INTERACTION OF SALINE AND
FRESH WATER ZONES
IN ALLAHABAD UNIT (SCARP – VI)
by
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ABSTRACT

A large network of canals was established during the last decades for delivering irrigation water in the Scarp-VI Project area. The canal network and irrigated areas became a potential source of recharge which caused a continuous rise in the water table. To lower the water table in the area 632 tubewells were installed during 1976-80. These wells are continuously monitored on yearly basis since the project started. The maps and reports regarding water quality and water level are prepared. According to water quality report published in 1990 it was revealed that some of the wells were converted from fresh to saline. To find out the extent of deterioration of tubewell water quality, 44-piezometers were installed on 7-pumping wells and water quality & piezometeric head data were collected and analyzed. This analysis shows a seasonal variation in water quality. This report explores possible reasons for this seasonal variation in water quality. For this purpose different numerical models such as MOC, MODFLOW and RADFLOW are used to study the overall regional flow behavior in the area. The results of this exercise indicate that the variation in water quality of the wells may be due to the movement of saline interface in the immediate vicinity of the wells depending on the recharge and pumping pattern.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

1.1 Background

The Salinity Control and Reclamation Project (SCARP VI) is mainly located within Rahimyar Khan district, and some parts of D.G. Khan, Bahawalpur and Sukkur district also come under the project area. The project covers the entire command areas of Panjnad Abbasia canal system. The Project area starts from Panjnad head works and ends near Guddu covering an area of 115 miles long and 30 miles wide on the average. With the introduction of the weir controlled irrigation and construction of canals the land was leveled and regular application of irrigation water was started. Seepage from the main canals and other water courses contributed generously to the ground water resulting in a rise of water table and salt build up in the productive soils of the area.

To control the menace of water logging and salinity in the project area a salinity control and reclamation project was launched. Under this programme 632 tubewells were installed during 1979-80. These wells are continuously monitored on yearly basis.

Since the operation started, maps & reports regarding water quality and water levels are prepared regularly. It was revealed from the data (Changes in Chemical Quality of Groundwater in Allahabad area 1988) that some of wells were

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converted from fresh to saline i.e. these wells were pumping fresh water at the time of installation but now these are pumping saline water.

The gradual salinization of tubewells in the project area indicated a need for a more scientific approach towards this problem. Therefore, under ISM/R project solute transport modeling study aiming to simulate the effect of lateral and upward salts movement was proposed. Since the solute transport modeling does not explain the causes or factors responsible for the deterioration of ground water quality rather it can correlate the effects of different factors controlling the movement of salts.

Before going into detailed solute transport modeling, it is necessary to understand the flow processes going on in the area those are responsible for the deterioration of ground water quality, hence a research study with objective defined below was initiated out under ISM/R.

1.2 Objectives

To critically study the movement of saline groundwater in the Allahabad unit SCARP-VI, analyzing the data collected and to understand flow governing processes causing the movement. This may help to estimate the rate of tubewell water quality deterioration and to plans appropriate measures to minimize rate of salinization.

These objectives are achieved with the help of different numerical models such as RADFLOW, MODFLOW and MOC alongwith the data collected for overall regional pattern of movement in the study area.

1.3 Literature Review

Previously, three studies were carried out in the area and reports containing useful information and results were published. These are;

a) Feasibility Report Allahabad Pilot Project (Unit-1) of Salinity Control and Reclamation Project, Panjnad - Abbasia area SCARP-VI.

b) Project Report Salinity Control and Reclamation Project (SCARP VI) Final Plan.

c) An Appraisal of Groundwater pollution in Allahabad Unit, SCARP-VI by Javed Zaman.

a) Allahabad Pilot Project Unit-1.
(Sabason Technical Services, 1974)

This report was prepared in 1974 by Sabason Technical Services for WAPDA. This report is a detailed feasibility report on Allahabad Unit (SCARP VI). It covers different aspects of the area such as Hydrology, Irrigation supplies, Tubewells etc, and makes recommendations about the future planning of the area.

The recharge/discharge components from different sources are summarized in Table 1. This data shows that 50% of the recharge to groundwater comes from farm losses. Canals , distributaries and minors contribute about 42%. A total number of 632 drainage tubewells were proposed in the

Table-1

Recharge to groundwater from various sources are:

(Sabasun Technical Services 1974)

1.	Seepage from river beds	=	0.0130	MAF
2.	Seepage from main canal & branches	=	0.1450	MAF
3.	Seepage from distributaries and minor channels.	=	0.0552	MAF
4.	Farm Losses	=	0.2248	MAF
5.	Inflow from adjoining area	=	0.0120	MAF
6.	Rainfall component	=	0.0131	MAF
	Total	=	0.4631	MAF

Discharge from groundwater reservoir.

1.	Tubewell pumpage from 307 private Tubewell and 2447 open wells and 43 Government tubewells.	=	0.130	MAF
2.	Outflow to the adjoining area	=	0.014	MAF
	Total	=	0.144	MAF

Net effect

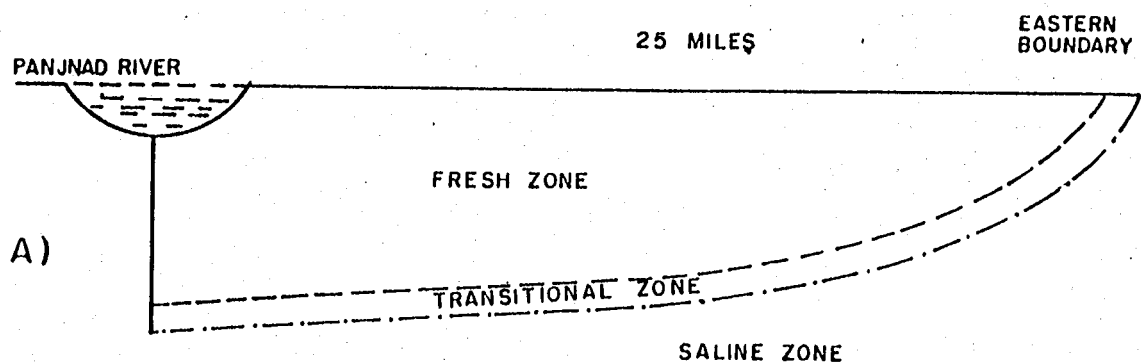|			
Recharge	=	0.4631	MAF
Discharge	=	0.1440	MAF
Net effect	=	0.3191	MAF

area. The total design discharge of these tubewells was 0.44 MAF.

A geo-chemical profile of the area up to a depth of 400 ft showing general chemical qualities of groundwater is also included in this report. This profile shows that the saline zone is separated from the fresh zone by a transitional zone or intermediate zone. The salts present in the saline zone are chlorides with an average TDS of 13,000 PPM, in the intermediate zone sulphates are dominant with an average TDS ranging from 1000 to 1500 ppm. The fresh zone mainly contains bi-carbonates with an average TDS ranging from 300 ppm to 1000 ppm. The boundary between saline and fresh zones is approximately established at 25 miles away from the river Indus towards the east. The slope of the salt water interface is approximately 75 feet per mile, if this slope is projected towards river Indus, the top of the salt water would be more than 1500 feet deep near the river (Fig 1.1).

b) **Panjnad Abbasia Salinity Control and Reclamation Project (SCARP VI), Final Plan (NESPAK & ILACO, 1981)**

This is a detailed design report covering all the important aspects of the project SCARP VI. This report was prepared by NESPAK in collaboration with ILACO Netherland in 1981. The results of a Geo-electrical survey are also included in this report, which was carried out by the consultants to establish the location of the interface between the fresh and saline water.

