.830	3.270	3.500	3.560

	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009	25.10.2009
SWL	3.480	2.914	2.520	2.330	2.140	2.250	2.566	2.870	3.114	3.630	3.550		
EC mS/cm	2.620	1.559	3.411	3.510	3.300	3.600	3.900	3.370	3.530	3.670	3.600	3.35	3.24



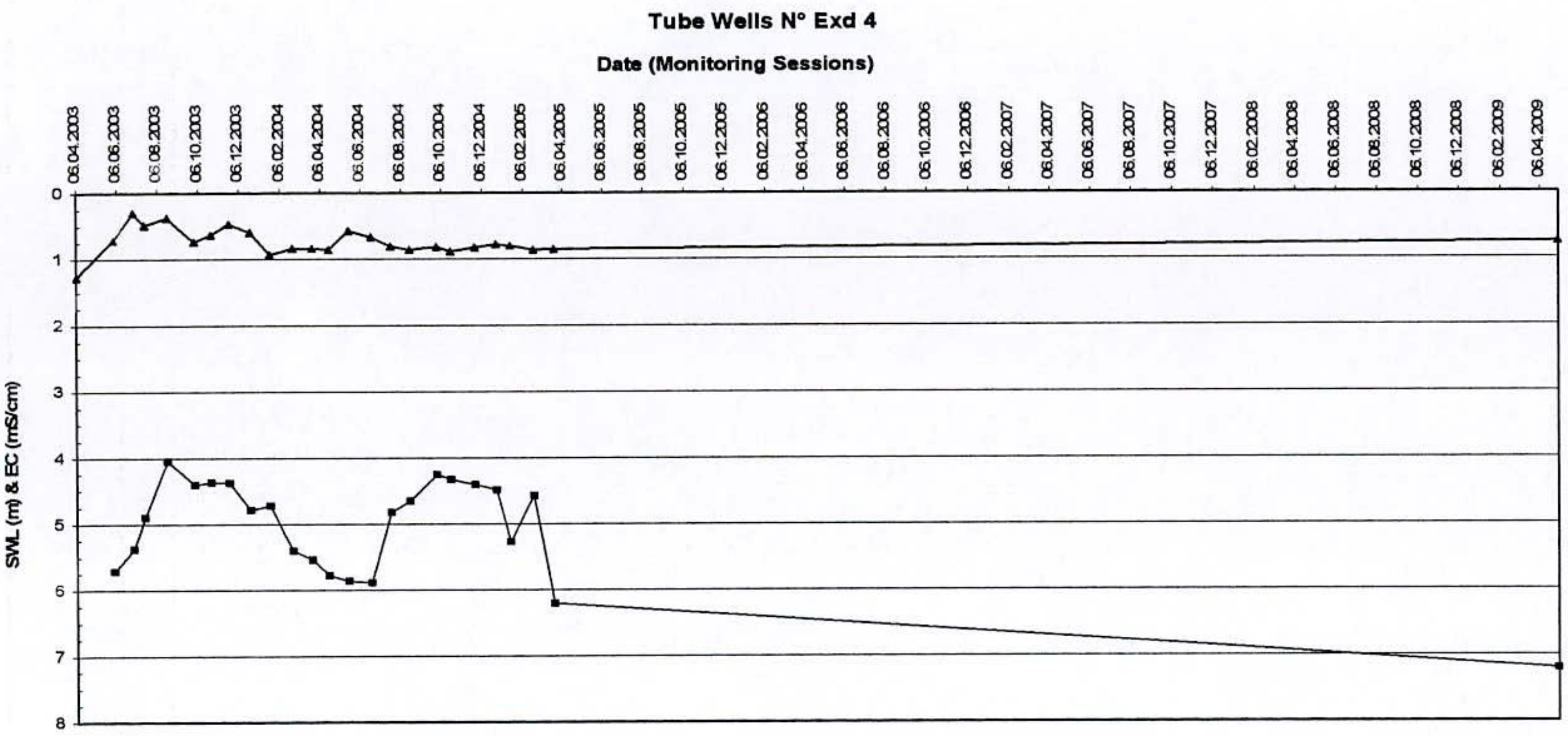
	06.04. 2003	28.04. 2003	01.06. 2003	30.06. 2003	17.07. 2003	20.08. 2003	30.09. 2003	25.10. 2003	21.11. 2003	23.12. 2003	21.01. 2004	24.02. 2004	24.03. 2004	18.04. 2004
SWL			3.294	3.400	2.890	2.680	2.480	2.288	2.516	2.656	2.820	3.256	3.566	3.780
EC mS/cm Exd 2	3.060	3.060	1.583	0.559	1.190	0.745	1.786	0.790	0.651	1.388	2.990	2.990	3.020	3.130

	18.05. 2004	21.06. 2004	21.07. 2004	18.08. 2004	28.09. 2004	19.10. 2004	25.11. 2004	27.12. 2004	17.01. 2005	21.02. 2005	24.03. 2005	02.05. 2009	25.10. 2009
SWL	3.730	3.370	2.940	2.706	2.500	2.520	2.670	2.850	3.190	3.656	3.830	4.70	2.95
EC mS/cm Exd 2	2.170	1.780	2.780	2.820	2.580	2.830	2.99	2.630	2.710	3.030	3.220	2.85	2.68



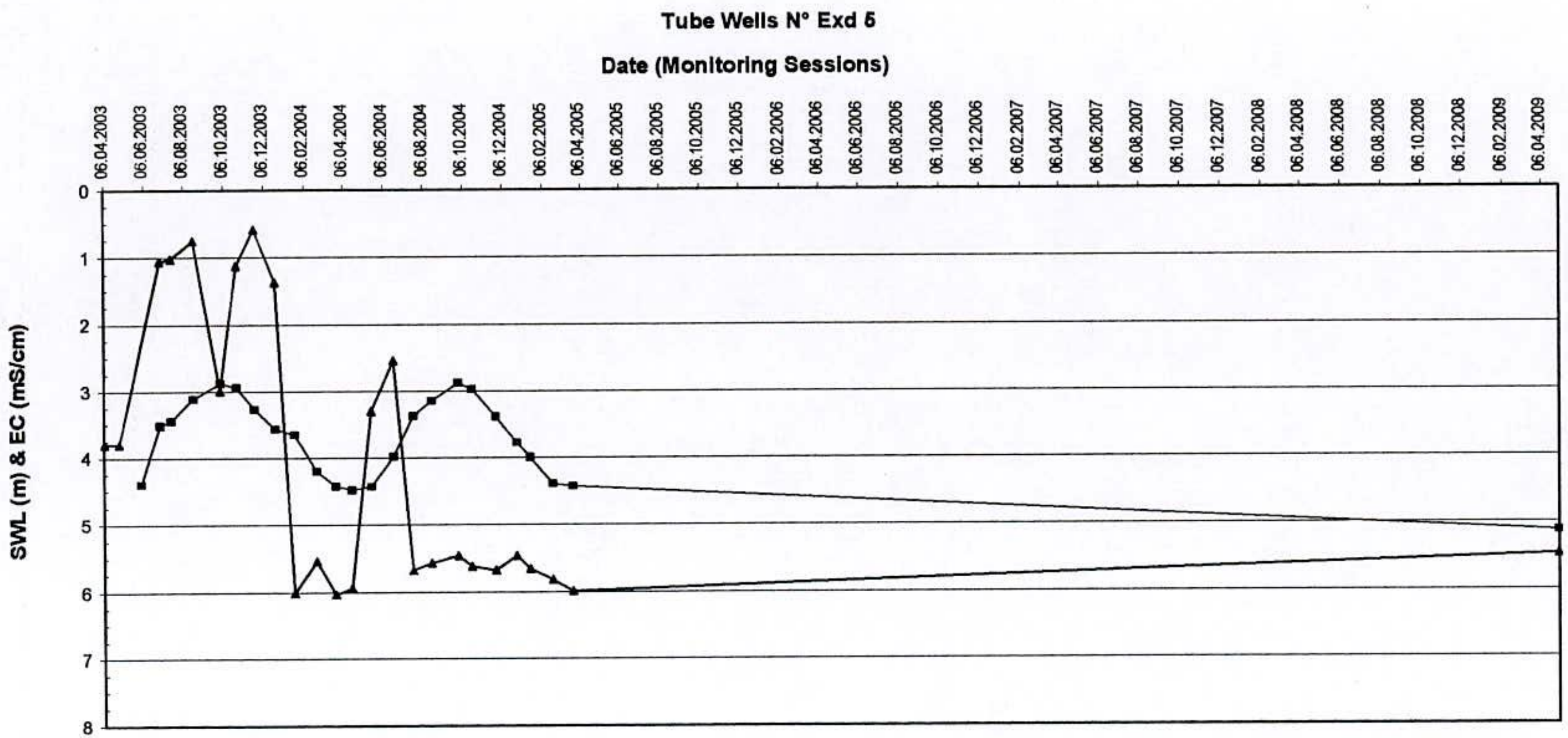
	06.04.2 003	28.04.2 003	01.06.2 003	30.06.2 003	17.07.2 003	20.08.2 003	30.09.2 003	25.10.2 003	21.11.2 003	23.12.2 003	21.01.2 004	24.02.2 004	24.03.2 004
SWL			3.715	3.190	3.570	3.100	2.740	2.450	2.790	2.990	3.400	3.830	3.774
EC mS/cm Exd 3	0.910		0.638	0.579	0.402	0.378	0.656	0.472	0.567	0.620	1.050	0.890	0.894

	18.04.2 004	18.05.2 004	21.06.2 004	21.07.2 004	18.08.2 004	28.09.2 004	19.10.2 004	25.11.2 004	27.12.2 004	17.01.2 005	21.02.2 005	24.03.2 005	02.05.2 009
SWL	3.920	4.270	3.520	2.860	2.680	3.030	2.740	2.880	3.450	3.700	4.170	3.480	4.68
EC mS/cm Exd 3	0.917	0.624	0.542	0.878	0.883	0.850	0.868	0.947	0.856	0.873	0.863	0.920	0.815



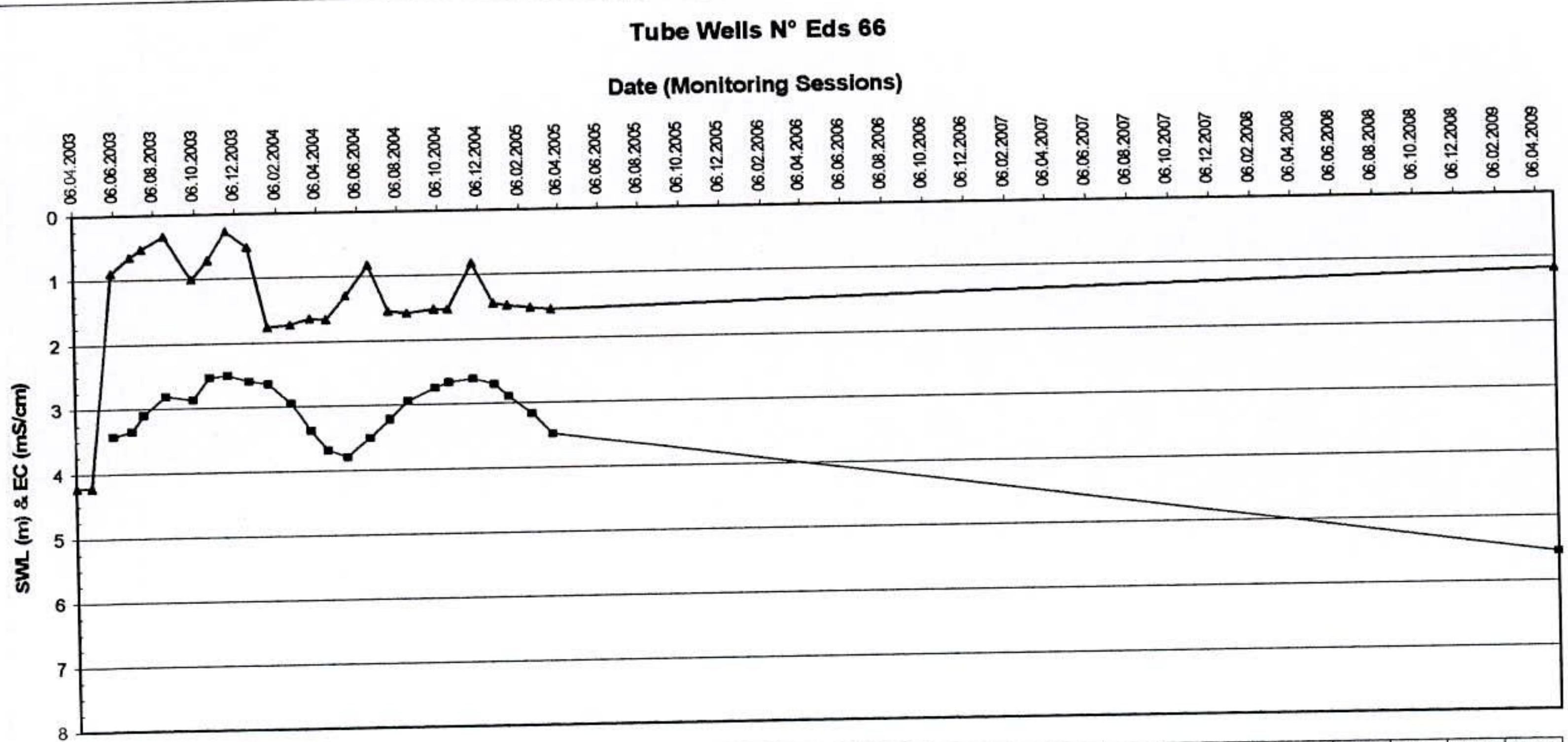
	06.04.2 003	28.04.2 003	01.06.2 003	30.06.2 003	17.07.2 003	20.08.2 003	30.09.2 003	25.10.2 003	21.11.2 003	23.12.2 003	21.01.2 004	24.02.2 004
Exd 4			5.710	5.380	4.900	4.046	4.410	4.364	4.376	4.790	4.720	5.410
EC mS/cm	1.270		0.710	0.300	0.480	0.369	0.735	0.624	0.463	0.589	0.930	0.840

	24.03.2 004	18.04.2 004	18.05.2 004	21.06.2 004	21.07.2 004	18.08.2 004	28.09.2 004	19.10.2 004	25.11.2 004	27.12.2 004	17.01.2 005	21.02.2 005	24.03.2 005	02.05.2 009
Exd 4	5.540	5.780	5.864	5.890	4.830	4.658	4.260	4.330	4.410	4.490	5.274	4.576	6.200	7.2
EC mS/cm	0.838	0.857	0.567	0.663	0.806	0.858	0.813	0.885	0.822	0.780	0.801	0.862	0.850	0.752



	06.04.2003	28.04.2003	01.06.2003	30.06.2003	17.07.2003	20.08.2003	30.09.2003	25.10.2003	21.11.2003	23.12.2003	21.01.2004	24.02.2004
SWL			4.400	3.510	3.440	3.110	2.880	2.940	3.270	3.560	3.650	4.200
EC mS/cm	3.800	3.800		1.060	1.023	0.758	2.990	1.125	0.590	1.370	6.010	5.540

	24.03.2004	18.04.2004	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009
SWL	4.430	4.490	4.440	3.986	3.380	3.150	2.880	2.970	3.390	3.780	4.000	4.400	4.440	5.13
EC mS/cm	6.030	5.940	3.300	2.540	5.680	5.570	5.460	5.620	5.680	5.460	5.660	5.820	5.990	5.47