A)

PANJNAD RIVER   25 MILES   EASTERN BOUNDARY

FRESH ZONE

TRANSITIONAL ZONE

SALINE ZONE

PRE - PROJECT

B)

PANJNAD RIVER

PUMPING WELL   LATERAL MOVEMENT   EASTERN BOUNDARY

FRESH ZONE

TRANSITIONAL ZONE

SALINE ZONE   UPCONING
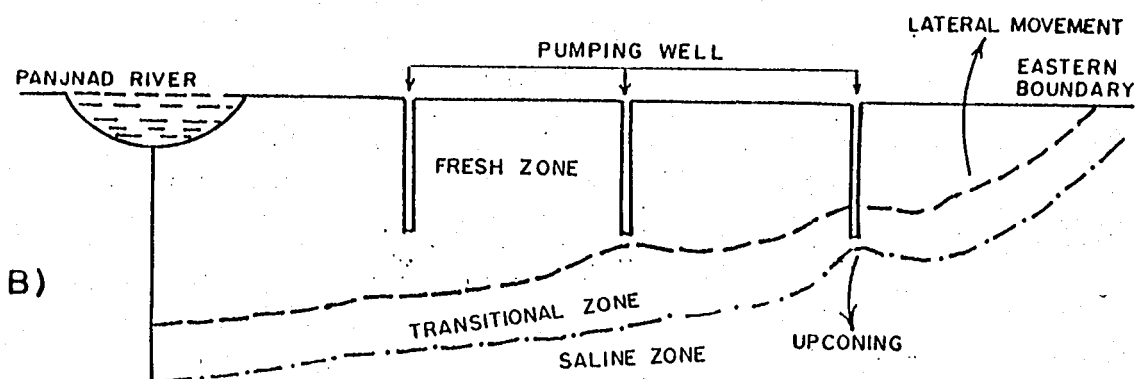
POST - PROJECT

FIG:-1.1 HYPOTHꞱICAL POSITION OF FRESH AND SALINE WATER INTERFACE. (SABASON TECHNICAL SERVICES 1974)

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The limit between fresh and saline water has been taken as an Ec value of approximately 1600 mS/cm. The results of this survey indicate that brackish water is found at relatively shallower depths i.e. at 65 to 130ft in the east of railway line that is considered to be approximate boundary between fresh and saline water zones while in the west of railway line its gradually increases in depths i.e. 300 to 400ft. Around Allahabad, the interface is found at a depth between 250 to 300ft. (Fig 1.2). The geo-chemistry of the fresh groundwater shows a predominance of bicarbonates like the river water while the saline water has the predominance of chlorides and sulphates ions, indicative of marine origin.

This report also contains the results of a computer model used to predict the water quality of the area after fifty years of the start of the project. According to the results obtained by the computer model, the rate of salinization of the aquifer is very slow. The increase in Ec value of the order of 10 to 12 mS/cm per year is anticipated in most of the fresh ground water zone. A maximum value of 600 mS/cm per year is predicted on its boundary. These results also show that the position of the boundary between an acceptable and high Ec values has hardly shifted after fifty years of project operations.
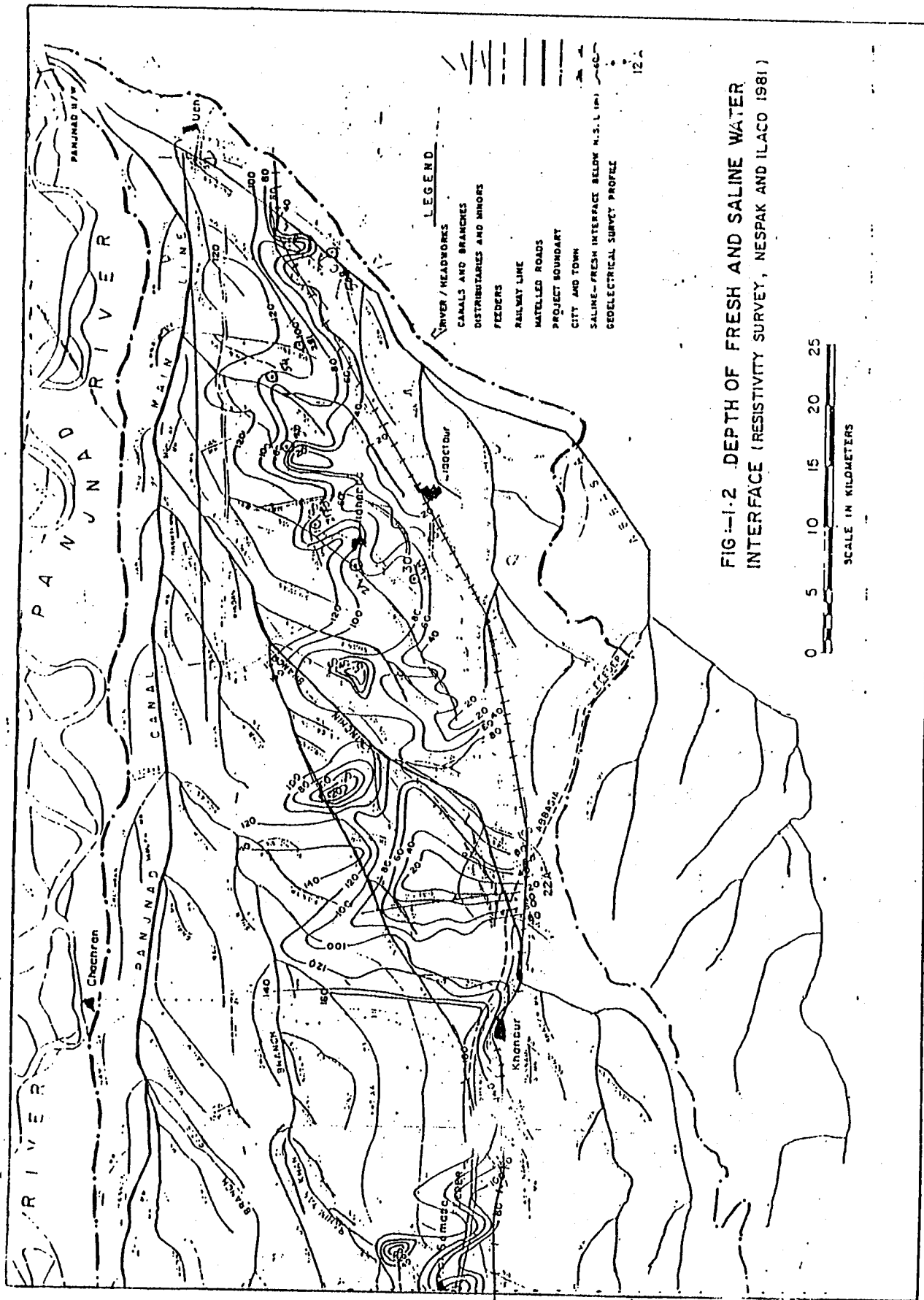
FIG-I.2 DEPTH OF FRESH AND SALINE WATER INTERFACE (RESISTIVITY SURVEY, NESPAK AND ILACO 1981)

LEGEND

RIVER / HEADWORKS
CANALS AND BRANCHES
DISTRIBUTARIES AND MINORS
FEEDERS
RAILWAY LINE
MATELLED ROADS
PROJECT BOUNDARY
CITY AND TOWN
SALINE-FRESH INTERFACE BELOW N.S.L (m)
GEOELECTRICAL SURVEY PROFILE

SCALE IN KILOMETERS
0   5   10   15   20   25

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c)   **Appraisal of Ground Water Pollution in Allahabad Unit.**
     SCARP-VI (Zaman, 1992)

          This study was completed under ISM/R Project with an
objective to determine the extent of lateral movement of
saline water.   This report describes the results of solute
transport model 'MOC'used to study the lateral saline water
movement in the fresh water aquifer.

          According to the results, lateral movement of the
saline water mainly occurs due to the lowering of depth to
water table caused by excessive pumpage. The drawdowns are
continuously increasing in the project area. The high water
table in the adjoining saline areas pushes the saline
interface towards fresh water zone. Steep hydraulic
gradients are created by over abstraction (Fig 1.3).

          The water quality contour having an E_c value of 1500
mS/cm is considered as the boundary of the fresh water zone.
This boundary is passing very close to Allahabad city in
1980. Due to excessive pumpage in North-West of Allahabad
large depression was created causing the boundary to move
in this direction. The present rate of movement is 110
ft/year approximately. The model results also indicate that
from the year 1987 to 2010 the boundary of fresh water zones
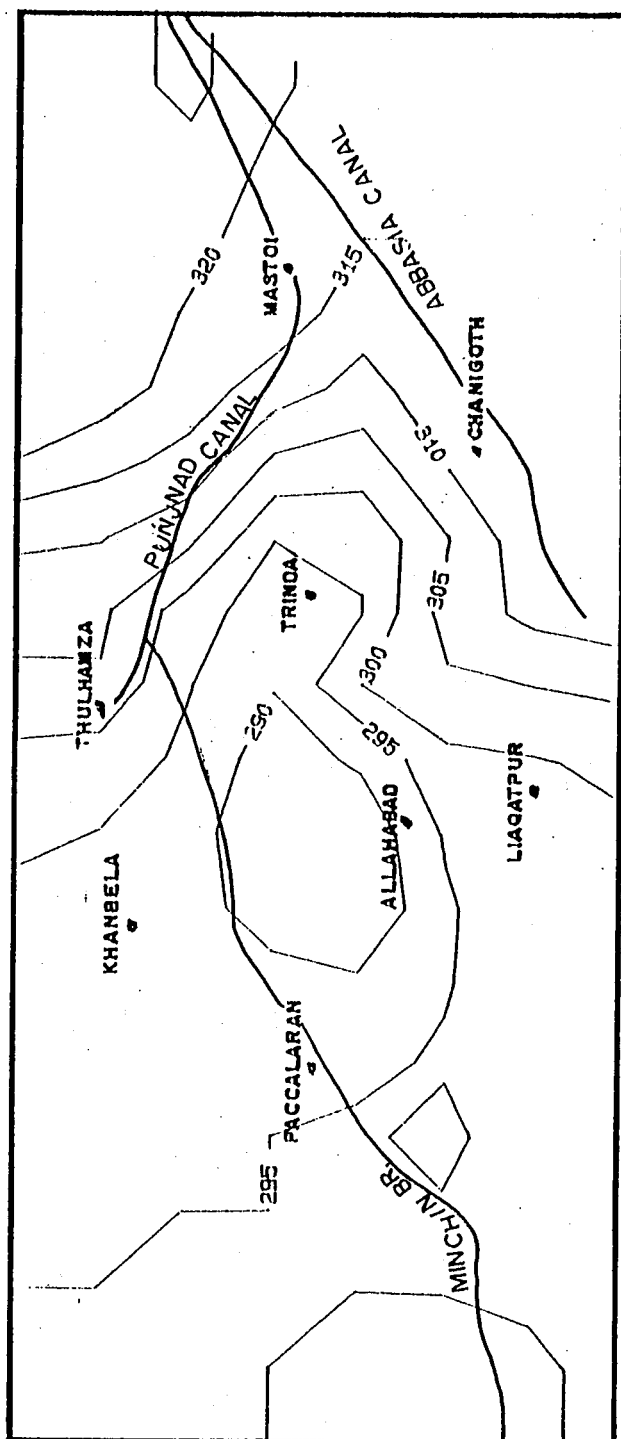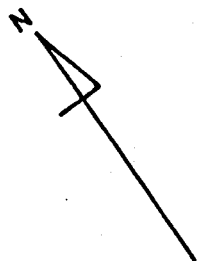will recede at a rate of 130 ft/year.

N

FIG:- I.3 PREDICTED WATER TABLE ELEVATIONS FOR 2010 A.D. USING
MOC (ZAMAN 1992)

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2.0   DATA COLLECTION

2.1   Introduction

SCARP-VI is being monitored regularly on a semi-annual basis and the data regarding water quality and water table elevations is being collected. The data collected by SMO over 16 years reveal that only 43.45% tubewells are continuously monitored over the period. The data include Ec values, SAR, RSC and concentration of various ions such as Na, Ca, Mg, Cl. SO4. CO3, HCO3, etc. According to the water quality standards adopted by WAPDA, the data collected have been classified into usable, marginal and hazardous. This criteria can be summarized as :

Criteria for Electrical Conductivity Ec

Usable	=	0-1500	mS/cm
Marginal	=	1501 - 2700	"
Hazardous	=	> 2700	"

Criteria for Residual Sodium Carbonate (RSC)

Usable	=	0 - 2.50	meq/lit
Marginal	=	2.51 - 5.00	"
Hazardous	=	> 5.00	"

Criteria for Sodium Adsorption Ratio (SAR)

Usable	=	0.0 - 10.0
Marginal	=	10.1 - 18.0

Hazardous   =   > 18.0

To find out the possible reasons for the gradual
salinizaton of tubewell water along eastern boundary, a
number of tubewells are selected in the area for detailed
monitoring. Around these wells, piezometers are installed
penetrating different depths to monitor the water quality of
the aquifer. The data is collected on bi-annual basis
regarding the water quality and the water level changes
since the commissioning of SCARPVI.

2.2 Location of Piezometers

A total of seven pumping wells are selected for
detailed monitoring. These wells are located in a line
along the eastern boundary. A set of four piezometers
having varying depths are installed around each pumping
well. The layout of these piezometers with reference to the
well is shown in (Fig 2.1a). Another set of 4 - piezometers
are installed 1/2 km away from each pumping well. The main
purpose of installing these piezometers is to monitor the
effects of existing pumping wells and canals on lateral salt
water intrusion and upconing.

2.3 Construction of Piezometers

The design of the piezometers mainly depends on,the
purpose for which these are being installed,the
hydrogeologic environment, the type of data is required
etc. As the monitoring wells are to be used to record water

GROUND LEVEL

200' 150' 100' 50'

50'

50'

50'

50'

10'
Perforations

B , SECTION

Piezometer

Tubewell

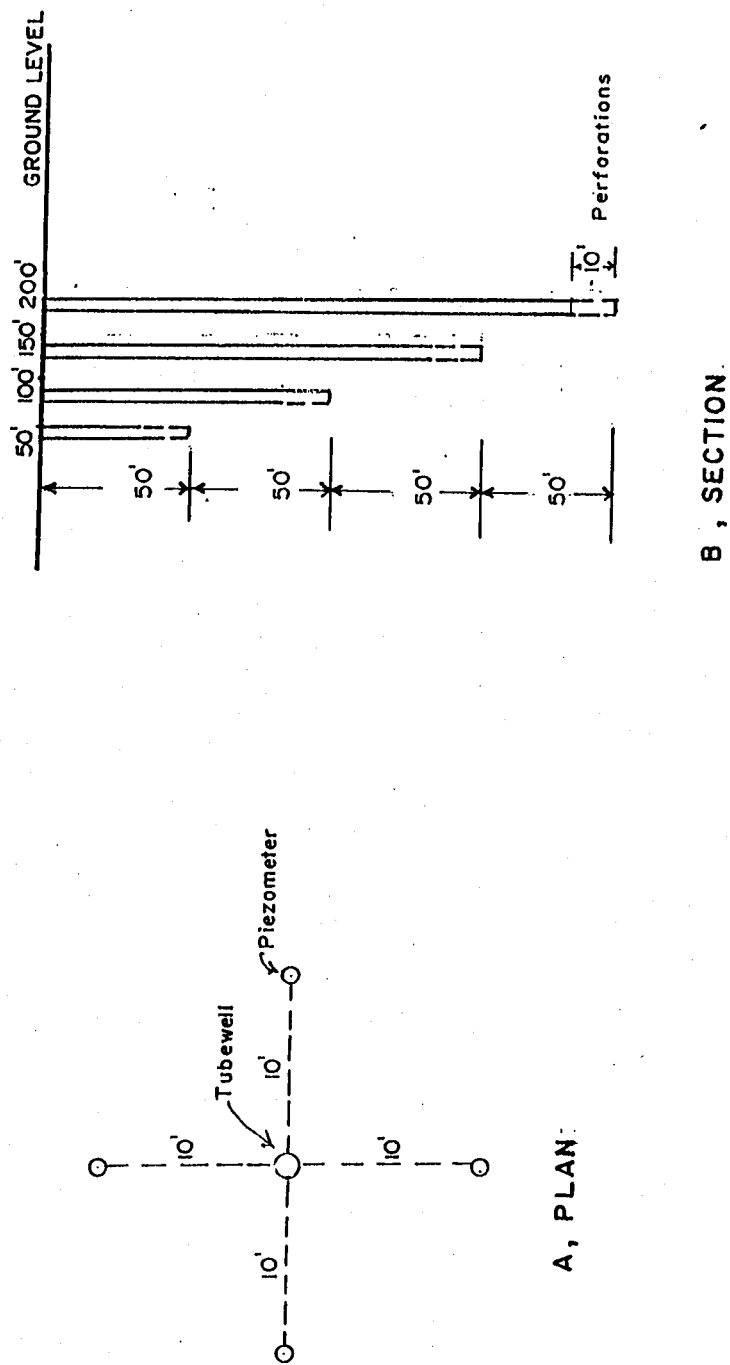10'