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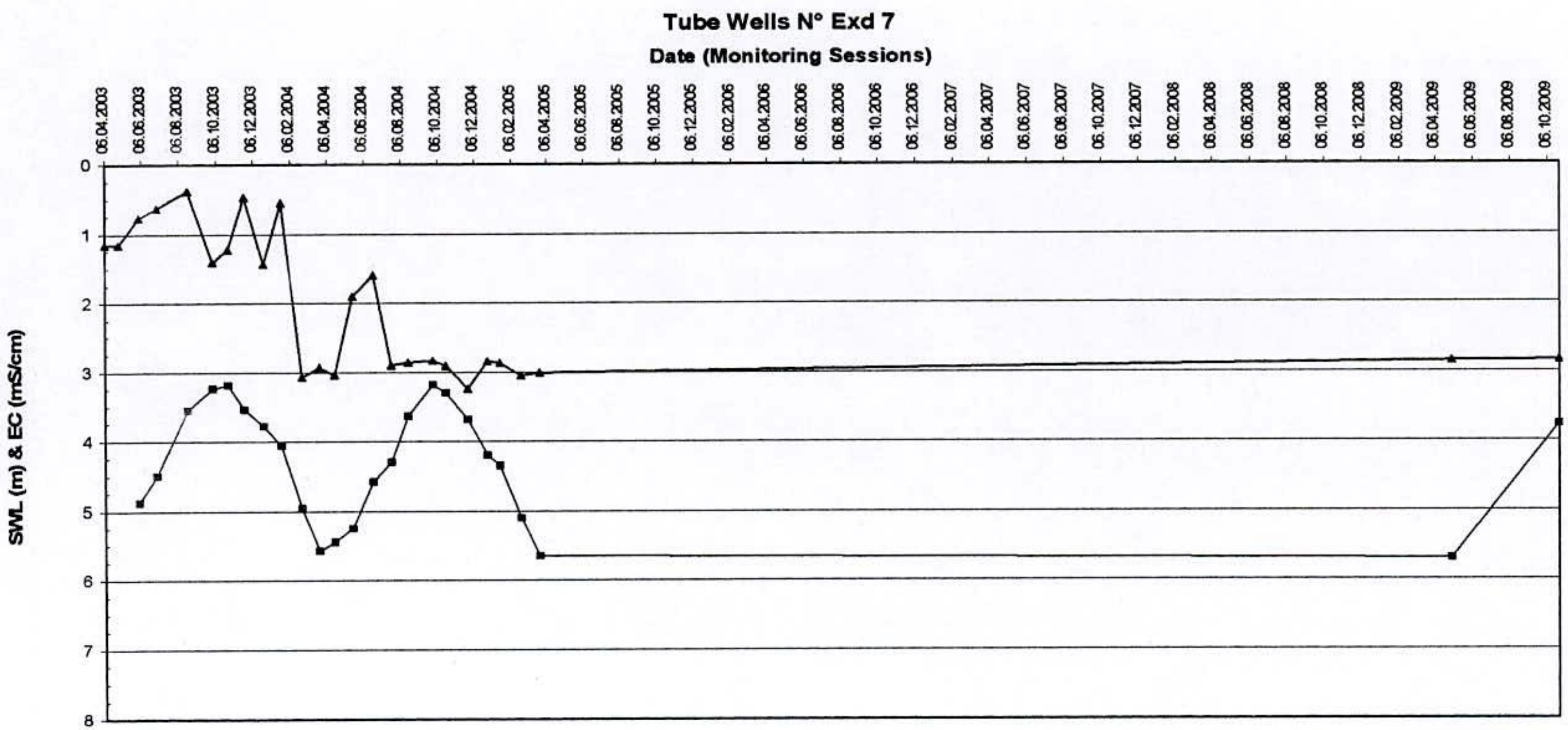
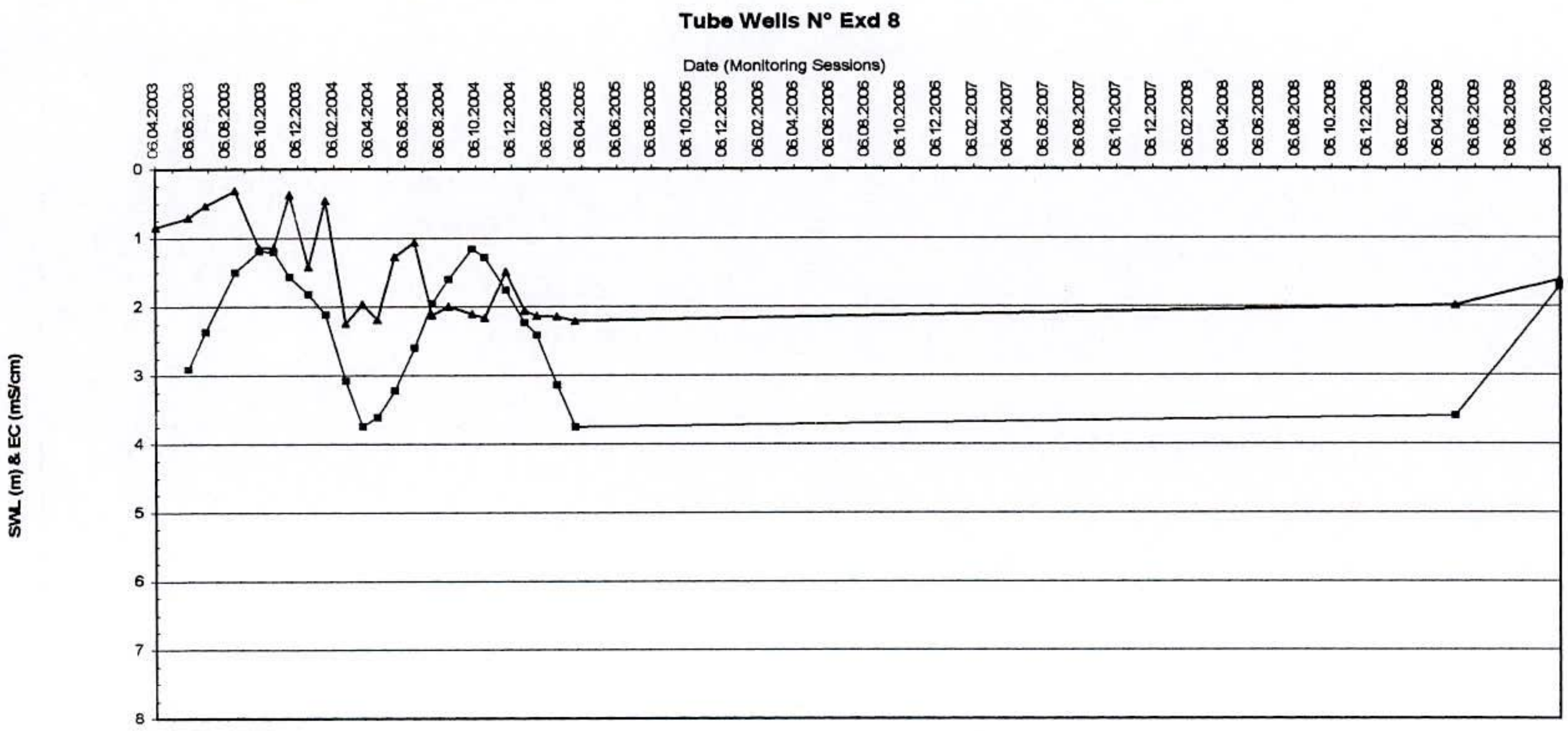
SWL			3.420	3.344	3.100	2.812	2.870	2.526	2.500	2.594	2.640	2.954	3.370	3.686
EC mS/cm	4.220	4.220	0.894	0.651	0.530	0.328	1.006	0.715	0.265	0.519	1.760	1.730	1.640	1.659

	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009
SWL	3.790	3.500	3.220	2.942	2.750	2.660	2.610	2.700	2.894	3.164	3.480	5.55
EC mS/cm	1.300	0.829	1.540	1.575	1.520	1.524	0.826	1.442	1.480	1.520	1.550	1.172



	06.04.2003	28.04.2003	01.06.2003	30.06.2003	17.07.2003	20.08.2003	30.09.2003	25.10.2003	21.11.2003	23.12.2003	21.01.2004	24.02.2004	24.03.2004
SWL			4.880	4.490		3.550	3.230	3.180	3.540	3.780	4.060	4.960	5.576
EC mS/cm	1.150	1.151	0.767	0.625		0.380	1.405	1.219	0.470	1.430	0.547	3.070	2.930

	18.04.2004	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009	25.10.2009
SWL	5.450	5.250	4.580	4.300	3.640	3.180	3.300	3.686	4.200	4.350	5.100	5.650	5.7	3.77
EC mS/cm	3.040	1.900	1.591	2.900	2.860	2.830	2.910	3.240	2.840	2.870	3.050	3.010	2.85	2.84



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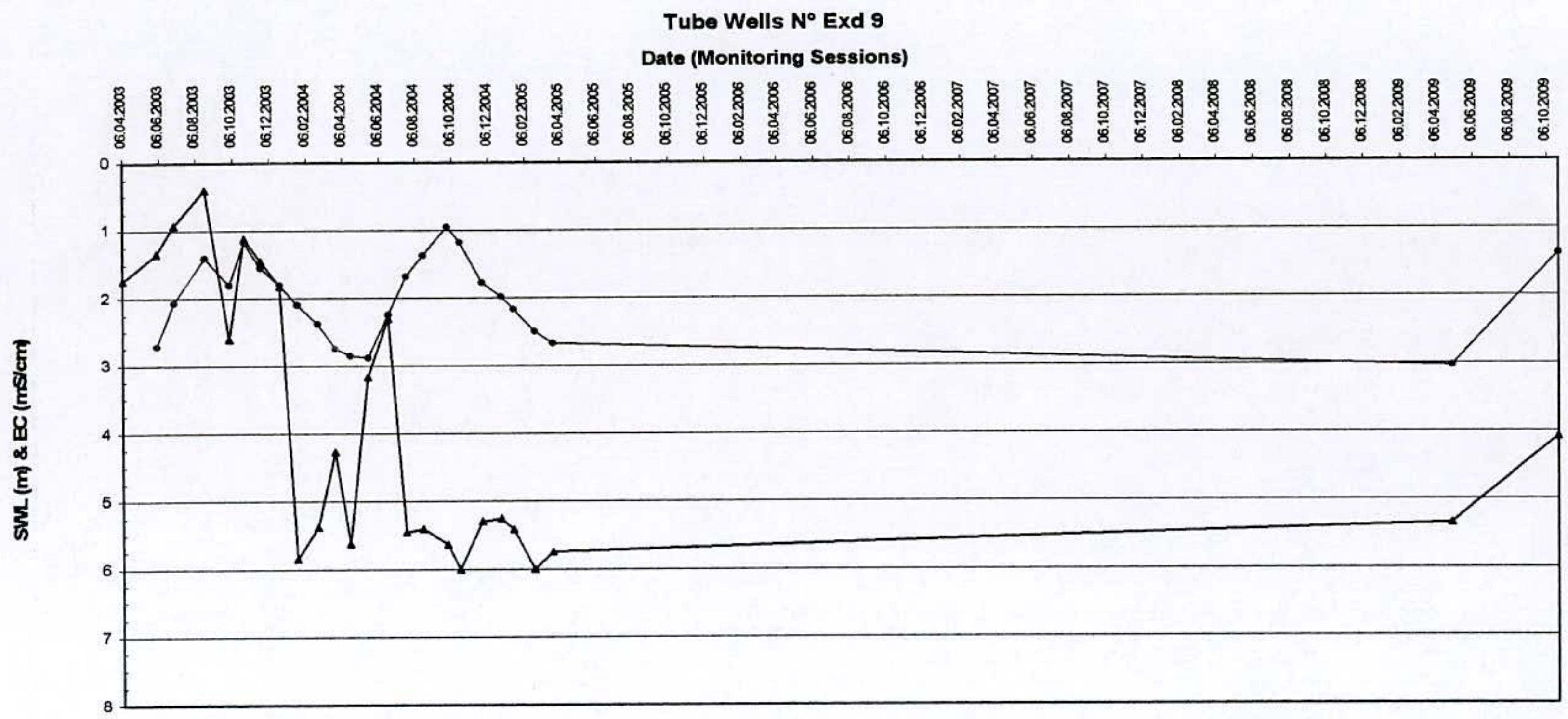
SWL			2.910	2.370		1.500	1.195	1.204	1.562	1.820	2.114	3.080	3.744	3.610
EC mS/cm	0.845		0.709	0.537		0.318	1.145	1.134	0.380	1.417	0.461	2.240	1.960	2.180

	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009	25.10.2009
SWL	3.220	2.590	1.960	1.600	1.160	1.280	1.760	2.230	2.410	3.140	3.750	3.6	1.72
EC mS/cm	1.270	1.063	2.120	1.994	2.100	2.160	1.490	2.050	2.130	2.140	2.200	1.985	1.609



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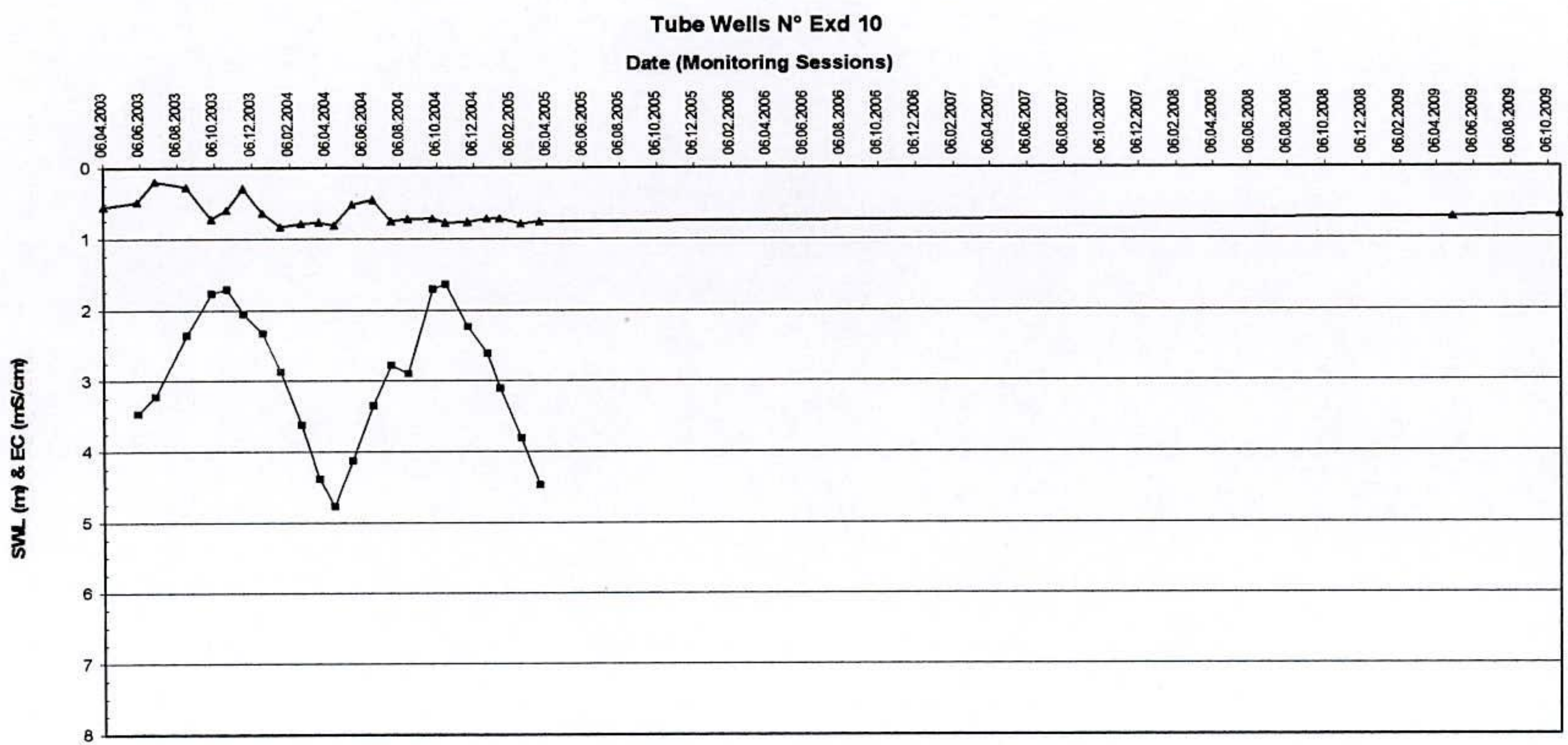
SWL			2.720	2.070		1.400	1.800	1.168	1.550	1.800	2.100	2.380	2.750	2.854	2.884	2.250	1.680	1.370	0.950	1.180	1.770	1.980	2.170	2.500	2.680	3.04	1.38
EC mS/cm	1.740		1.340	0.923		0.402	2.610	1.118	1.442	1.816	5.840	5.370	4.270	5.620	3.170	2.300	5.450	5.400	5.630	6.000	5.290	5.250	5.410	6.000	5.740	5.34	4.085



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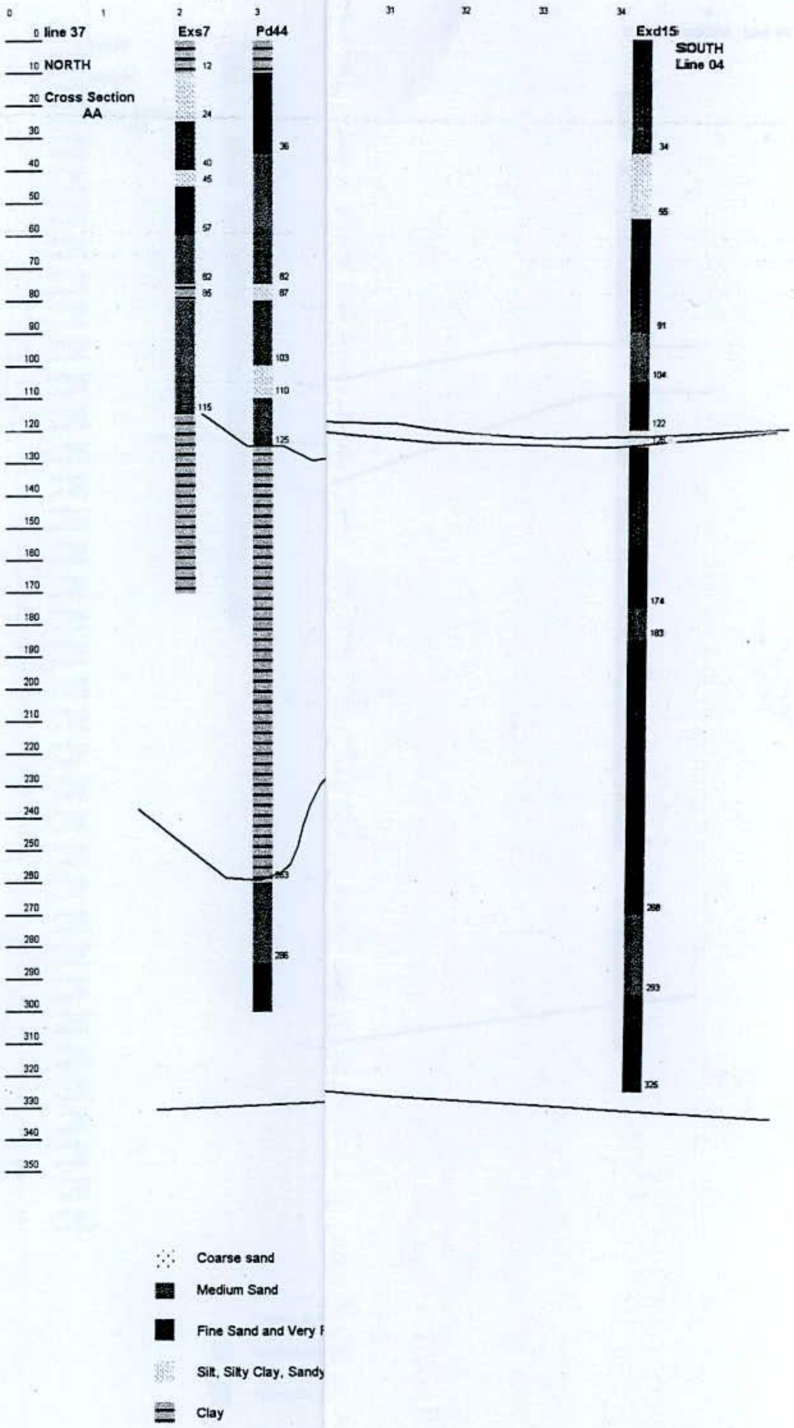
SWL			3.466	3.220		2.360	1.770	1.708	2.050	2.336	2.870	3.620	4.390	4.770
EC mS/cm	0.550		0.484	0.196		0.270	0.722	0.593	0.293	0.640	0.832	0.790	0.770	0.811

	18.05.2004	21.06.2004	21.07.2004	18.08.2004	28.09.2004	19.10.2004	25.11.2004	27.12.2004	17.01.2005	21.02.2005	24.03.2005	02.05.2009	25.10.2009
SWL	4.130	3.350	2.780	2.900	1.710	1.640	2.240	2.610	3.110	3.810	4.480		
EC mS/cm	0.518	0.452	0.754	0.722	0.715	0.773	0.768	0.720	0.716	0.790	0.759	0.71	0.683

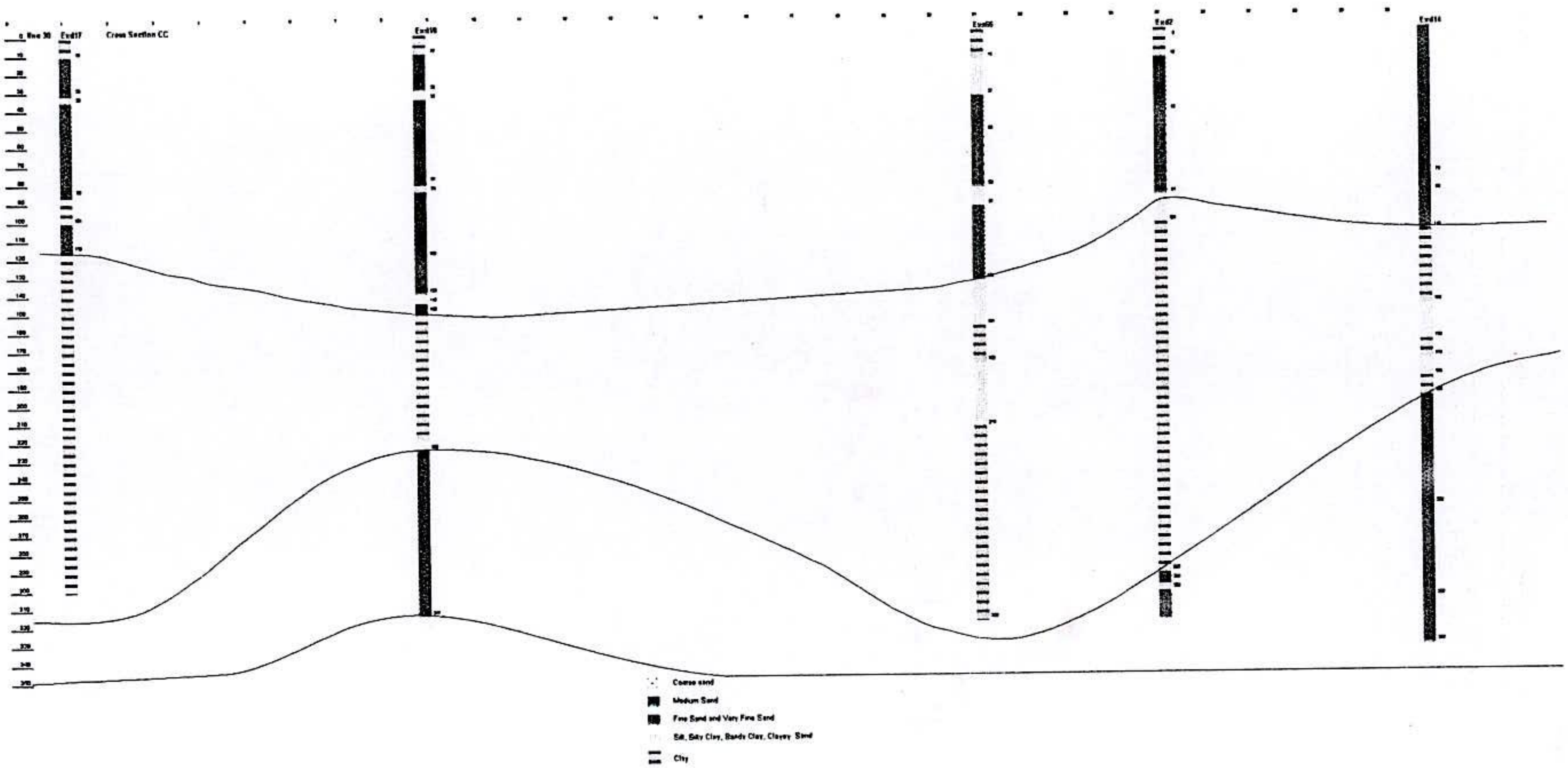
Appendix – 3

Litho-Stratigraphical Cross Sections


line 37
NORTH
Cross Section
AA
Exs7
Pd44
Exd15
SOUTH
Line 04
Coarse sand
Medium Sand
Fine Sand and Very F
Silt, Silty Clay, Sandy
Clay

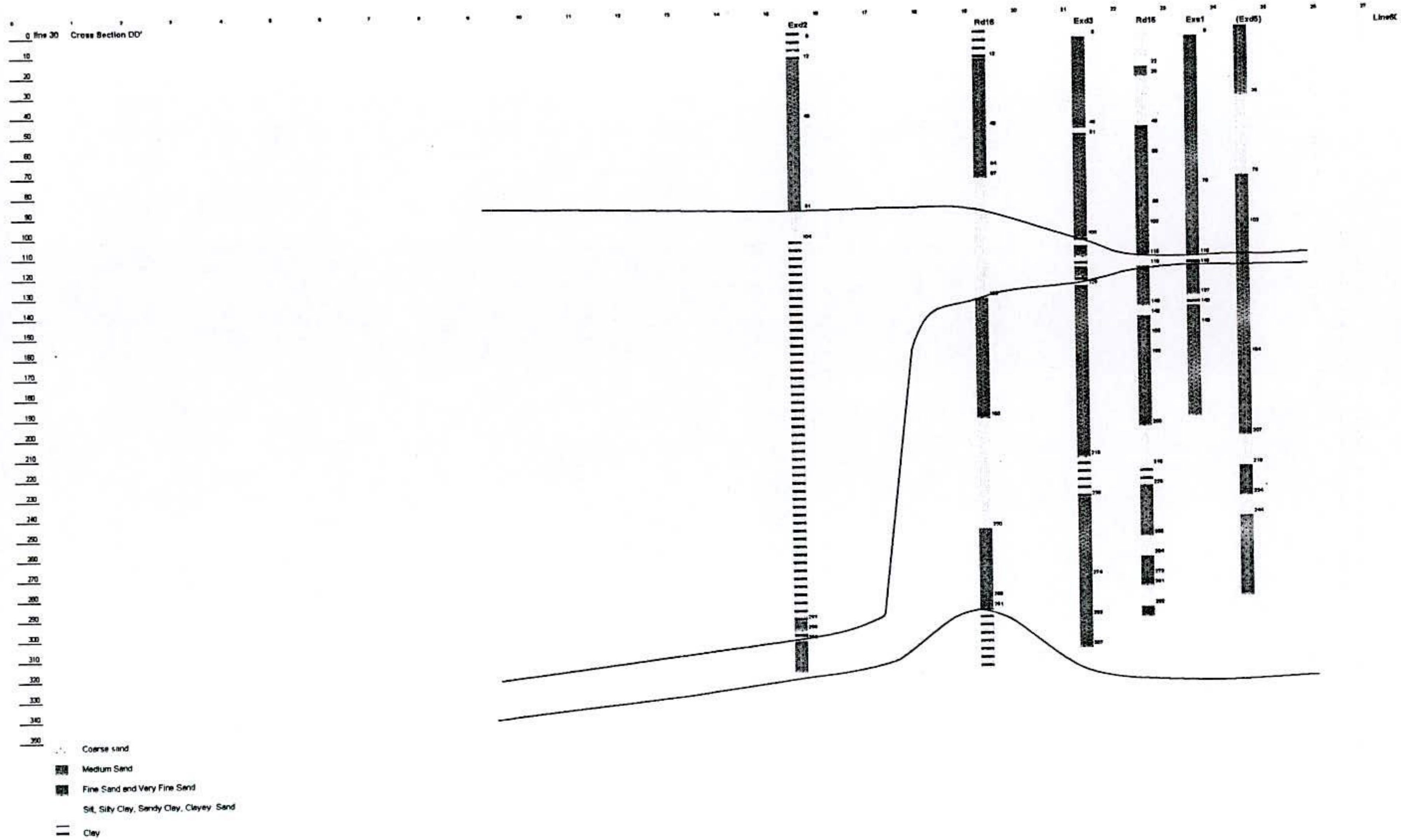
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section CC



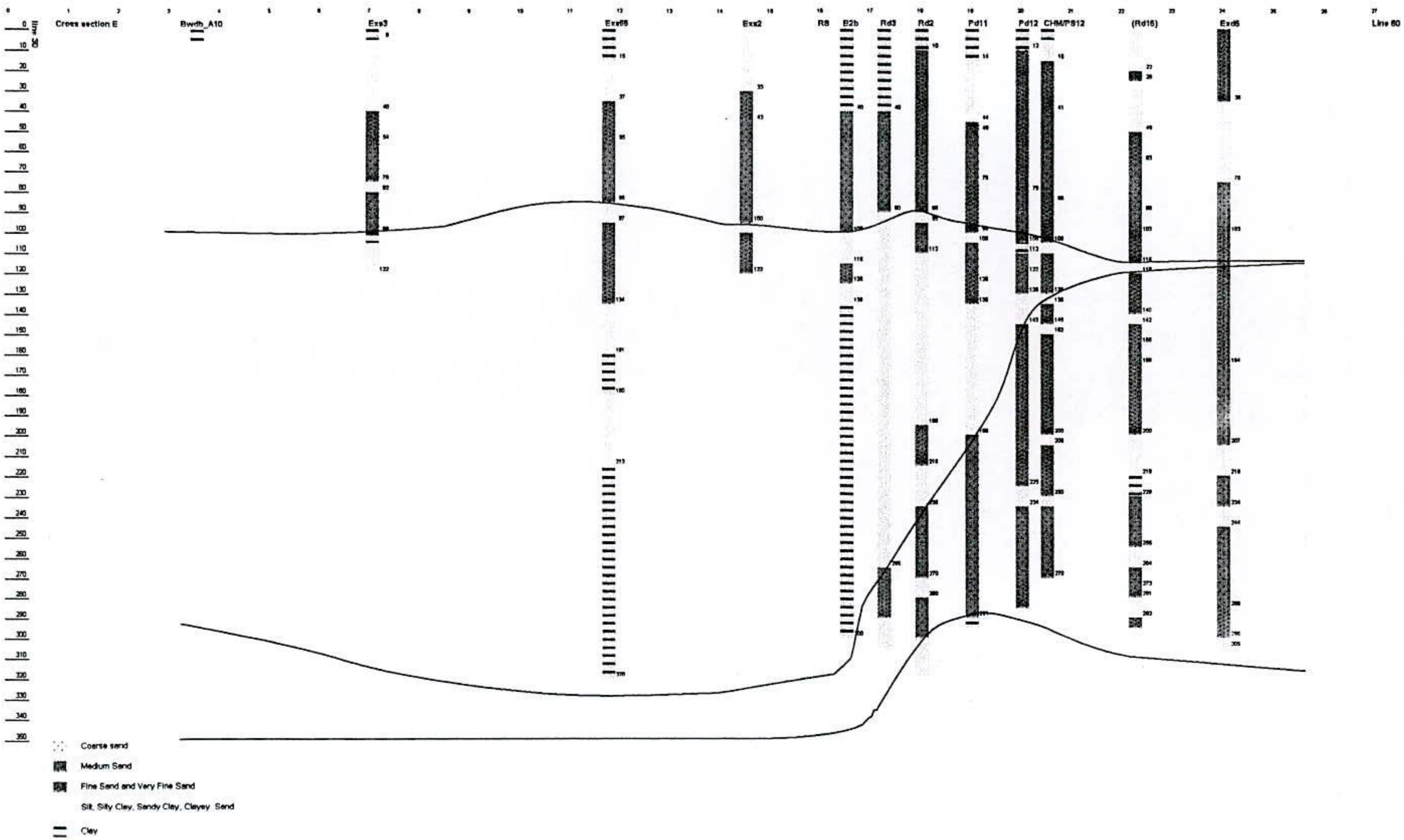
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section DD



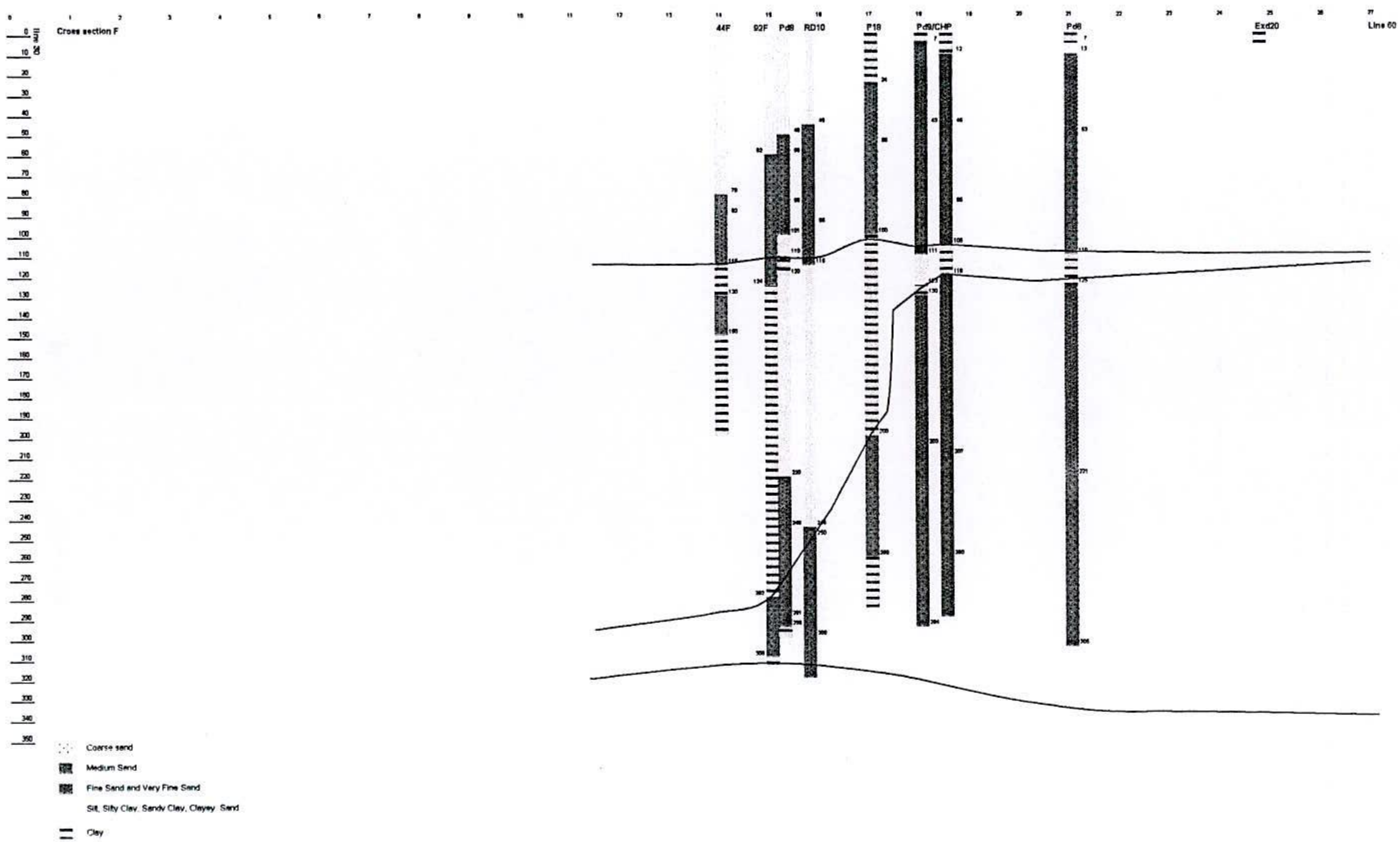
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section EE



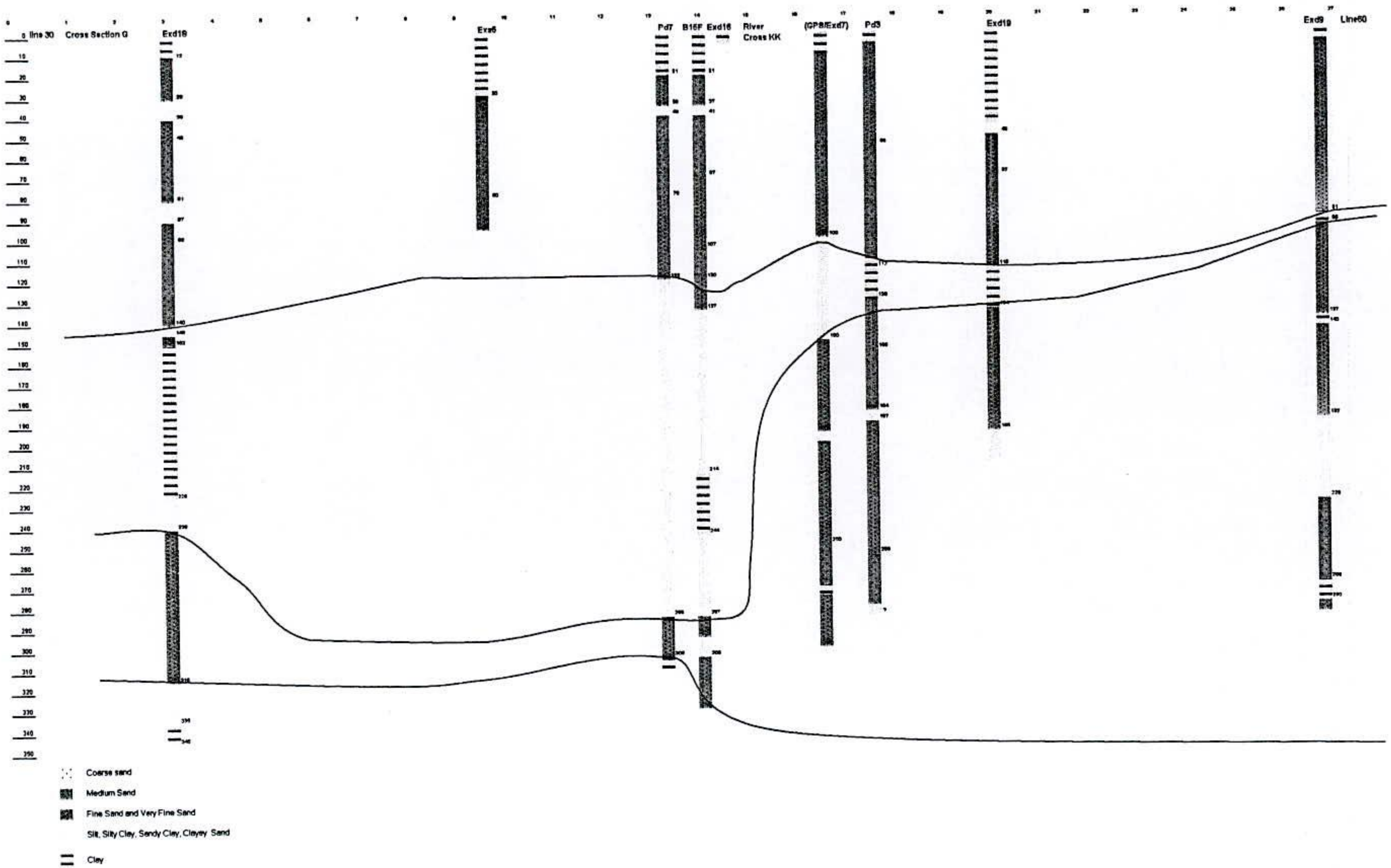
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section FF