10'

10'

10'

A , PLAN

FIG: 2·1 LAYOUT OF PIEZOMETERS AROUND PUMPING WELL

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level changes as well as to obtain water quality samples, a 4 inch diameter casing and 10 ft perforated screen is used for each well. The PVC pipes being light weight and low cost are used for the casing and the strainer.

As the water samples are to be collected from specific depths and high yields are relatively less important, only 10 feet long screen was considered sufficient (Fig 2.1b). The open area of the screen approximates the natural porosity of the aquifer material which is nearly 20%. Slot size as small as possible was used to stop the sand particles to enter the well. The penetration depths of piezometers range from 50 to 200 ft with a 50 ft interval. The variable depths are provided to collect data regarding the water quality changes with depth.

At some locations deeper observation bore holes penetrated (up to a depth of 300 ft) are also provided with perforation along the full depth of the casing. These are installed to cross check the reliability of the piezometeric data.

2.4 Sampling Techniques

In order to make sure that the true chemical nature of the groundwater is being sampled, and not the stagnant water from within the casing. The samples are collected after removing at least three times the well bore volume of water from the well.

The water level readings are taken with M-Scope meter. The wire is lowered into the bore hole, when it touches the water table the electrical circuit is completed, which is indicated by a deflection of a needle. The corresponding length of wire lowered in the well is recorded to measure water table depth.

The Ec measurements are taken at the site with the help of a resistivity meter. The electrodes are attached with a long wire lowered in the bore hole and the corresponding value of Ec is recorded. The Ec meter was calibrated in the laboratory each time before going to the field.

3.0 ANALYSIS OF DATA (RESULTS & DISCUSSION)

3.1 Introduction

The piezometers are installed in the area around seven selected pumping wells. The layout of the monitoring wells is shown in (Fig 2.1). The criteria of selecting these wells was to monitor the lateral movement of saline water into the fresh water zone. The purpose of installing the piezometers at different depths was to record the changes in water quality around the wells at these depths and also to record the effects of canals and pumping wells on the lateral salt water movement and upconing.

The water level data collected from the piezometers on monthly basis exhibit seasonal variation in water levels. The data observed is presented in plotted form in APP.A.

This data reveals a unique seasonal behavior with respect to changes in water quality. To understand this phenomenon it is important to look into the regional setup of the aquifer along with prevailing boundary and initial conditions.

The regular monthly observations discontinued after one year. After March 1992, only four readings are taken namely, during April, June, October, and December.

3.2 Regional Groundwater Behavior

The lithology of the project area indicates that alluvial deposits form an unconfined aquifer. In some places, semiconfined conditions may prevail due to the presence of clay layers. The depth to water table in the area generally ranges from 10-12 feet. Permeability values derived from the analysis of pumping tests by Hantush method lies between 55 to 200 ft / day.

The project area is served by Panjnad and Abbasia canals originating from Panjnad barrage at Panjnad river. The water is conveyed to the fields through a network of branch canals, distributaries, minors and water courses. Panjnad canal with a full supply capacity of 9567 cusecs feeds a cultural command area of 1.364 million acres, while Abbasia canal with full supply of 1064 cusecs irrigate a culturable command area of 0.116 million acres. Panjnad canal is designed to deliver seasonal supplies to fresh ground water zone and perennial supplies to saline ground water zone. The railway line forms the boundary between its perennial and non perennial commands. The Abbasia is primarily a perennial canal with some non-perennial area in its head reach.

Historically, the groundwater flow was in the south-easterly direction away from the river. However,

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is shown in (Fig 3.2).

The data shows that there is a continuous rise in water level from May to September, because crop water requirements are high during the summer months. To meet these requirements, framers apply excessive amount of water to protect their fields from wilting resulting in a greater recharge to water table. The non-perennial canals also start working during these months allowing additional recharge to the ground water.

For the months of October to January, the data shows a sharp fall in water level indicating a reduction in recharge to the water table. This may be due to a lesser amount of water application to the fields for crop water requirement are low and also non-perennial canals stop working. There is again a rise in water level during in the month of February, due to the lesser evaporation losses in winter months.

A similar fluctuation pattern was observed by Nadeem(1989) when a loam profile was simulated in an unsaturated zone with a typical irrigation water application pattern at the surface.

FIG-3.2: MONTHWISE BEHAVIOUR OF AQUIFER AROUND TUBEWELL
NO. 38 IN ELECTRICAL CONDUCTIVITY AND WATER LEVELS
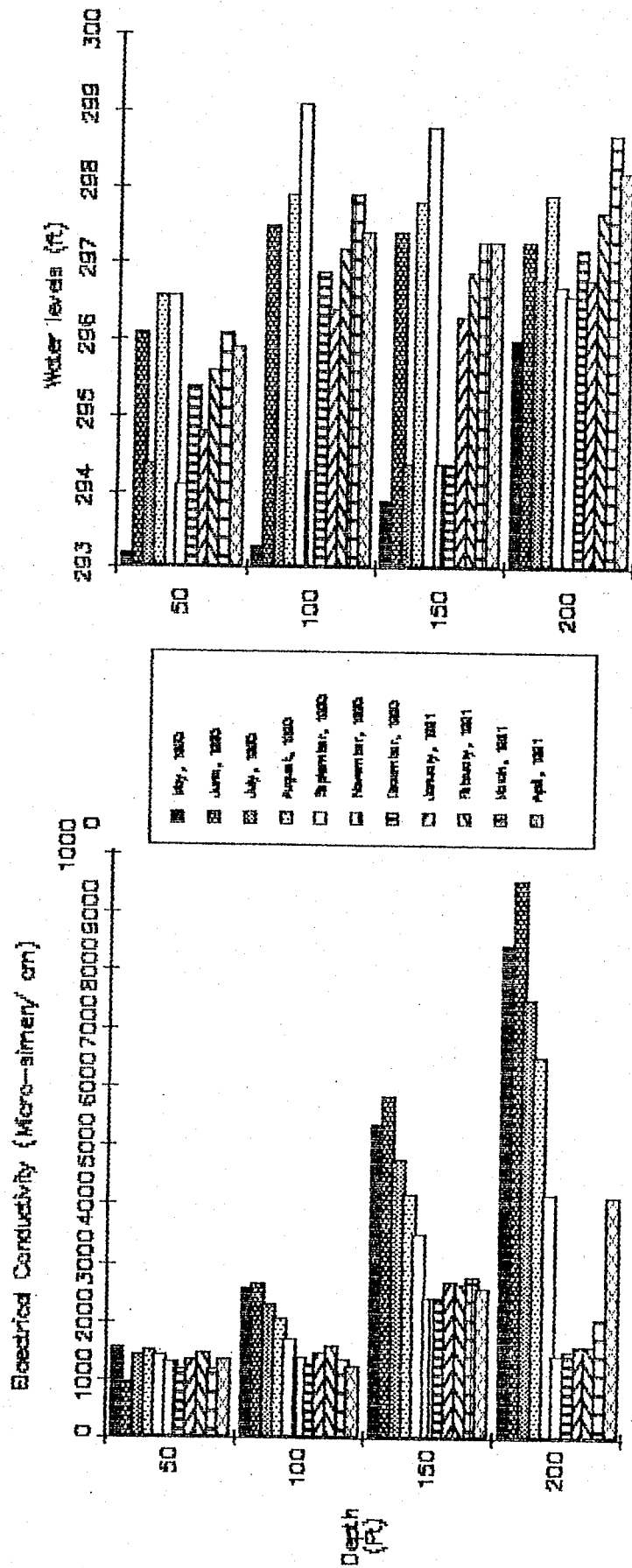
3.2.2 Ec Changes