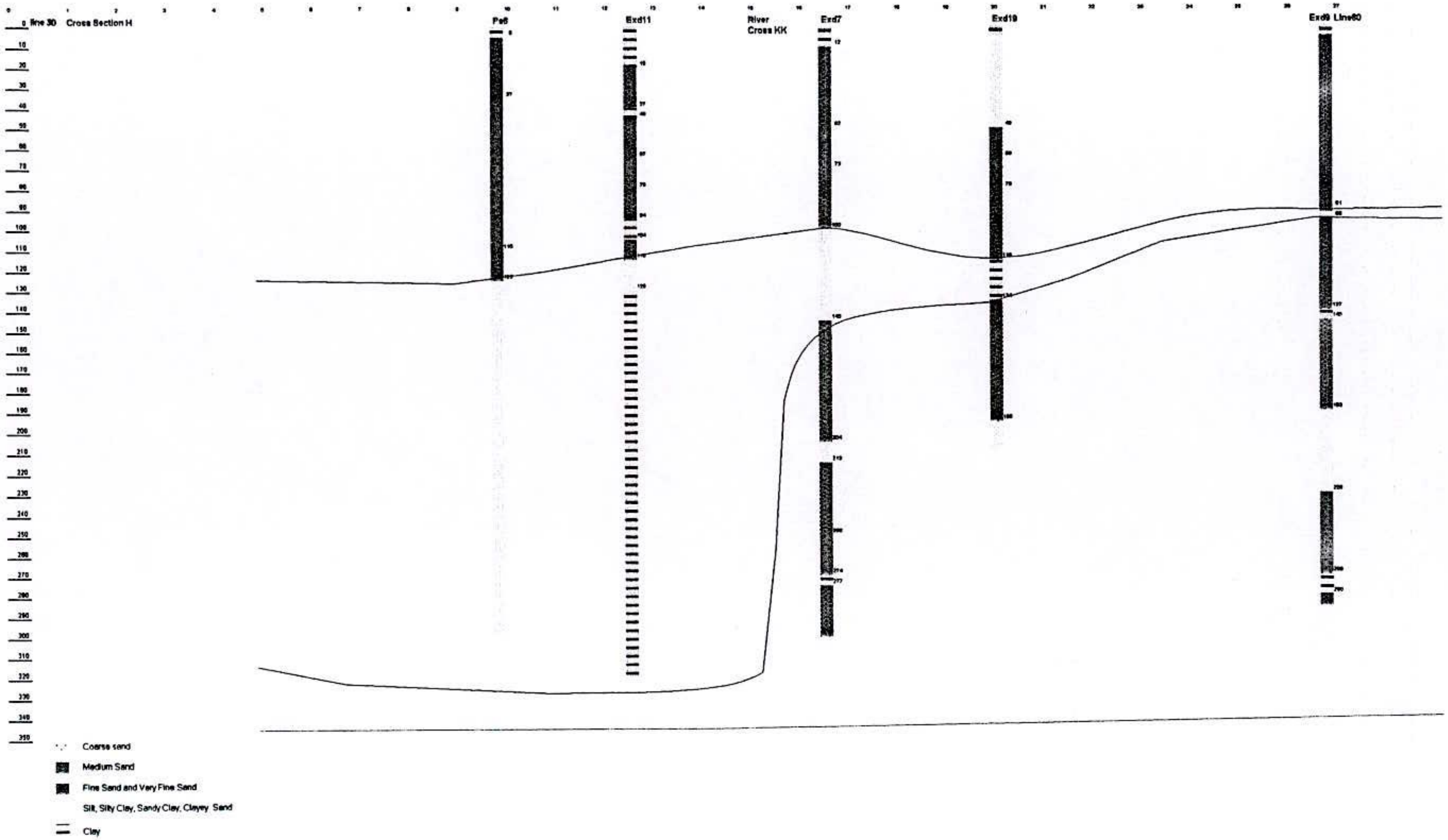
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section GG



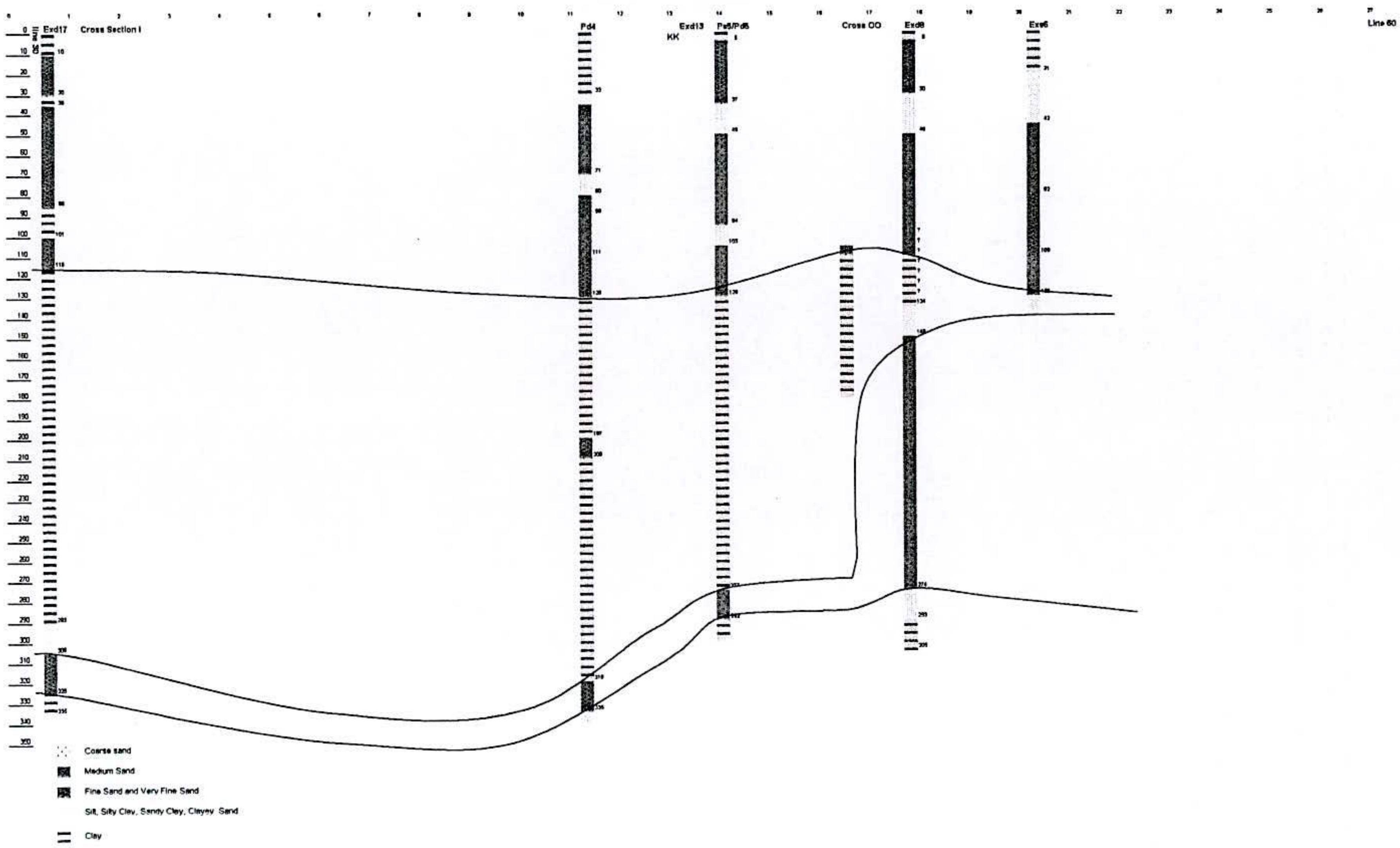
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section HH



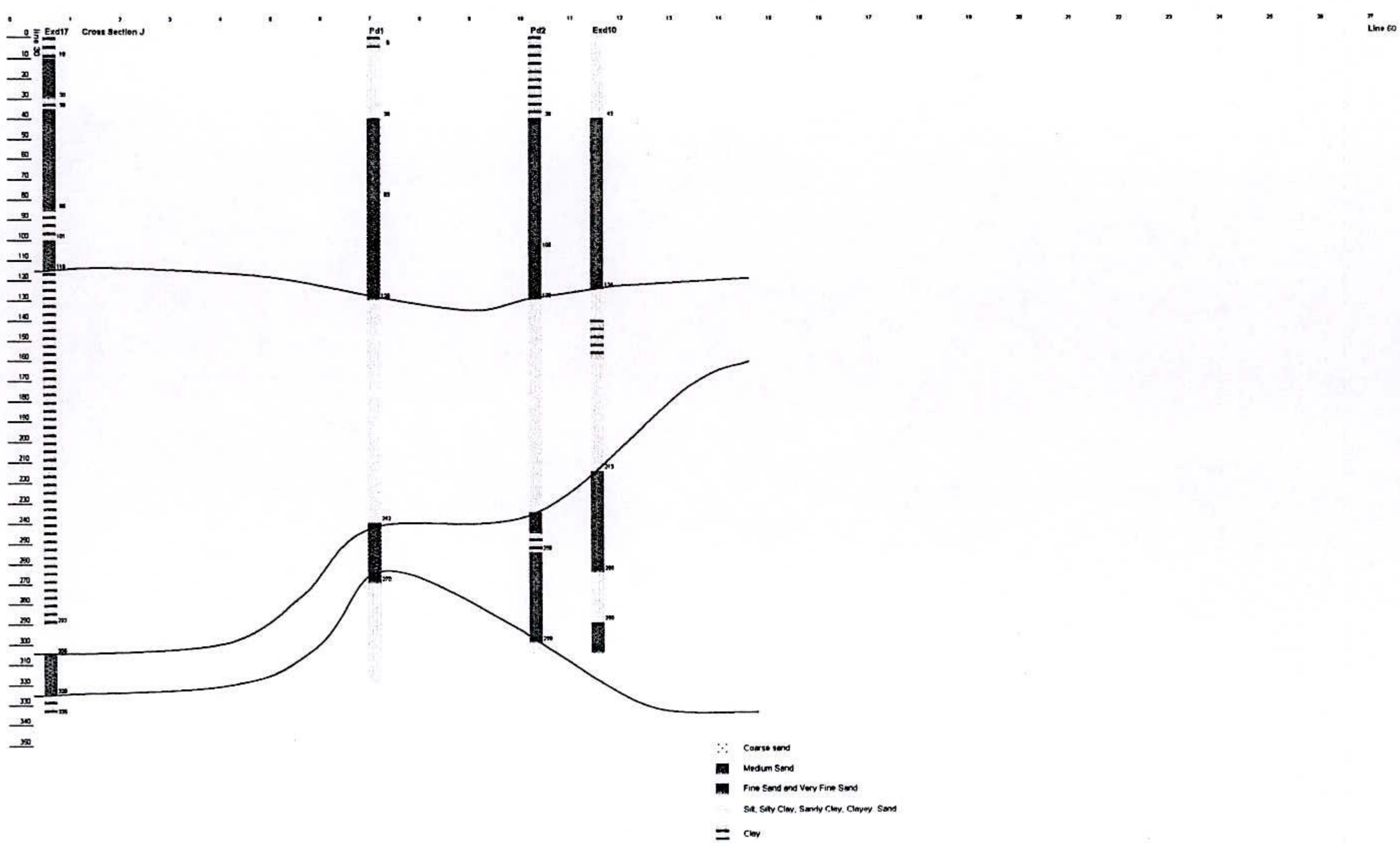
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section II



APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section JJ



Approval

This is to certify that the thesis work submitted by Md. Wahiduzzaman entitled as "**Availability of Groundwater for Drinking Purpose in Khulna City**" has been approved for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in November, 2009.

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11. Karanath, K.R, (1989) Director, Ground Water Department, Andhra Pradesh, Hyderabad, India, *HYDROGEOLOGY*, Tata McGraw-Hill Publishing Company Limited, New Delhi, India.

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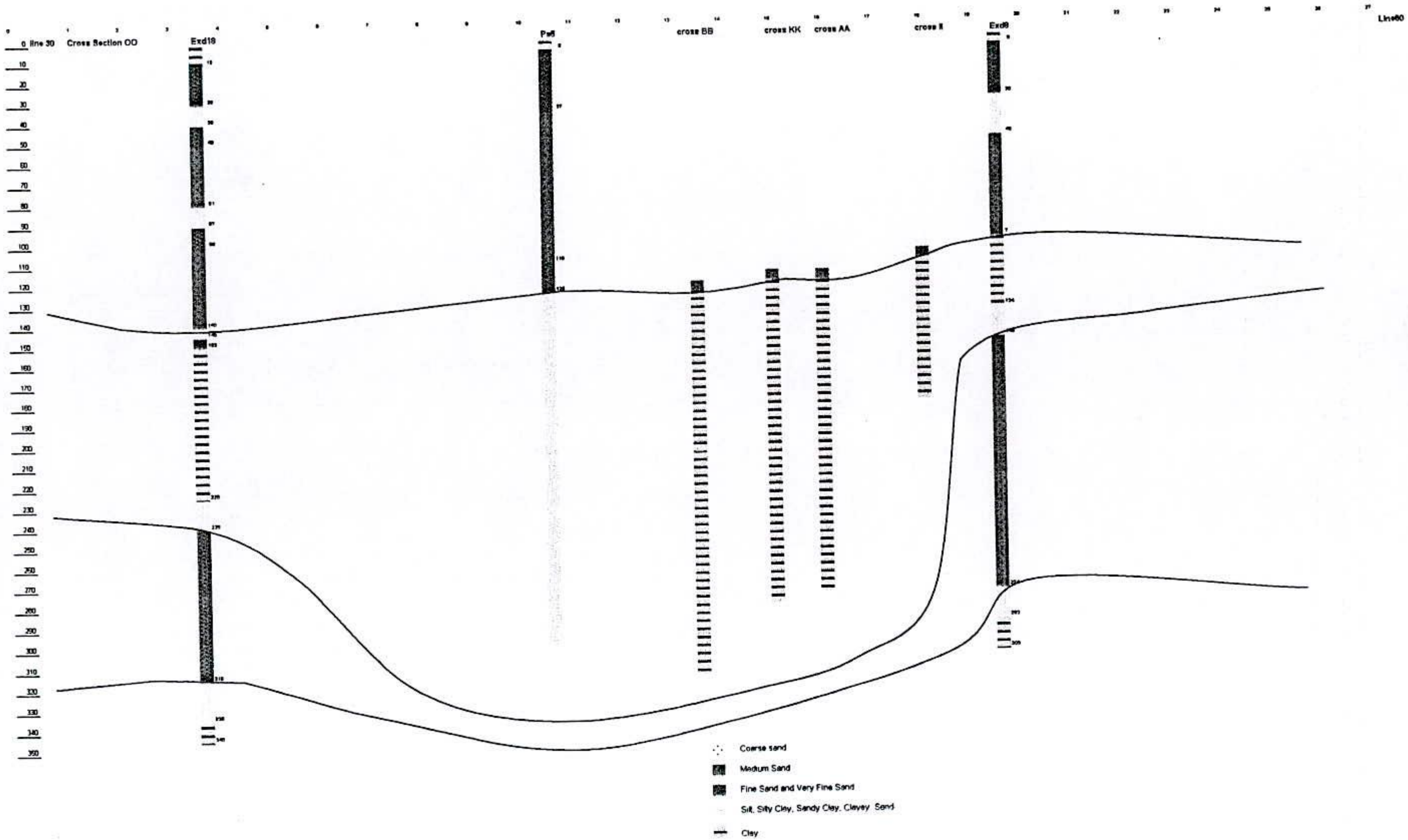
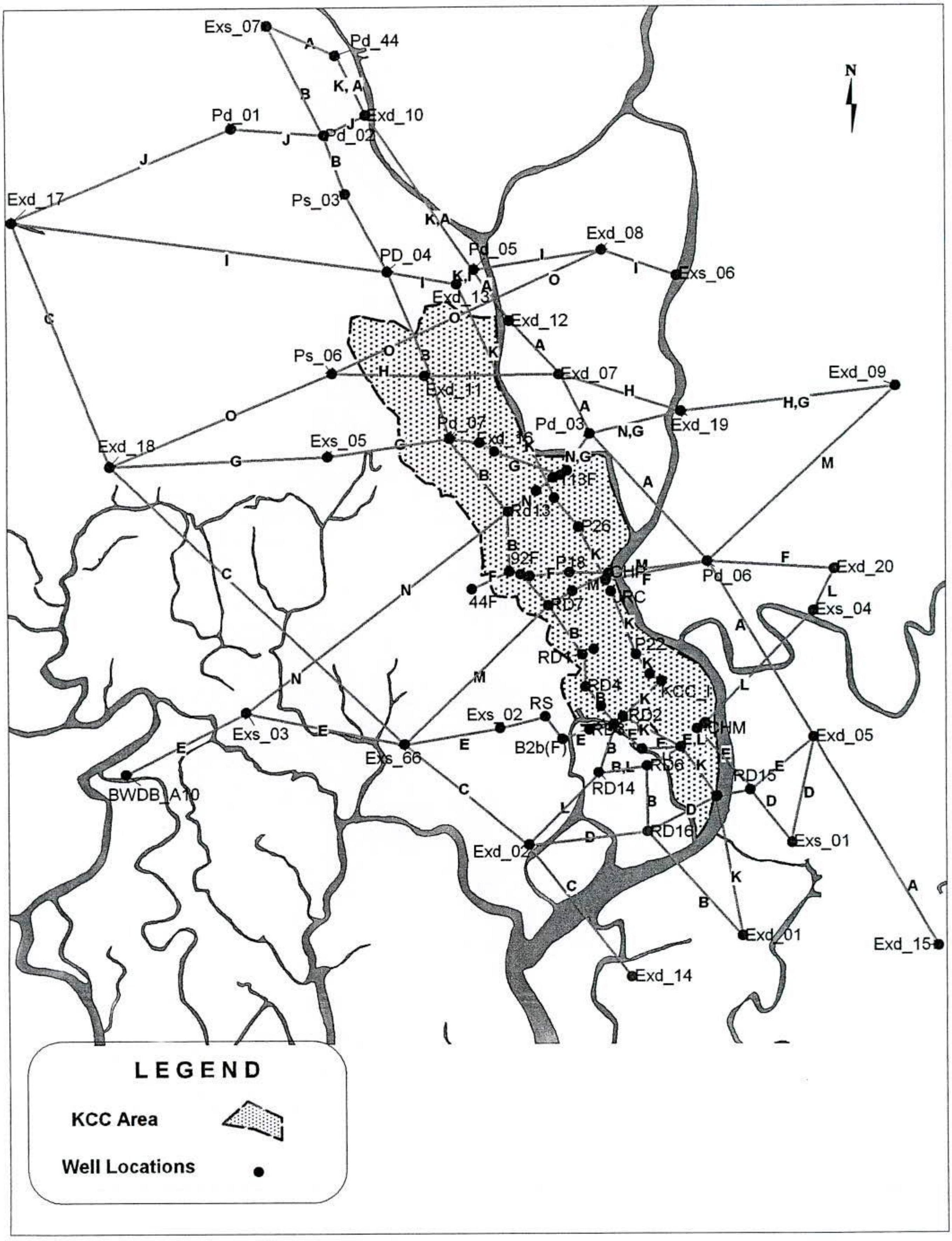
13. MacDonald, M. (1997). Municipal Services Project of LGED. *Feasibility Report; Khulna Water Supply Expansion Component.* Volume -I. Main Report.

14. MacDonald, M. (1997). *Municipal Services Project of LGED. Feasibility Report*; Khulna Water Supply Expansion Component. Volume -II: Appendices.

APPENDIX 3 : GEOLOGICAL CROSS SECTIONS
Cross section OO

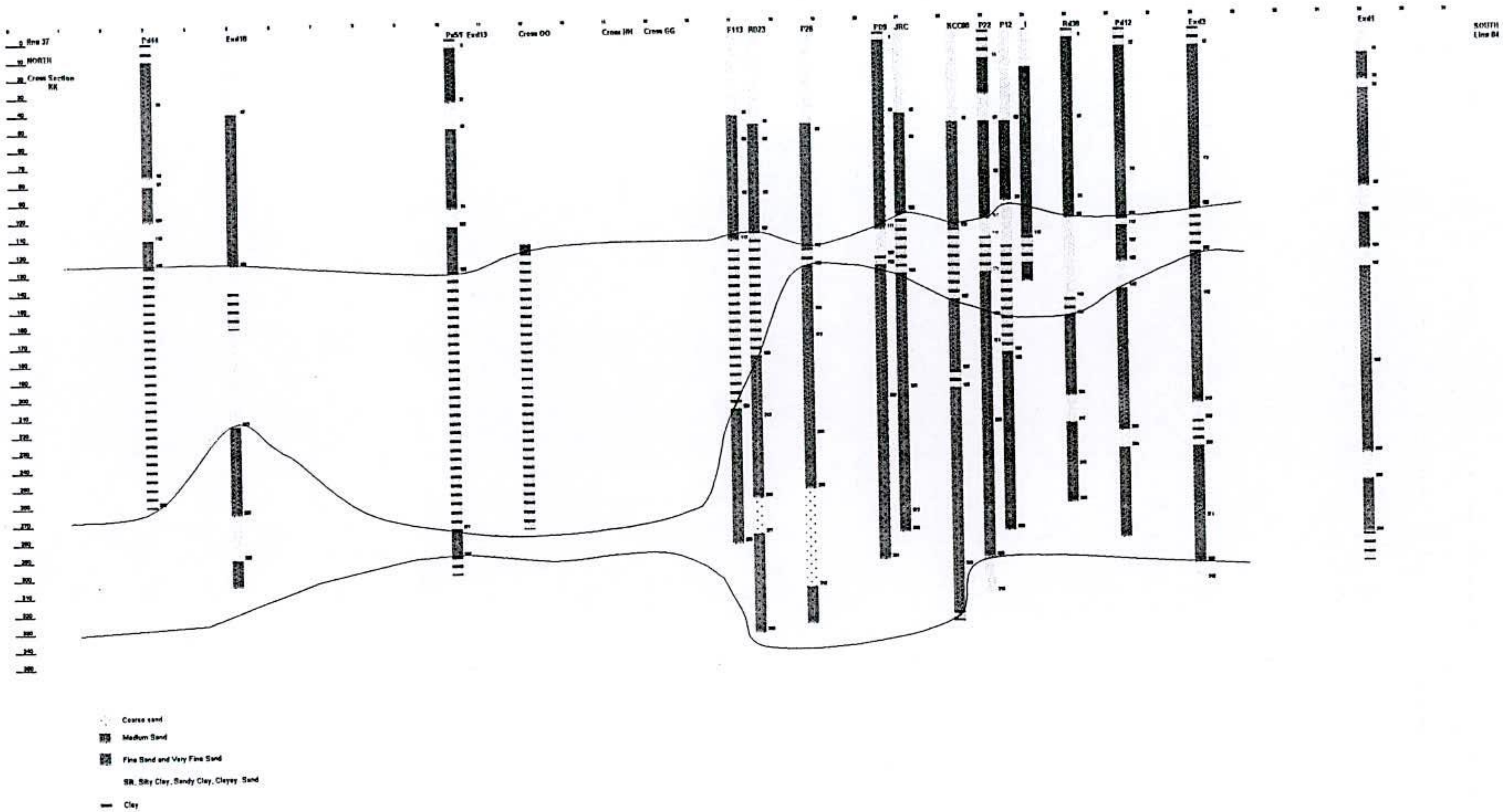


LAYOUT MAP OF GEOLOGICAL CROSS SECTIONS



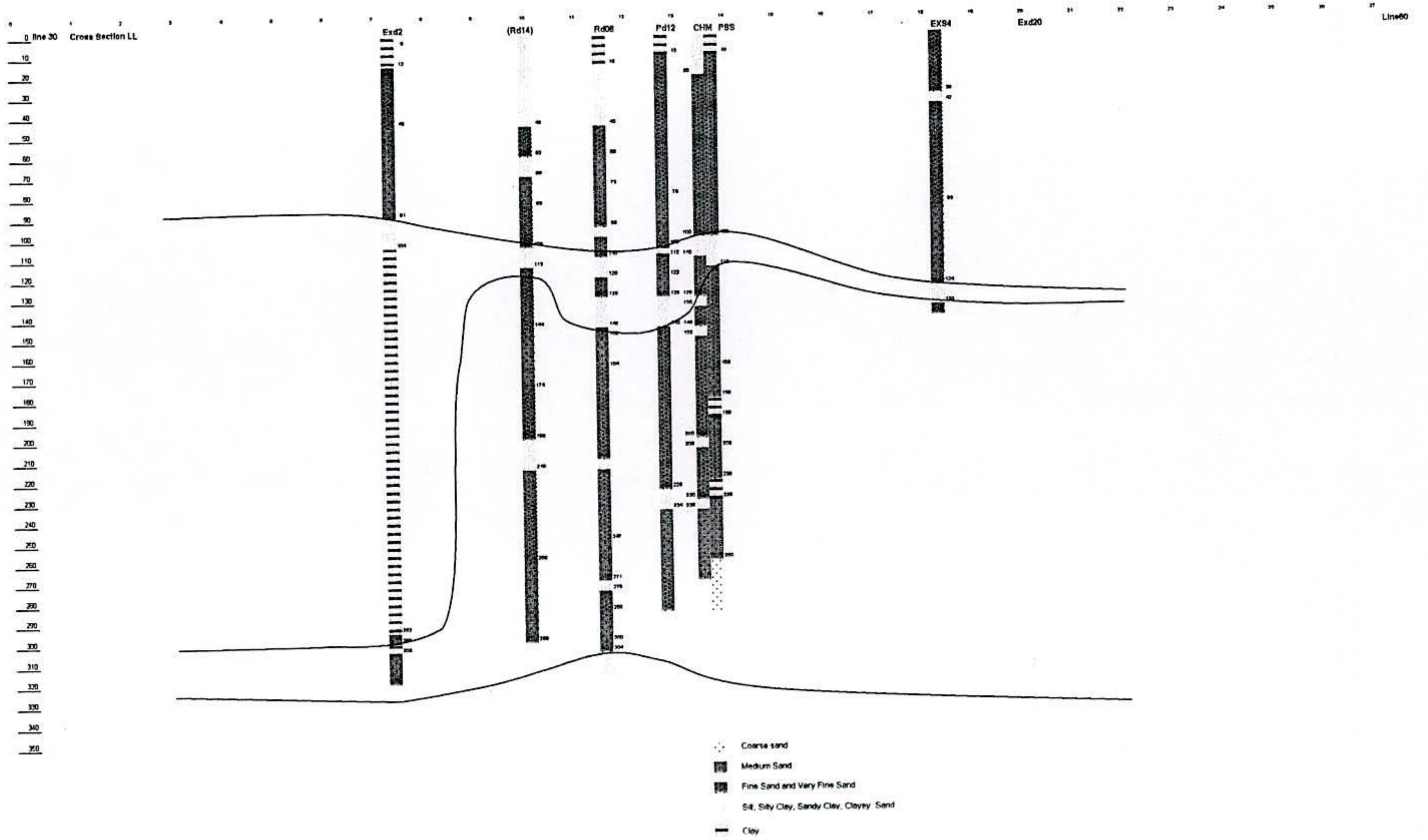
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section KK



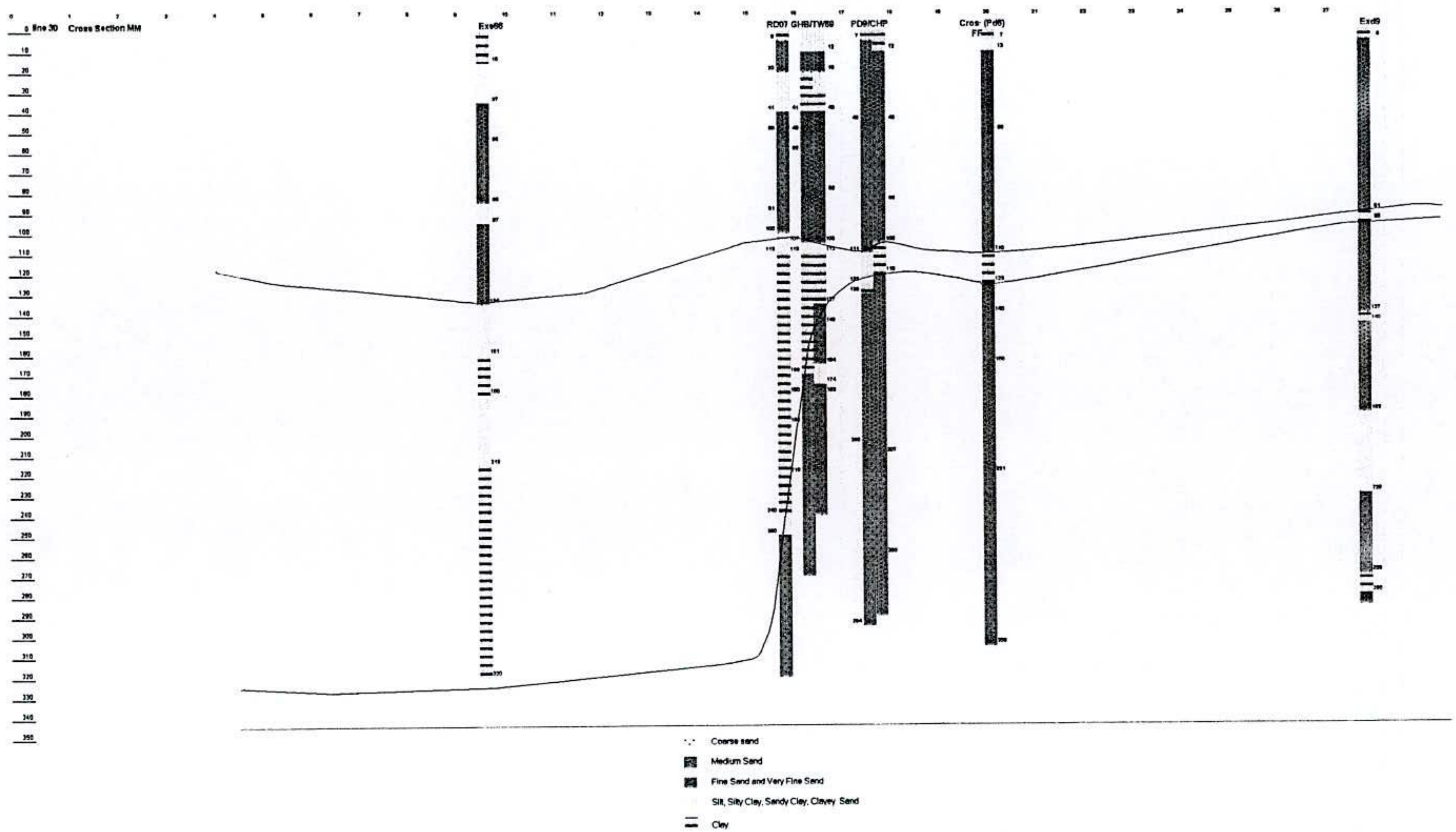
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section LL



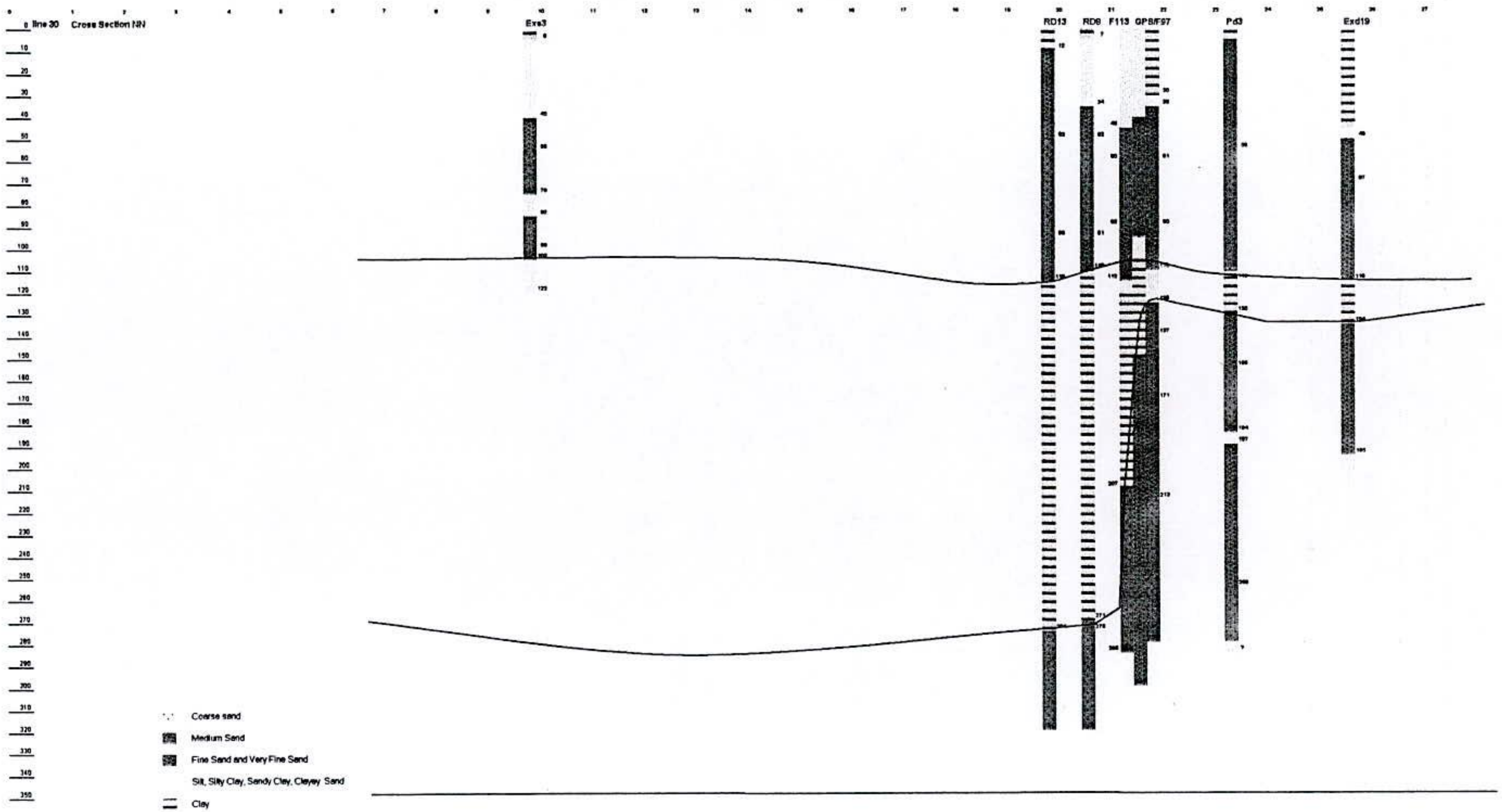
APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section MM



APPENDIX 3 : GEOLOGICAL CROSS SECTIONS

Cross section NN



Appendix – 4

Aquifer Test Tables and Graphs

Table 4-1 : Locations of the Wells for Aquifer Tests in Deep Aquifers

Serial No	X	Y	Well name	Well No
1	89.544	22.849	Khalishpur KCC Office (New)	K B
2	89.568	22.793	Tootpara Well Field	K H
3	89.546	22.856	Khalishpur TV Center	K 48
4	89.526	22.838	Rayer Mahal	K 59
5	89.568	22.808	PTI Mor	K L
6	89.572	22.809	KCC Rest House	K M
7	89.553	22.821	KDA Staff Quarter	K D
8	89.548	22.802	Arambagh - 2	K J
9	89.535	22.849	Mujgunni Well Field 4	K E
10	89.520	22.908	Cable Factory	BSCIC