This data reveals a continuous change in water quality of all the piezometers. Some of the wells show a wide variation in EC values. The observed EC data for Well 38 is plotted in (Fig 3.2). During the months of May to September the piezometers around the wells are showing highly saline water whereas in rest of the months the water is moderately saline or of marginal quality.

For a 200 ft deep piezometer, the observed Ec values range from 2000 mS/cm in November to 10,000 mS/cm during June, 1990. The change from 10,000 to 2,000 mS/cm is gradual and water quality improves during June to November period. After November, the water quality again starts deteriorating. A similar trend is observed in all the piezometers around the well 38.

The piezometers installed around other wells also show a similar behavior with some exception. A different range of Ec values depending on their location with respect to the saline zone is observed.

3.2.3 Relationship between Ec and Water Levels Changes

The rise and fall of water level seems to have some effect on the changes in the water quality of the wells. The graphs prepared between water level and the corresponding

water quality show that when water level falls down the corresponding Ec Value in subsequent months goes high. And when the water level goes high the corresponding Ec values decreases gradually in the following months (Fig 3.3). It appears that there is a lag of one or two months between the peaks of the two values.

To understand this phenomenon it is imperative to study the interaction of saline and fresh water zones in the area. An attempt is made to explore different factors that may directly or indirectly influence the Ec values in the piezometers. These are described as under:

1. Influence of Recharge Pattern

The recharge to ground water plays a vital role in bringing the water quality changes. The water seeps down from the surface to the ground water resulting in a rise in water table. This increases the depth of fresh ground water layer thereby pushing back the underlying saline water.

On the other hand, when there is no inflow from the surface, the water table tends to fall down resulting in a decrease in depth of the fresh water column thereby causing the saline water to intrude into the well.

The data plotted for the year 1992 in (Fig 3.3) shows abnormally high water levels. The year 1992 being a wet
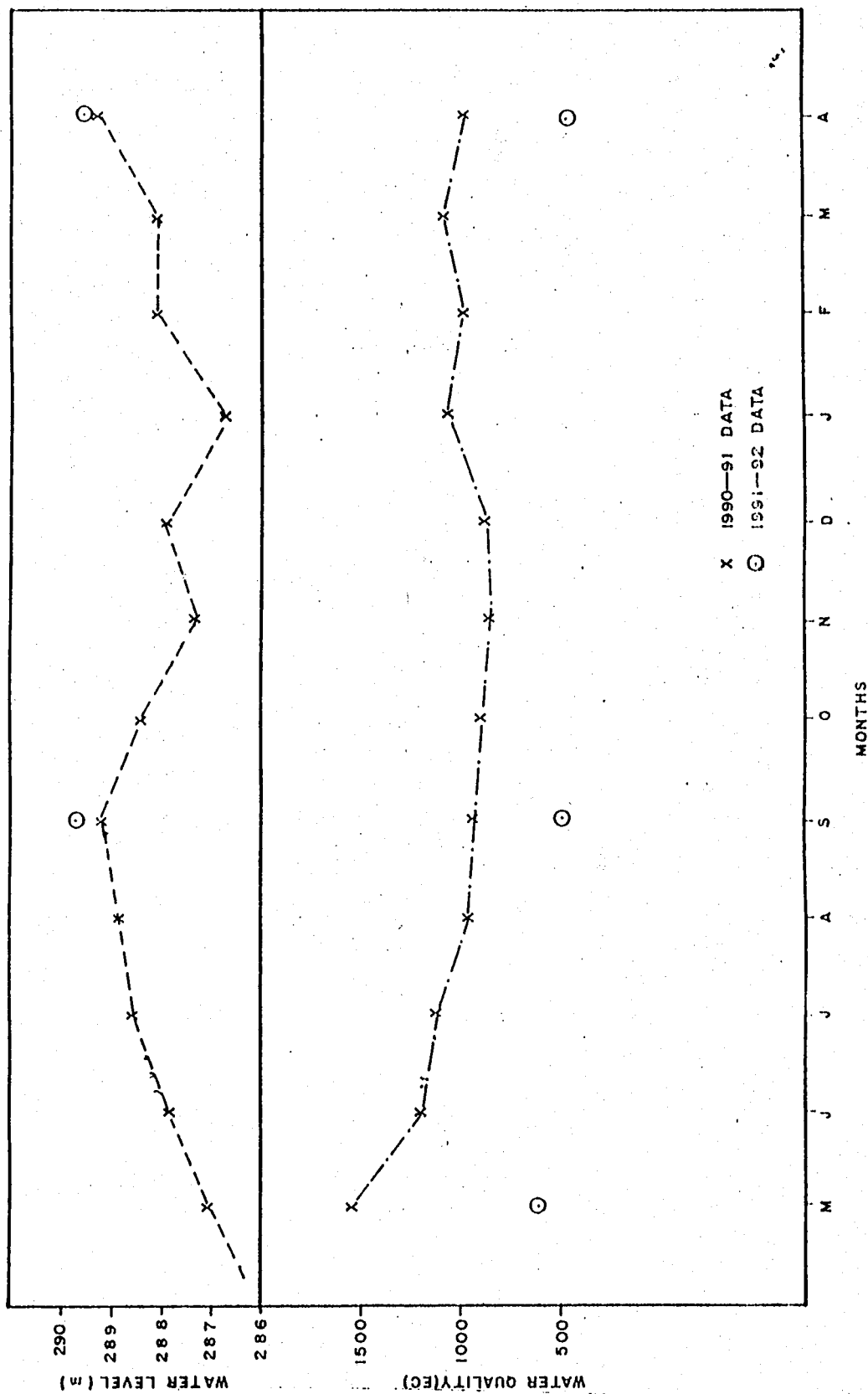
FIG:-3.3 OBSERVED EC AND CORRESPONDING WATER LEVEL FOR 50 ft. DEEP PIEZOMETER OF WEEL 2A.

X 1990—91 DATA
⊙ 1991—92 DATA

MONTHS

WATER LEVEL (m)

WATER QUALITY(EC)

year, high rainfall and flooding of a larger area
surrounding the river may have introduced excessive recharge
in to the aquifer. These observations also support the idea
that when the water level in the aquifer rises, i.e recharge
increases the overall water quality improves.

2. Influence of Pumping Pattern

The other possibility of the observed water quality
changes is the rate/pattern at which the water is being
pumped from the aquifer. During March to May crop water
requirements are high, to meet the requirement excessive
pumpage from the aquifer may cause the saline water beneath
fresh zone to rise. Whereas, during June to November the
crop water requirement is low, so the pumpage from the
aquifer is also low this may cause an improvement in Ec
value.