Table 4-2: Aquifer Test Data of Arambag 72 Hour Pumping

Date: 07.04 to 10.04.05

Planed Discharge m3/h: 50 m3/h

TW N° KCC KJ Arambagh II 07.04 at 22h

Observation W. No Pdj , Distance & Coordinates: 13,7m

Pumping Duration		TW K J			Pdj			Date	Hours
H.M.S.	Second	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)		
00.00.00	0	5.71	5.71	0.00	5.24	5.24	0.00	07.04	22h 00
00.00.30	30	5.71	7.95	2.24	5.24	5.30	0.06		
00.01.00	60	5.71	7.89	2.18	5.24	5.34	0.10		22h 01
00.01.30	90	5.71	7.90	2.19	5.24	5.34	0.10		
00.02.00	120	5.71	7.89	2.18	5.24	5.35	0.11		22h 02
00.03.00	180	5.71	7.84	2.13	5.24	5.35	0.11		22h 03
00.05.00	300	5.71	7.84	2.13	5.24	5.36	0.12		22h 05
00.07.30	450	5.71	7.84	2.13	5.24	5.37	0.13		
00.10.00	600	5.71	7.84	2.13	5.24	5.38	0.14		22h 10
00.15.00	900	5.71	7.84	2.13	5.24	5.38	0.14		22h 15
00.20.00	1200	5.71	7.84	2.13	5.24	5.39	0.15		22h 20
00.30.00	1800	5.71	7.85	2.14	5.24	5.39	0.15		22h 30
00.50.00	3000	5.71	7.89	2.18	5.24	5.39	0.15		22h 50
01.15.00	4500	5.71	7.91	2.20	5.24	5.38	0.14		23h 15
01.40.00	6000	5.71	7.89	2.18	5.24	5.36	0.12		23h 40
02.30.00	9000	5.71	7.83	2.12	5.24	5.30	0.06	08.04	00h 30
03.20.00	12000	5.71	7.78	2.07	5.24	5.25	0.01		01h 20
05.00.00	18000	5.71	7.67	1.96	5.24	5.13	-0.11		03h 00
08.20.00	30000	5.71	7.64	1.93	5.24	5.12	-0.12		06h 20
12.30.00	45000	5.71	7.94	2.23	5.24	5.42	0.18		10h 30
16.40.00	60000	5.71	8.64	2.93	5.24	5.90	0.66		14h 40
25.00.00	90000	5.71	8.17	2.46	5.24	5.59	0.35		23h 00
33.20.00	120000	5.71	7.93	2.22	5.24	5.36	0.12	09.04	07h 20
38.00.00	136800	5.71	8.40	2.69	5.24	5.78	0.54		12h 00
48.00.00	172800	5.71	8.27	2.56	5.24	5.70	0.46		22h 00
54.00.00	194400	5.71	7.79	2.08	5.24	5.20	-0.04	10.04	04h 00
62.30.00	225000	5.71	8.43	2.72	5.24	5.86	0.62		12h 30
72.00.00	259200	5.71	8.44	2.73	5.24	5.80	0.56		22h 00

Table 4-3: Aquifer Test Data of Arambag for 12 hour Pumping

Date: 05.04 to 05.04.05
Planed Discharge m3/h: 118 m3/h

TW N° K J Arambagh II 05.04 at 06h 30 min.

Observation W. No. Pdj , Distance 13.7m.

Pumping Duration		KCC K J			Pdj				
H.M.S.	Second	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)		
00.00.00	0	5.35	5.35	0.00	4.81	4.81	0.00		06h 30'
00.00.30	30	5.35	11.60	6.25	4.81	4.96	0.15		
00.01.00	60	5.35	12.25	6.90	4.81	5.05	0.24		
00.01.30	90	5.35	12.49	7.14	4.81	5.10	0.29		
00.02.00	120	5.35	12.60	7.25	4.81	5.12	0.31		
00.03.00	180	5.35	12.66	7.31	4.81	5.15	0.34		
00.05.00	300	5.35	12.82	7.47	4.81	5.21	0.40		
00.07.30	450	5.35	12.90	7.55	4.81	5.25	0.44		
00.10.00	600	5.35	13.04	7.69	4.81	5.29	0.48		
00.15.00	900	5.35	13.23	7.88	4.81	5.33	0.52	05.04	
00.20.00	1200	5.35	13.26	7.91	4.81	5.37	0.56		
00.30.00	1800	5.35	13.43	8.08	4.81	5.44	0.63		
00.50.00	3000	5.35	13.54	8.19	4.81	5.55	0.74		
01.15.00	4500	5.35	13.66	8.31	4.81	5.67	0.86		
01.40.00	6000	5.35	13.78	8.43	4.81	5.77	0.96		
02.30.00	9000	5.35	14.16	8.81	4.81	5.93	1.12		
03.20.00	12000	5.35	14.04	8.69	4.81	6.05	1.24		
05.00.00	18000	5.35	14.05	8.70	4.81	6.08	1.27		
08.20.00	30000	5.35	14.37	9.02	4.81	6.32	1.51		
12.00.00	43200	5.35	14.55	9.20	4.81	6.38	1.57		

Table 4-4: Aquifer Test Data of Rayer Mahal for 72 Hrs Pumping

Date: 30.03 to 02.04.05

Planed Discharge m^3/h: 40 m3/h

TW No. K 59 Rayer Mahal & Coordinates: 30.03 at 06h 22 min.

Observation W. No. Pd59 , Distance & Coordinates: 35m

Pumping Duration		TW K 59			Pd 59				
H.M.S.	Second	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)		
00.00.00	0	5.11	5.11	0.00	4.57	4.57	0.00		06h 20'
00.00.30	30	5.11	13.56	8.45	4.57	4.58	0.01		
00.01.00	60	5.11	13.88	8.77	4.57	4.59	0.02		
00.01.30	90	5.11	14.60	9.49	4.57	4.60	0.03		
00.02.00	120	5.11	14.77	9.66	4.57	4.63	0.06		
00.03.00	180	5.11	12.54	7.43	4.57	4.65	0.08		
00.05.00	300	5.11	11.47	6.36	4.57	4.66	0.09		06h 25'
00.07.30	450	5.11	11.22	6.11	4.57	4.66	0.09		
00.10.00	600	5.11	12.02	6.91	4.57	4.65	0.08		
00.15.00	900	5.11	12.06	6.95	4.57	4.67	0.10		
00.20.00	1200	5.11	12.02	6.91	4.57	4.68	0.11	30.03	
00.30.00	1800	5.11	12.02	6.91	4.57	4.69	0.12		
00.50.00	3000	5.11	12.01	6.90	4.57	4.70	0.13		
01.15.00	4500	5.11	12.02	6.91	4.57	4.71	0.14		07h 35'
01.40.00	6000	5.11	12.25	7.14	4.57	4.74	0.17		
02.30.00	9000	5.11	12.32	7.21	4.57	4.76	0.19		08h 50'
03.20.00	12000	5.11	12.38	7.27	4.57	4.79	0.22		09h 40'
05.00.00	18000	5.11	12.39	7.28	4.57	4.81	0.24		11h 20'
08.20.00	30000	5.11	12.42	7.31	4.57	4.86	0.29		14h 40'
12.30.00	45000	5.11	13.50	8.39	4.57	4.89	0.32		18h 50'
16.40.00	60000	5.11	14.15	9.04	4.57	4.85	0.28		23h 00'
25.00.00	90000	5.11	14.29	9.18	4.57	4.75	0.18		07h 20'
33.20.00	120000	5.11	14.35	9.24	4.57	4.90	0.33	31.03.	15h 40'
38.00.00	136800	5.11	15.27	10.16	4.57	4.88	0.31		08h 20'
48.00.00	172800	5.11	14.99	9.88	4.57	4.75	0.18		06h 20'
54.00.00	194400	5.11	14.36	9.25	4.57	4.82	0.25	01.04.06	12h 20'
62.30.00	225000	5.11	15.15	10.04	4.57	4.90	0.33		
72.00.00	259200	5.11	14.79	9.68	4.57	4.74	0.17	02.04.07	06h 20'

Table 4-5 : Aquifer Test Data of KCC Rest House for 10 Hrs Pumping

Aquifer test, constant yield, 10h. At KCC TW No. m Rest House

Yield 72 m^3/h ..... Date 18 to 19.03.2005 Distance KCC m to Pdm = 18.4m

Borehole No. m				Piezometer No. Pdm		
Pumping Time	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)
0	6.55	6.55	0.00	6.19	6.19	0.00
30	6.55	9.72	3.17	6.19	6.21	0.02
60	6.55	10.22	3.67	6.19	6.30	0.11
90	6.55	10.30	3.75	6.19	6.34	0.15
120	6.55	10.32	3.77	6.19	6.35	0.16
180	6.55	10.32	3.77	6.19	6.37	0.18
300	6.55	10.36	3.81	6.19	6.40	0.21
450	6.55	10.37	3.82	6.19	6.42	0.23
600	6.55	10.36	3.81	6.19	6.42	0.25
900	6.55	10.40	3.85	6.19	6.44	0.26
1200	6.55	10.42	3.87	6.19	6.45	0.29
1800	6.55	10.37	3.82	6.19	6.48	0.29
3000	6.55	10.30	3.75	6.19	6.48	0.28
4500	6.55	10.35	3.80	6.19	6.47	0.28
6000	6.55	10.39	3.84	6.19	6.45	0.26
9000	6.55	10.38	3.83	6.19	6.41	0.22
12000	6.55	10.30	3.75	6.19	6.38	0.19
18000	6.55	10.28	3.73	6.19	6.29	0.10
30000	6.55	10.14	3.59	6.19	6.14	0.05
36000	6.55	10.36	3.81	6.19	6.37	0.18

Table 4-6: Aquifer Test Data of PTI Mor for 10 Hrs Pumping

Aquifer test, constant yield, 10h. At KCC TW No. PTI Mor (I)

Yield 122 m^3/h Date 19 to 0.03.2005 Distance TW to Pd PTI Mor = 9.1m

Borehole No. I				Piezometer No. PdI		
Pumping Time	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)
0	6.25	6.25	0.00	6.30	6.30	0.00
30	6.25	13.30	7.05	6.30	6.41	0.11
60	6.25	13.40	7.15	6.30	6.47	0.17
90	6.25	13.40	7.15	6.30	6.50	0.20
120	6.25	13.35	7.10	6.30	6.52	0.22
180	6.25	13.39	7.14	6.30	6.54	0.24
300	6.25	13.40	7.15	6.30	6.58	0.28
450	6.25	13.20	6.95	6.30	6.59	0.29
600	6.25	13.18	6.93	6.30	6.6	0.32
900	6.25	13.31	7.06	6.30	6.62	0.33
1200	6.25	13.42	7.17	6.30	6.63	0.35
1800	6.25	13.32	7.07	6.30	6.65	0.37
3000	6.25	13.46	7.21	6.30	6.67	0.36
4500	6.25	13.42	7.17	6.30	6.66	0.36
6000	6.25	13.41	7.16	6.30	6.64	0.34
9000	6.25	13.47	7.22	6.30	6.59	0.29
12000	6.25	13.43	7.18	6.30	6.55	0.25
18000	6.25	13.41	7.16	6.30	6.47	0.17
30000	6.25	13.34	7.09	6.30	6.46	0.16
36000	6.25	13.46	7.21	6.30	6.71	0.41

Table 4-7 : Aquifer Test Data of Tootpara for 10 Hrs Pumping

Aquifer test, constant yield, 10h. At KCC TW No. h Tootpara

Yield 111 m^3/h (145 at Fm) Date 20 to 21.03.2005 Distance TW h to Pdh = 13.3 m

Borehole No. h				Piezometer No. Pdh		
Pumping Time	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)
0	5.32	5.32	0.00	4.93	4.93	0.00
30	5.32	12.78	7.46	4.93	5.13	0.20
60	5.32	13.80	8.48	4.93	5.21	0.28
90	5.32	14.06	8.74	4.93	5.24	0.31
120	5.32	14.14	8.82	4.93	5.27	0.34
180	5.32	14.21	8.89	4.93	5.30	0.37
300	5.32	14.24	8.92	4.93	5.35	0.42
450	5.32	14.28	8.96	4.93	5.37	0.44
600	5.32	14.30	8.98	4.93	5.40	0.47
900	5.32	14.34	9.02	4.93	4.43	0.52
1200	5.32	14.41	9.09	4.93	5.45	0.55
1800	5.32	14.38	9.06	4.93	5.48	0.57
3000	5.32	14.38	9.06	4.93	5.50	0.57
4500	5.32	14.39	9.07	4.93	5.50	0.57
6000	5.32	14.59	9.27	4.93	5.50	0.57
9000	5.32	14.56	9.24	4.93	5.48	0.55
12000	5.32	14.62	9.30	4.93	5.45	0.52
18000	5.32	14.58	9.26	4.93	5.40	0.47
30000	5.32	14.69	9.37	4.93	5.34	0.41
31800	5.32	14.68	9.36	4.93	5.33	0.40

Table 4-8: Aquifer Test Data of KDA for 10 Hrs. Pumping

Aquifer test, constant yield, 10h. At KCC TW No. d / KDA

Yield 116 m^3/h Date 21 to 2.03.2005 Distance TW No. d to Pdd KDA = 3.74m

Borehole No. d				Piezometer No. Pdd		
Pumping Time	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)
0	5.92	5.92	0.00	5.46	5.46	0.00
30	5.92	12.84	6.92	5.46	5.55	0.09
60	5.92	13.53	7.61	5.46	5.61	0.15
90	5.92	13.67	7.75	5.46	5.63	0.17
120	5.92	13.79	7.87	5.46	5.64	0.18
180	5.92	13.77	7.85	5.46	5.66	0.20
300	5.92	13.82	7.90	5.46	5.68	0.22
450	5.92	13.82	7.90	5.46	5.69	0.23
600	5.92	13.83	7.91	5.46	5.7	0.25
900	5.92	13.86	7.94	5.46	5.71	0.25
1200	5.92	13.81	7.89	5.46	5.71	0.26
1800	5.92	13.95	8.03	5.46	5.72	0.26
3000	5.92	13.71	7.79	5.46	5.71	0.25
4500	5.92	13.69	7.77	5.46	5.70	0.24
6000	5.92	13.70	7.78	5.46	5.68	0.22
9000	5.92	13.82	7.90	5.46	5.64	0.18
12000	5.92	13.70	7.78	5.46	5.59	0.13
18000	5.92	13.81	7.89	5.46	5.57	0.11
30000	5.92	13.84	7.92	5.46	5.65	0.19
36000	5.92	13.98	8.06	5.46	5.83	0.37

Table 4-9: Aquifer Test Data of Mujgunni for 12 Hrs. Pumping

Date: 24.03.05

Planed Discharge m^3/h: 24 to 25.03.

TW No. e and Pde & Coordinates: Mujgunni KCC e

Observation W. No. Distance & Coordinates: 6m.

Pumping Duration		TW			Observation Well		
H.M.S.	Second	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)
00.00.00	0	4.92	4.92	0.00	4.67	4.67	0.00
00.00.30	30	4.92	14.29	9.37	4.67	4.80	0.13
00.01.00	60	4.92	15.22	10.30	4.67	4.93	0.26
00.01.30	90	4.92	15.60	10.68	4.67	4.97	0.30
00.02.00	120	4.92	15.79	10.87	4.67	5.00	0.33
00.03.00	180	4.92	15.95	11.03	4.67	5.03	0.36
00.05.00	300	4.92	16.20	11.28	4.67	5.07	0.40
00.07.30	450	4.92	16.38	11.46	4.67	5.10	0.43
00.10.00	600	4.92	16.41	11.49	4.67	5.11	0.44
00.15.00	900	4.92	16.44	11.52	4.67	5.14	0.47
00.20.00	1200	4.92	16.40	11.48	4.67	5.15	0.48
00.30.00	1800	4.92	16.50	11.58	4.67	5.17	0.50
00.50.00	3000	4.92	16.60	11.68	4.67	5.22	0.55
01.15.00	4500	4.92	16.70	11.78	4.67	5.25	0.58
01.40.00	6000	4.92	16.76	11.84	4.67	5.25	0.58
02.30.00	9000	4.92	16.61	11.69	4.67	5.26	0.59
03.20.00	12000	4.92	16.87	11.95	4.67	5.27	0.60
05.00.00	18000	4.92	16.77	11.85	4.67	5.24	0.57
08.20.00	30000	4.92	16.78	11.86	4.67	5.16	0.49
12.30.00	45000	4.92	17.06	12.14	4.67	5.33	0.66

Table 4-10: Aquifer Test Data of Khalishpur TV Centre for 10 Hrs. Pumping

Date: 28.03.05 At 08h 23

Planed Discharge 2 m^3/h or 40 mm on V notch

TW No. KCC 48 & Pd48 Coordinates: Khalishpur TV Center

Observation W. No. Distance & Coordinates:

3m.

Pumping Duration		TW			Observation Well		
H.M.S.	Second	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)
00.00.00	0	7.10	7.10	0.00	6.32	6.32	0.00
00.00.30	30	7.10	14.29	8.54	6.32	6.32	0.00
00.01.00	60	7.10	15.22	8.75	6.32	6.33	0.01
00.01.30	90	7.10	15.60	8.95	6.32	6.33	0.01
00.02.00	120	7.10	15.79	9.02	6.32	6.33	0.01
00.03.00	180	7.10	15.95	9.08	6.32	6.34	0.02
00.05.00	300	7.10	16.20	9.25	6.32	6.34	0.02
00.07.30	450	7.10	20.00	9.90	6.32	6.34	0.02
00.10.00	600	7.10	16.41	10.22	6.32	6.34	0.02
00.15.00	900	7.10	16.44	10.57	6.32	6.34	0.02
00.20.00	1200	7.10	16.40	10.78	6.32	6.35	0.03
00.30.00	1800	7.10	16.50	10.96	6.32	6.36	0.04
00.50.00	3000	7.10	16.60	11.03	6.32	6.37	0.05
01.15.00	4500	7.10	16.70	11.02	6.32	6.38	0.06
01.40.00	6000	7.10	16.76	11.09	6.32	6.39	0.07
02.30.00	9000	7.10	16.61	11.08	6.32	6.42	0.10
03.20.00	12000	7.10	16.87	11.12	6.32	6.44	0.12
05.00.00	18000	7.10	16.77	11.14	6.32	6.41	0.09

Table 4-11: Aquifer Test Data of Khalishpur KCC Branch Office

Date: 27.03.05 at 08h.

Planed Discharge 100 m^3/h

TW No. K B & Pdb Coordinates: Khalishpur KCC Branch Office

Observation W. No., Distance 9.8 m & Coordinates: 10 m.

Pumping Duration		TW			Observation Well		
H.M.S.	Second	SWL (m)	DWL (m)	DD (m)	SWL (m)	DWL (m)	DD (m)
00.00.00	0	6.90	6.90	0.00	6.59	6.59	0.00
00.00.30	30	6.90			6.59		
00.01.00	60	6.90	12.15	5.25	6.59		
00.01.30	90	6.90	12.22	5.32	6.59	6.89	0.30
00.02.00	120	6.90	12.22	5.32	6.59	6.91	0.32
00.03.00	180	6.90	12.12	5.22	6.59	6.92	0.33
00.05.00	300	6.90	11.97	5.07	6.59	6.93	0.34
00.07.30	450	6.90	11.95	5.05	6.59	6.94	0.35
00.10.00	600	6.90	12.00	5.10	6.59	6.95	0.36
00.15.00	900	6.90	12.03	5.13	6.59	6.96	0.37
00.20.00	1200	6.90	12.12	5.22	6.59	6.97	0.38
00.30.00	1800	6.90	11.78	4.88	6.59	6.97	0.38
00.50.00	3000	6.90	11.75	4.85	6.59	6.99	0.40
01.15.00	4500	6.90	11.73	4.83	6.59	7.00	0.41
01.40.00	6000	6.90	11.70	4.80	6.59	7.00	0.41
02.30.00	9000	6.90	11.69	4.79	6.59	7.00	0.41
03.20.00	12000	6.90	11.69	4.79	6.59	6.99	0.40
05.00.00	18000	6.90	11.34	4.44	6.59	6.95	0.36
08.20.00	30000	6.90	11.45	4.55	6.59	6.96	0.37
12.00.00	43200	6.90	11.69	4.79	6.59	7.02	0.43

Table 4-12: Aquifer Test Data of Shiromoni Cable Factory for 50 Minutes

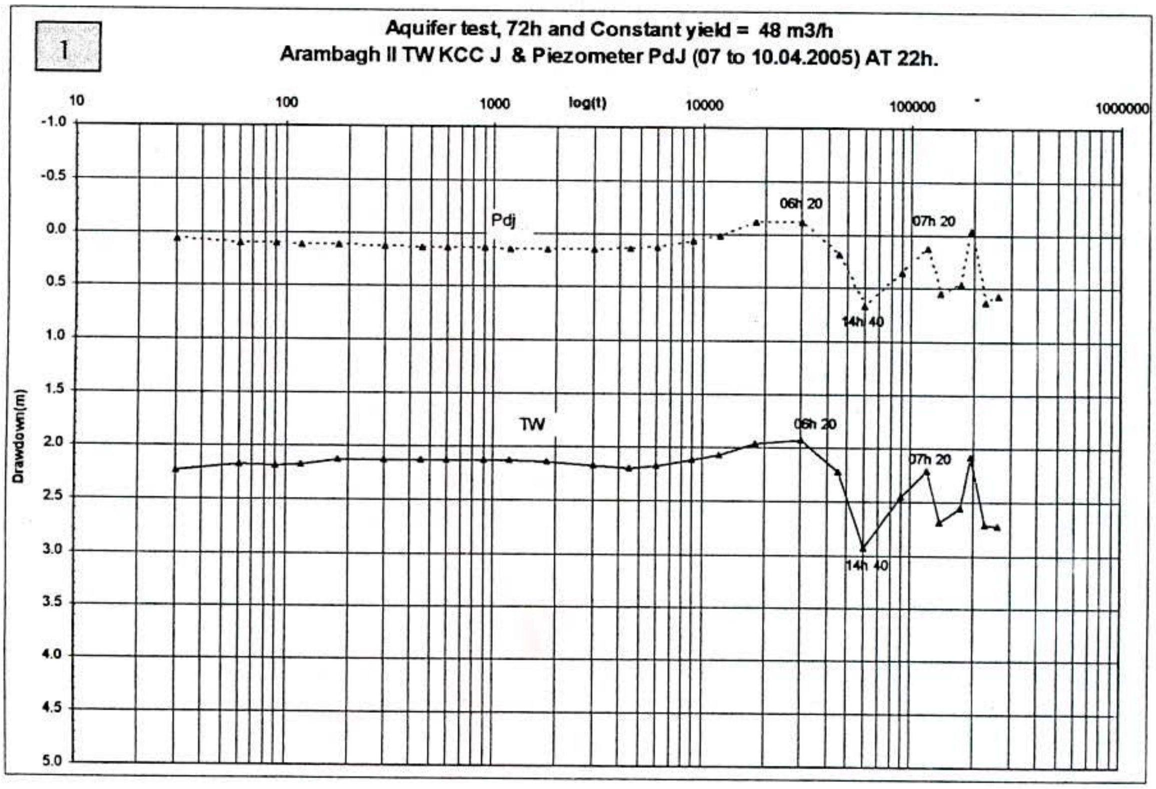
Date: 22.04 at 22h to 23.04.05

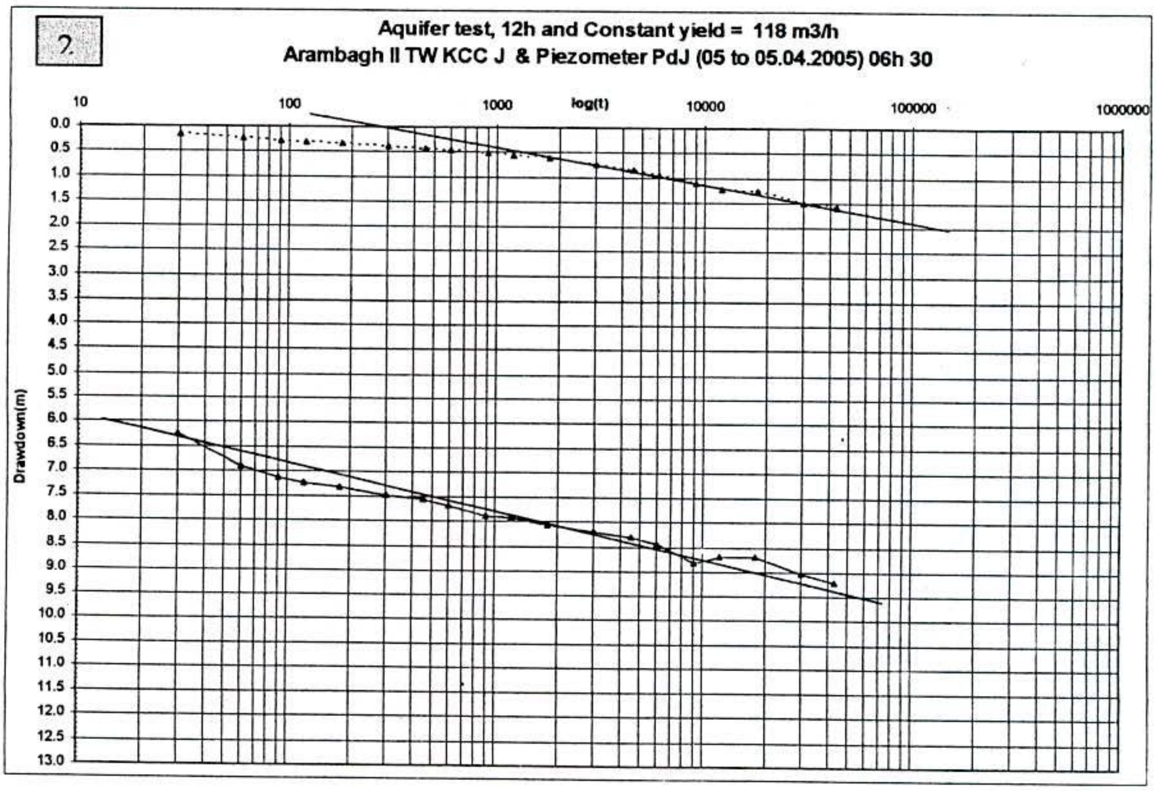
Planed Discharge m3/h: 16 m^3/h

TW No Cable Factory / Badamtala Between Phultala & Fulbari Gate 22.04 at 22h

Coordinates: X=89.519722 & Y=22.9080556

Pumping Duration		TW		
H.M.S.	Second	SWL (m)	DWL (m)	DD (m)
00.00.00	0	8.1	8.1	0
00.00.30	30	8.1	11.64	3.54
00.01.00	60	8.1	13.52	5.42
00.01.30	90	8.1	15.04	6.94
00.02.00	120	8.1	16.12	8.02
00.03.00	180	8.1	17.52	9.42
00.05.00	300	8.1	19.12	11.02
00.07.30	450	8.1	19.96	11.86
00.10.00	600	8.1	20.45	12.35
00.15.00	900	8.1	20.98	12.88
00.20.00	1200	8.1	21.52	13.42
00.30.00	1800	8.1	21.98	13.88
00.50.00	3000	8.1	22.99	14.89


1
Aquifer test, 72h and Constant yield = 48 m3/h
Arambagh II TW KCC J & Piezometer PdJ (07 to 10.04.2005) AT 22h.
log(t)
Drawdown(m)
Pdj
06h 20
07h 20
14h 40
TW
06h 20
07h 20
14h 40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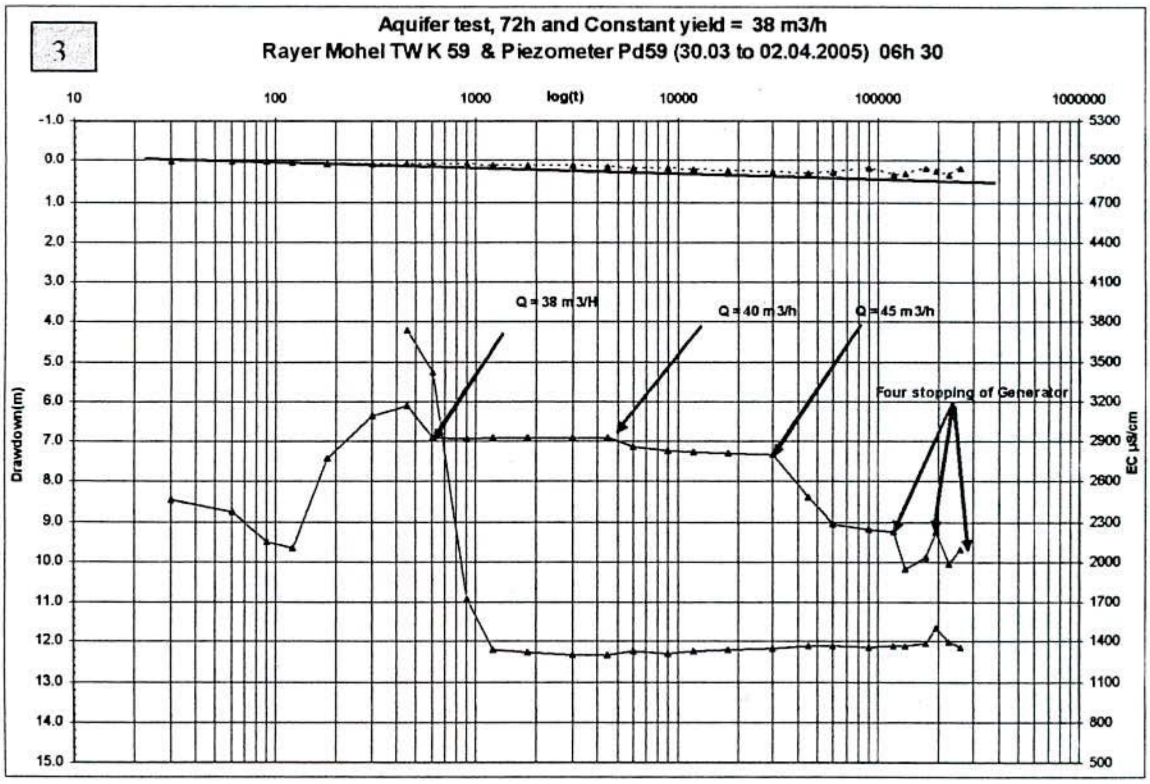
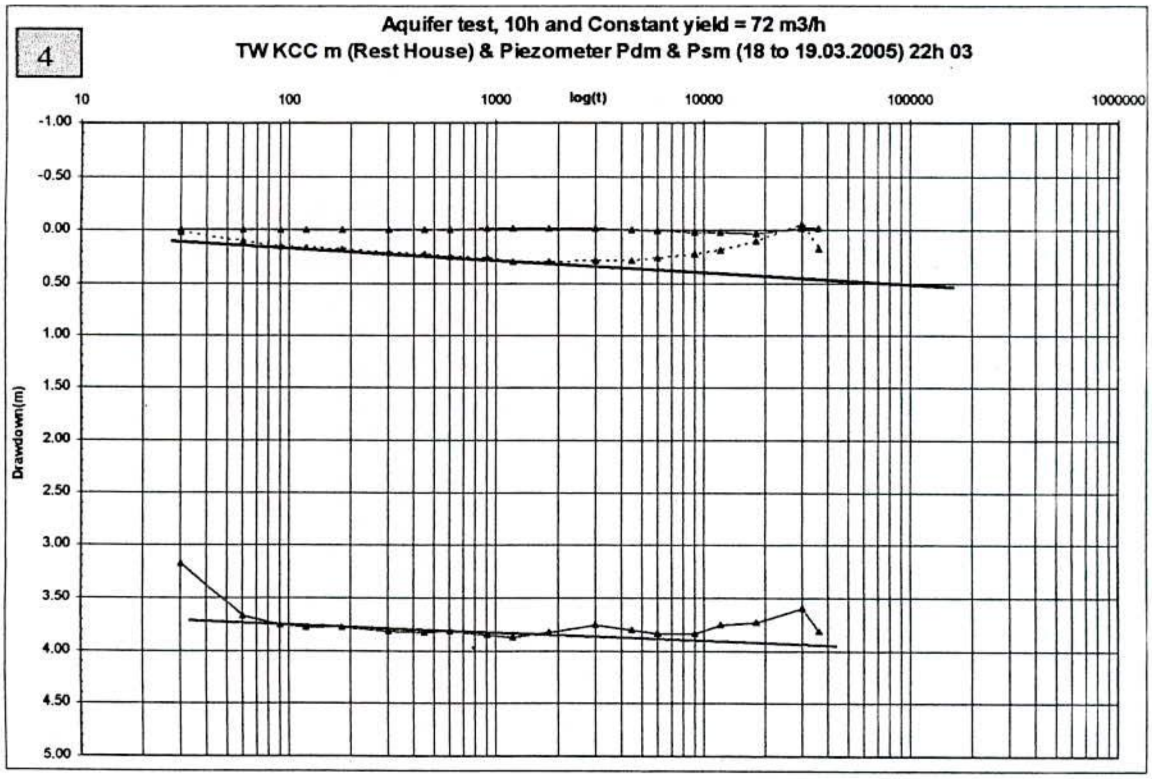
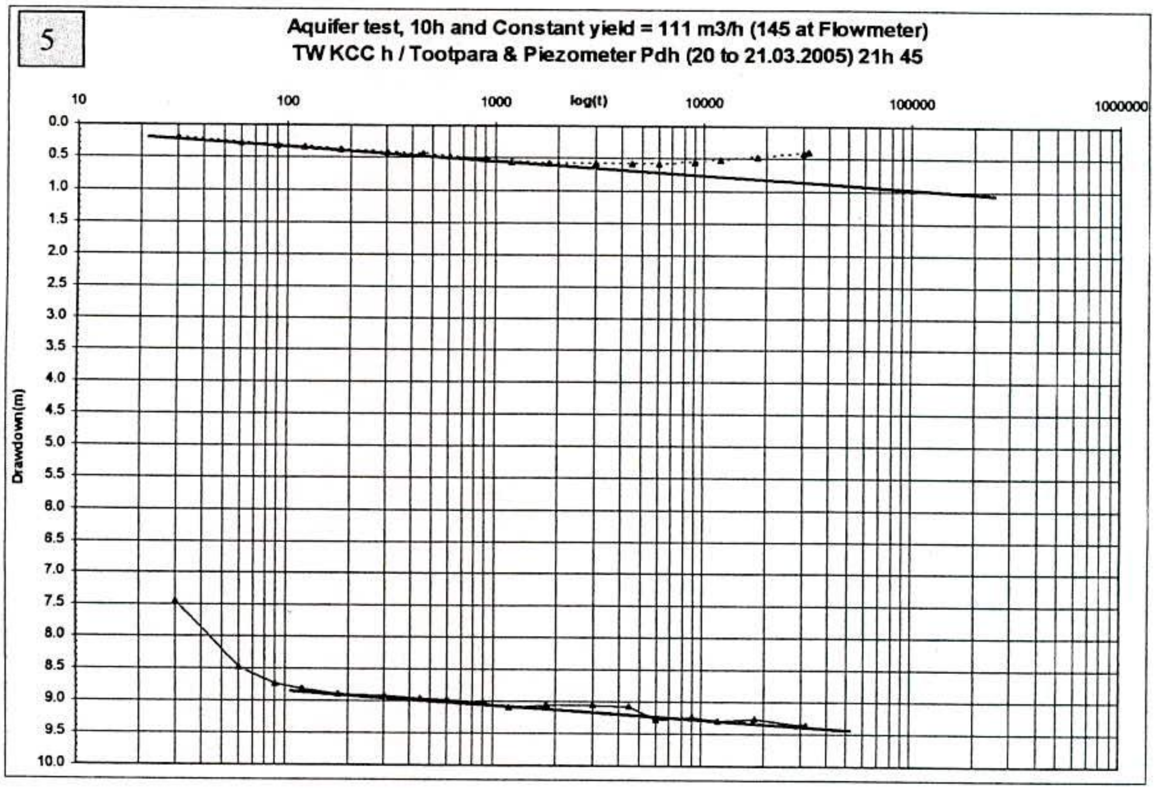
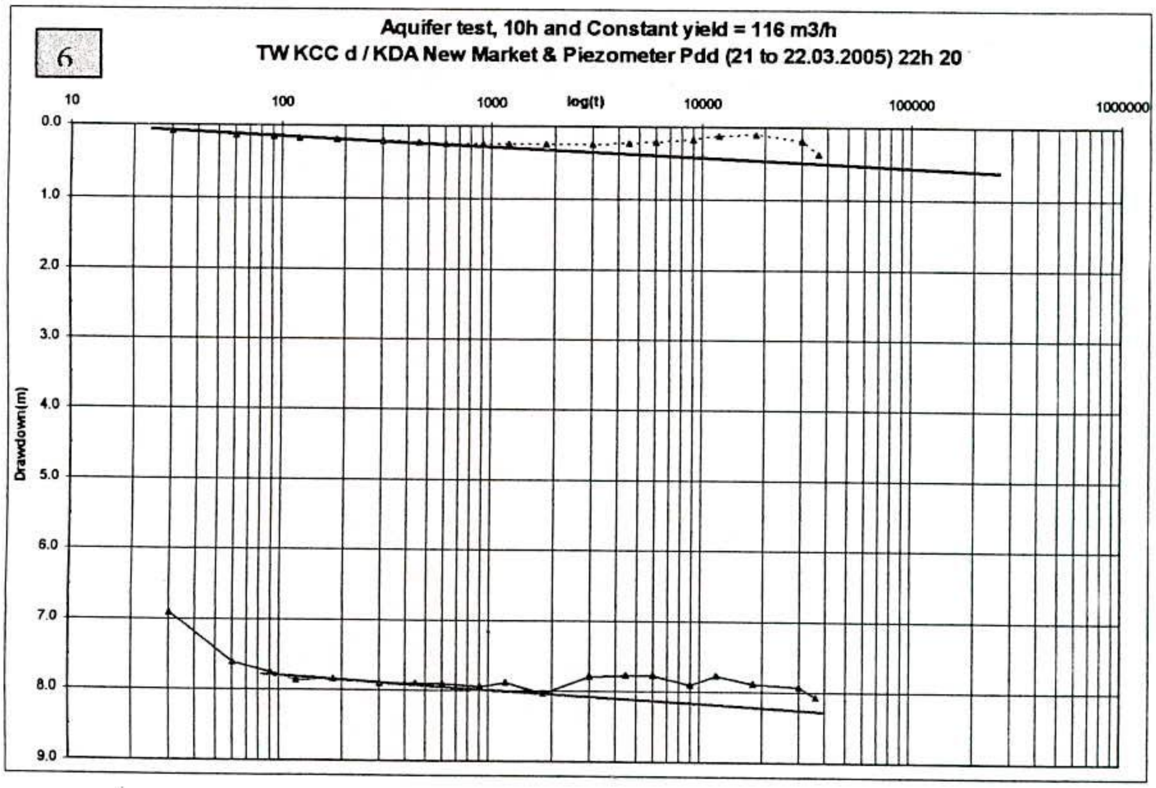
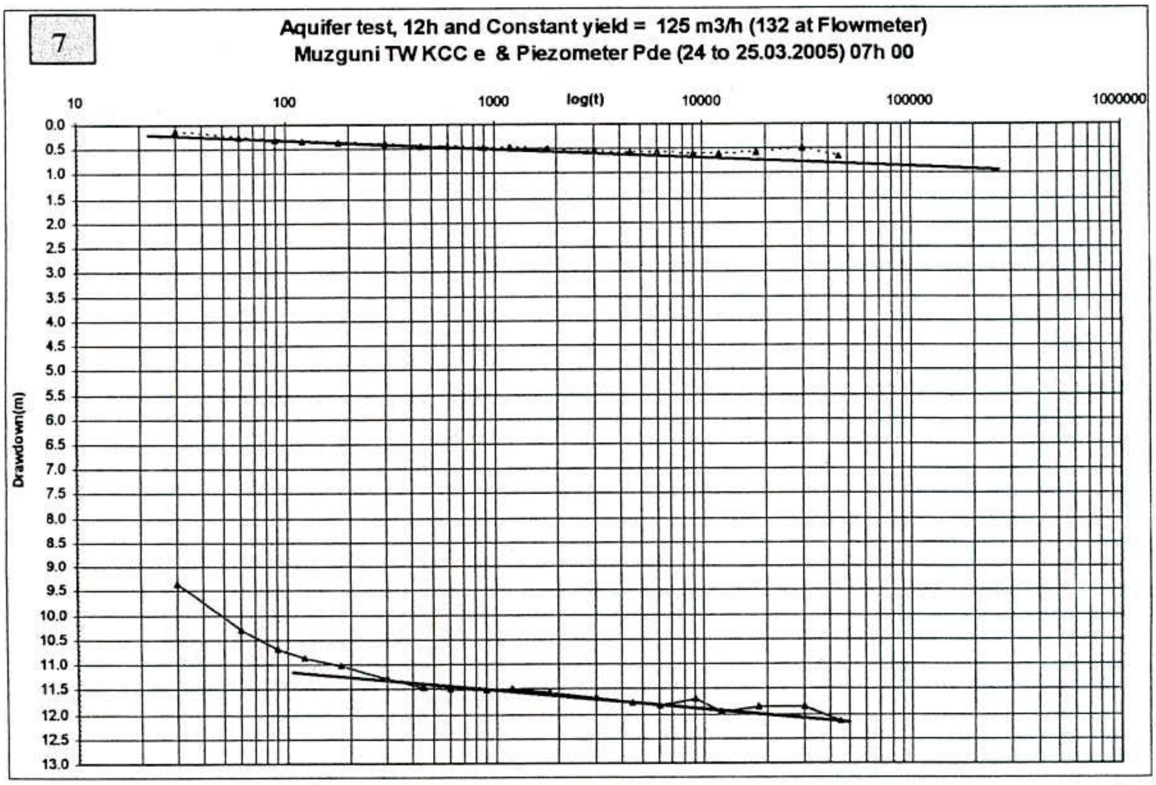
Aquifer test, 12h and Constant yield = 118 m3/h
Arambagh II TW KCC J & Piezometer PdJ (05 to 05.04.2005) 06h 30
log(t)
Drawdown(m)