3.3 Interaction of Canals and Wells

All the piezometers around the pumping wells and the
half kilometer distance from the wells are located very
close to the canals, distributaries and minors, therefore it
is important to see the effect of canal seepage loss on the
changes in water quality of the wells.

For this purpose, a clear understanding of the
hydraulics of flow towards a well in unconfined condition is
required. When a well is located far away from major

sources and sinks like rivers and other pumping wells it is commonly assumed that the flow towards the well is symmetrical. Before studying more complex situations. It will be useful to start from the basic assumption of symmetrical flow towards a single well. This condition is studied using a time variant radial flow model for unconfined conditions called RADFLOW.

i) Flow towards a Well

The model RADFLOW (developed by Gary S.Johnson) is based on finite difference technique which simulates non-steady,three dimensional, radially symmetric flow to a well. The aquifer may be heterogeneous and anisotropic.

The drawdown contours formed by the model shows that if a well pumps out water continuously for 5-8 hours the drawdown occurs within the radius of 1/2 km. Maximum drawdown occurs near the well and it gradually flattens away from the well.

The flow lines generated by the model indicates that maximum flow lines originate at the water table. This shows that maximum amount of water to a well is contributed from water table (more than 80%) while 5-20% of water comes from lower part of the aquifer (Fig 3.4). It also indicates that about 70-80% of water is coming from within the radius of
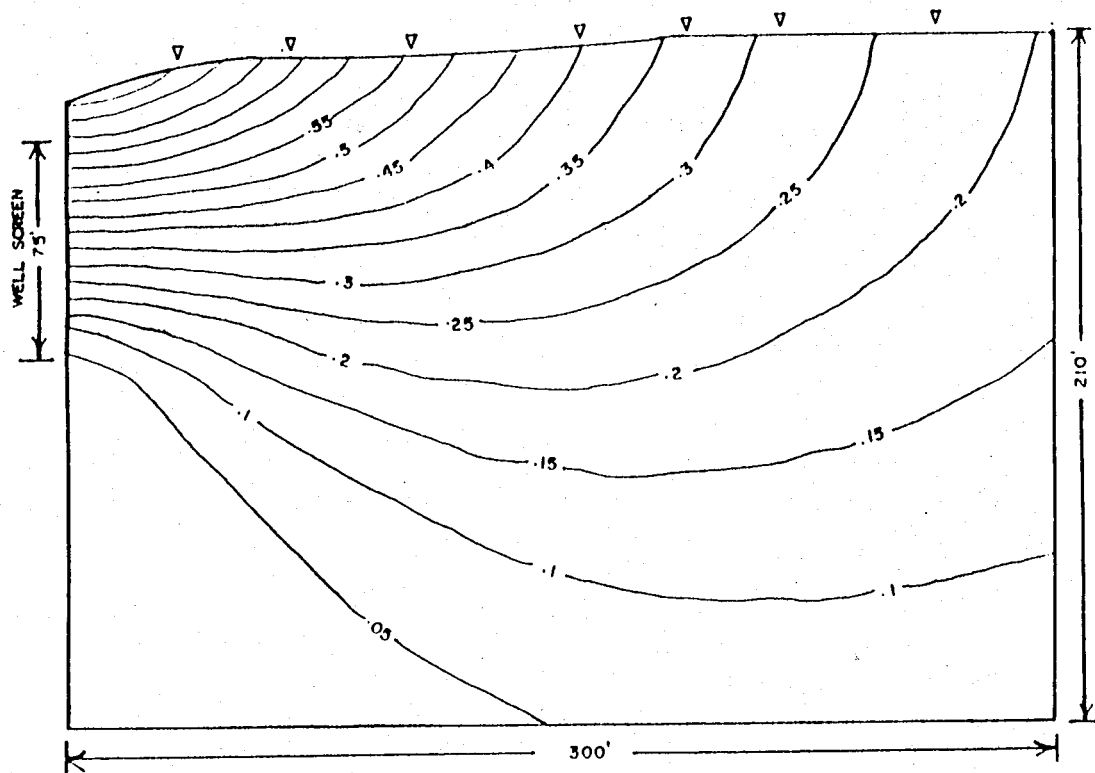
FIG:- 3.4 FLOW PATTERN TOWARDS A WELL IN UNCONFINED CONDITIONS
USING RADFLOW.

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300ft. Only 5% of water is contributing to the well beyond 200ft depth.

From this exercise two things are come out clearly:

1) The pumping well has little influence on the set of piezometers installed at half km distance from the well.

2) When the water is available from the water table, very limited amount of water is taken from the lower layers.

RADFLOW is basically a radially symmetric flow model therefore when a canal passing very close to a well on one side, the flow towards the well no longer remains symmetric. Hence, the model fails to simulate the interaction of canal and a well.

ii) Flow towards a Well with a nearby Canal

To study the interaction of canals with nearby well, no simple mathematical approach is available. A regional three dimensional flow model is required to simulate this situation. Therefore, USGS model MODFLOW (developed by McDonaldl M:G. and A.W Harbaugh) is employed to study the interaction.

Modflow is a three dimension flow model and has a facility to divide the aquifer into a number of layers in the vertical direction. This model was used by taking into consideration only one well along side of a canal. A mesh grid of 20x20 covering 1000 ft from each side of the well was employed (Fig 3.5). A 300 feet deep aquifer was divided into three layers, the thickness of each layer is assumed as 100 feet.

When a small canal (minor) is assumed, the heads generated by the model show that the flow towards the well is nearly uniform from all side. Thus a minor which is flowing at about 100-150 feet away from the well do not have a major effect on the flow distribution around the well. This is mainly due to the absence of a direct hydraulic connection between the minor and the aquifer.

The minor is flowing 20-30 feet above the water table surface and the discharge in the minor is insufficient to influence the water table around the well to a noticeable value. If the magnitude of seepage is higher, there is a possibility that the well may extract sizably amount of water from the canal.

iii) Regional Model Study

To see whether an increase or decrease in recharge component affects the water quality of the area and to what
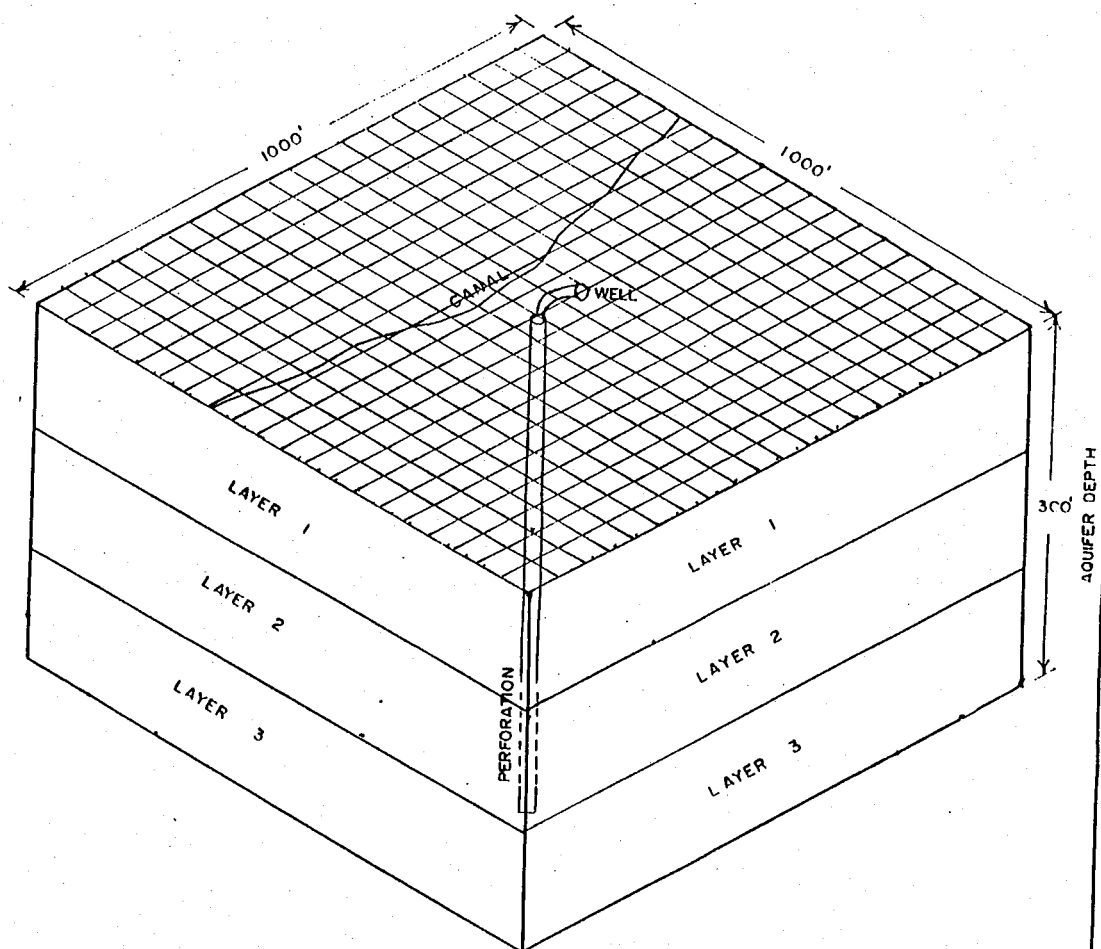
FIG. 3·5   LAYOUT OF THE MODEL DOMAIN USED FOR MODFLOW.