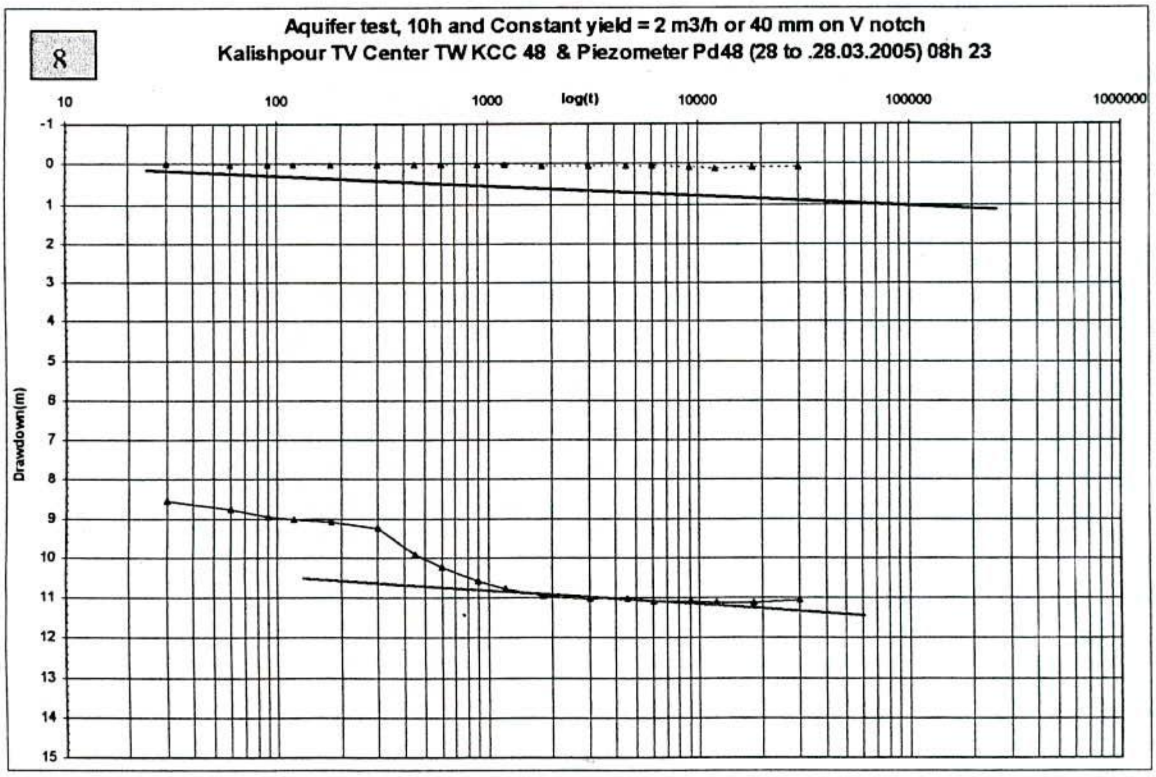

3
Aquifer test, 72h and Constant yield = 38 m3/h
Rayer Mohel TW K 59 & Piezometer Pd59 (30.03 to 02.04.2005) 06h 30
log(t)
Drawdown(m)
EC µS/cm
Q = 38 m3/H
Q = 40 m3/h
Q = 45 m3/h
Four stopping of Generator


4
Aquifer test, 10h and Constant yield = 72 m3/h
TW KCC m (Rest House) & Piezometer Pdm & Psm (18 to 19.03.2005) 22h 03
log(t)
Drawdown(m)


5
Aquifer test, 10h and Constant yield = 111 m3/h (145 at Flowmeter)
TW KCC h / Tootpara & Piezometer Pdh (20 to 21.03.2005) 21h 45
10
100
1000
log(t)
10000
100000
1000000
Drawdown(m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0

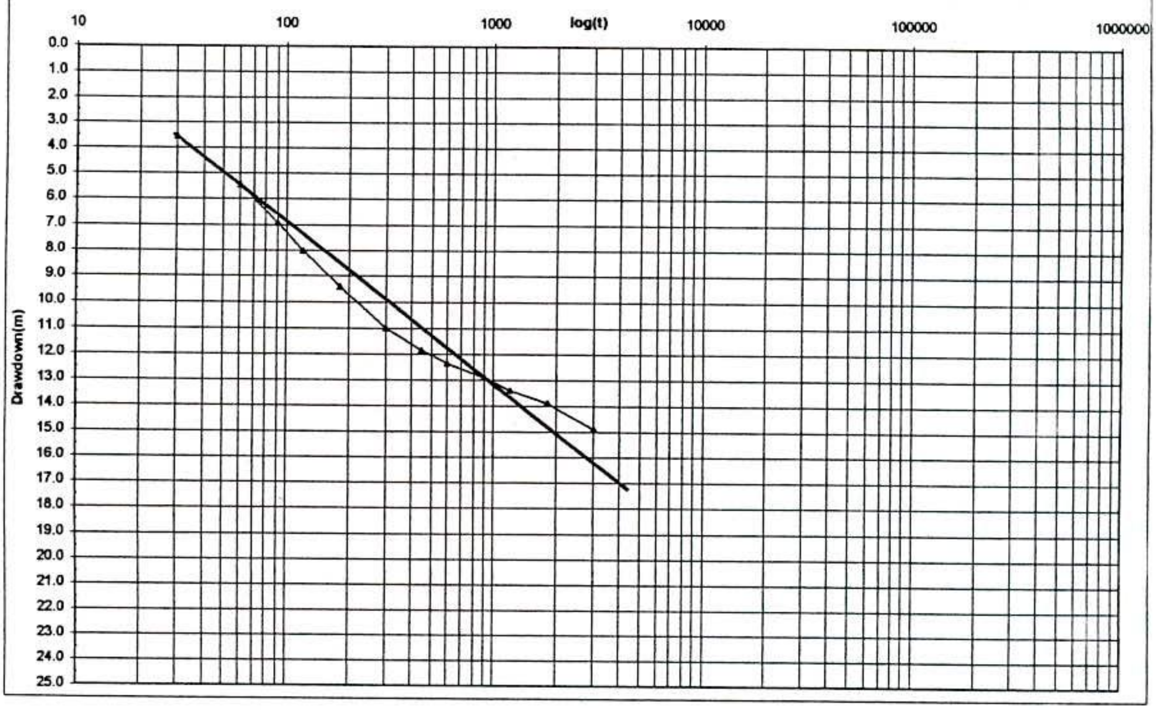

6
Aquifer test, 10h and Constant yield = 116 m3/h
TW KCC d / KDA New Market & Piezometer Pdd (21 to 22.03.2005) 22h 20
10
100
1000
log(t)
10000
100000
1000000
Drawdown(m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0


7
Aquifer test, 12h and Constant yield = 125 m3/h (132 at Flowmeter)
Muzguni TW KCC e & Piezometer Pde (24 to 25.03.2005) 07h 00
10
100
1000
log(t)
10000
100000
1000000
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
Drawdown(m)


8
Aquifer test, 10h and Constant yield = 2 m3/h or 40 mm on V notch
Kalishpour TV Center TW KCC 48 & Piezometer Pd48 (28 to .28.03.2005) 08h 23
10
100
1000
log(t)
10000
100000
1000000
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Drawdown(m)

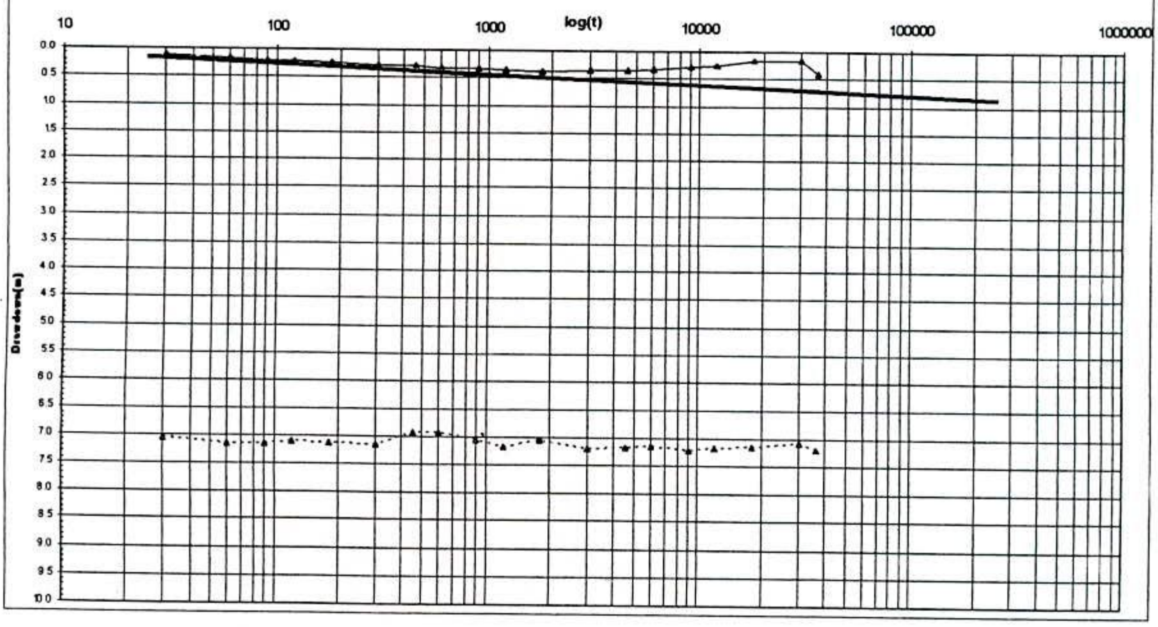
9

Aquifer test, 24h and Constant yield = 17 m3/h
Cable Factory Between Phultala & Phulbari Gate (From 22.04.05 to 23.04.2005) At 22h



10

Aquifer test, 10h and Constant yield = 122 m3/h
TW KCC I / PTI More & Piezometer Pdl (19 to 20.03.2005) 22h 40



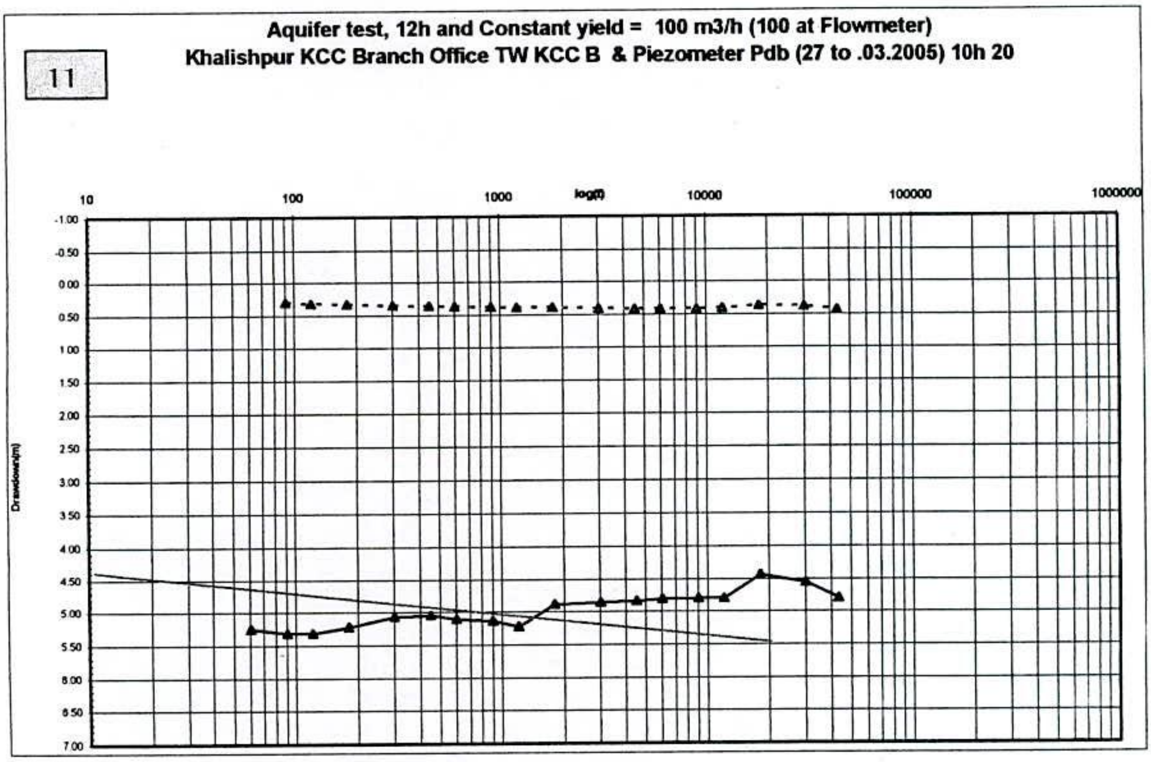


Figure 4- 1-11: Time vs. Drawdown Curves for Aquifer Tests

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