extent, the regional model used by Zaman (1991) was employed with some modification. The change was made in recharge/discharge components to study the regional behavior of the aquifer.

Zaman (1991) used the USGS solute transport model "MOC" (developed by Konikow and Breadehoeft, 1978) to study the lateral salt water movement towards the fresh zone in Allahabad unit, SCARPVI. The model can be applied to one or two dimensional problem with steady or transient flow. The outcome of the study has already been discussed in section 1.3.C

The area was divided into 20x20 cells. The distance between the nodes is assumed as 12,670 feet in X-direction and 5,280 feet in Y-direction. The data files prepared by Zaman (1991) are used with slight modifications mainly in the recharge components. Only two recharge options are considered; a reduction of the recharge from canals & minors by 25% and the next one for a reduction of 50%.

The results show that due to a reduction in the recharge magnitude from the water courses only, the water quality has deteriorated considerably over a period of 20 years and large depressions in water table start appearing indicating over-exploitation of the fresh groundwater.

The seasonal fluctuations of the water quality was not
apparent from the model results, because the model does not
have sufficient capability to accommodate the variable
recharge pattern over a period of time.

It is important to mention that the model is capable
only giving two dimensional effect of salt water movement
i.e lateral movement of saline interface. The modelling of
the real conditions in the aquifer requires a three
dimensional solute transport model which is not presently
available.

3.4   Position of the Fresh/Saline Water Interface

An interface is a surface where saline and fresh water
are in contact with each other. In fact, it is the boundary
of the fresh water zone. It is important to know the
position of the interface to determine the safe yield of the
aquifer, the location of the pumping wells and their
capacity. In the present situation, the boundary is helpful
in determining the extent of intrusion of saline water into
the fresh zone.

To mark the position of fresh/saline interface the SMO
data can be utilized in conjunction with the data collected
under ISM/R project. SMO has been collecting data regarding
water quality on bi-annual basis since the commissioning of
Scarp-VI (1976-1979).

From this data water quality maps are prepared and published at regular intervals. The water quality changes taking place in the aquifer are monitored with reference to the pre-project data. A typical water quality map is shown in (Fig 3.6). The latest map was prepared in 1991 based on water quality data collected during 1989-1990. These changes are marked on the map where water quality has improved or deteriorated during 1976 to 1990.

This map is helpful in locating the lateral position of the saline and fresh water zones in the area. Using the map in conjunction with the piezometeric data can help us to locate the vertical position of the saline/fresh water interface .

The map shows that in 1979 the larger part of the Allahabad unit area was under useable water quality zone. Only some localized patches of marginal water quality were present. But after 10 years of project operation, the water quality has changed in south-eastern part of the area. The changes show that along the south-eastern boundary of the area, useable ground water has now become hazardous or marginal. The hazardous water has intruded from south-eastern part to the central part of the area in the form of a wedge (Fig 3.6).

FIG:- 3·6 REGIONAL WATER QUALITY CHANGES USING OBSERVED DATA COLLECTED SMO.
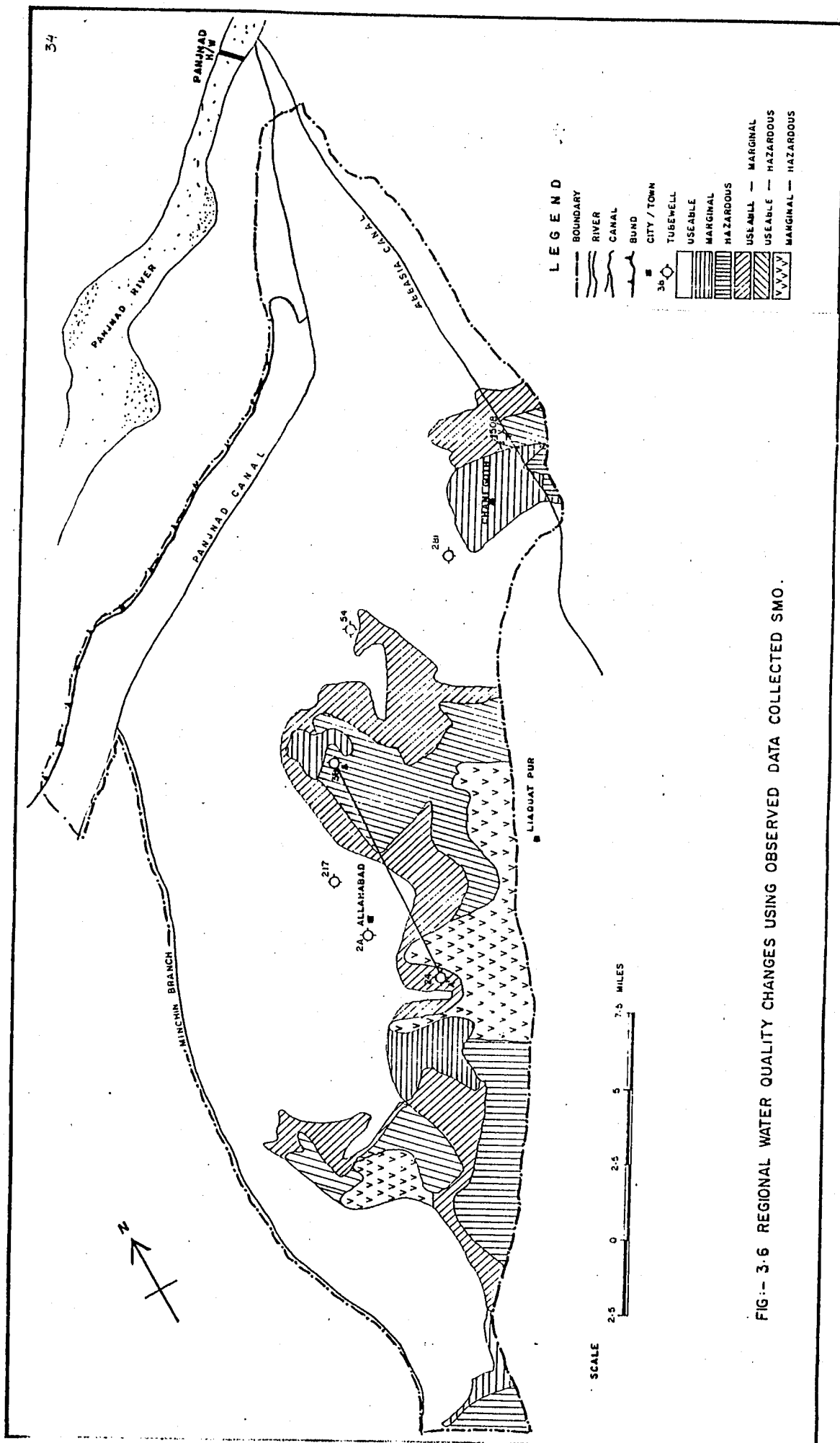
The piezometeric data indicate deterioration of water quality with an increase in depth below the water table. The saline zone in which Ec value is > 10000 mS / cm appears to be at a depth greater than 300ft. It is apparent from the data that the saline zone seems to have intruded into the pumping wells due to upconing and lateral movement along the south-eastern boundary of the area.

3.5 Thickness of the Transitional Zone

The interface between saline water and fresh water is rarely sharp. A gradual transition is always present between the two. To differentiate between fresh, saline and transitional zones following criteria is observed:

1. Fresh zone   Ec < 1500 mS/cm

2. Transitional zone   1500 > Ec < 10,000mS/cm

3. Saline zone   Ec > 10,000 mS/cm

For this purpose, vertical cross-sections of the observed water quality changes are utilized which are lying in a straight line normal to the interface. This section is shown in (Fig 3.6) as AA'.

The well no.38 and 24 are located in hazardous zone. The Ec data of piezometers installed around these two wells when superimposed on SMO data gives useful information about the vertical position of the saline interface and thickness of the transitional zone.

The data reveals that in the winter months when wells pump out low Ec water, the transitional zone (having Ec 1500-10,000 mS/cm) in Well 38 appears to be starting at a depth of 120 feet below the ground, similarly in Well no.24 the zone is found at a depth beyond 300 feet. On the other hand in the summer months when wells pump out high Ec water the transitional zone in well no.38 is encountered at 40 feet below ground level, whereas in well no.24 this zone appears nearly at 165 feet depth (Fig 3.6A).

It means that transitional zone move up and down between summer & winter. This zone move 80-100 feet up and down near well no.38, while near the well no.24 the movement of this zone is about 200 feet. The thickness of transitional zone is about 150 feet near well no.38 and it gradually decreases to 70 feet near the well no.24 in summer months. Whereas in winter months the thickness of transitional zone cannot be estimated as it is not visible from the observed data (Fig 3.6A).

The saline zone having Ec >10,000 mS/cm in summer months is encountered in well no.38 at a depth of 200 feet while in the corresponding well it is found nearly at a 230 feet depth. But in winter months when wells pump out fresh water the saline zone in well no.38 moves down to beyond 300 feet depth whereas in well no.24 this zone appears to be at depths greater than 300 feet (Fig 3.6A). It seems that
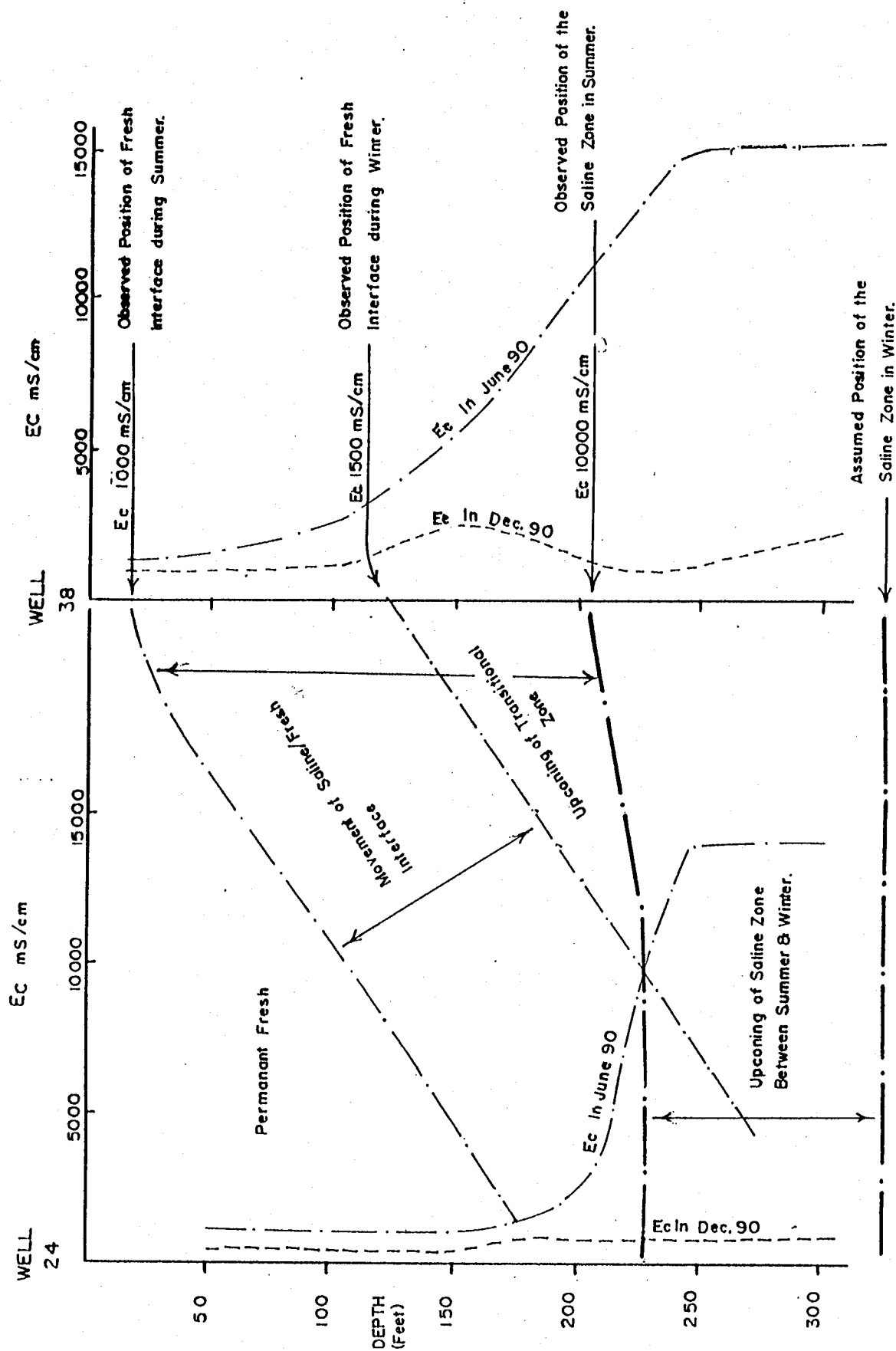
FIG:- 3·6A MOVEMENT OF FRESH/SALINE WATER INTERFACE ALONG SECTION A A'

saline zone moves up to 200 feet in summer months and falls down to a depth greater than 300 feet in the winter months due to recharge and pumping patterns.

3.6 Long Term Trend in Water Quality

To correlate the observed periodic changes in water quality in the piezometers with the tubewell data of previous 16 years, Ec changes of some selected well are plotted from the year 1976 through 1992 (Fig 3.7). This figure shows a clear trend in water quality deterioration of the tubewells over the observation period.

The same data was plotted on monthly basis with no regard to the year of observation to explore the seasonal behavior of water quality changes (Fig 3.8). A continuous seasonal change in water quality is not apparent mainly due to non-uniformity/discontinuity of the data collected.

The data shows that along the south-eastern boundary, the wells are pumping hazardous water, because these wells are either located far way from the recharge source or at the tail of the canals or distributaries. The geo-chemical analysis of water samples from these wells indicated a dominance of Na, Cl and So4 ions. The concentration of these ions has appreciably increased during the historic period (Fig 3.9) which clearly indicates the lateral saline water intrusion from eastern boundary of the area.
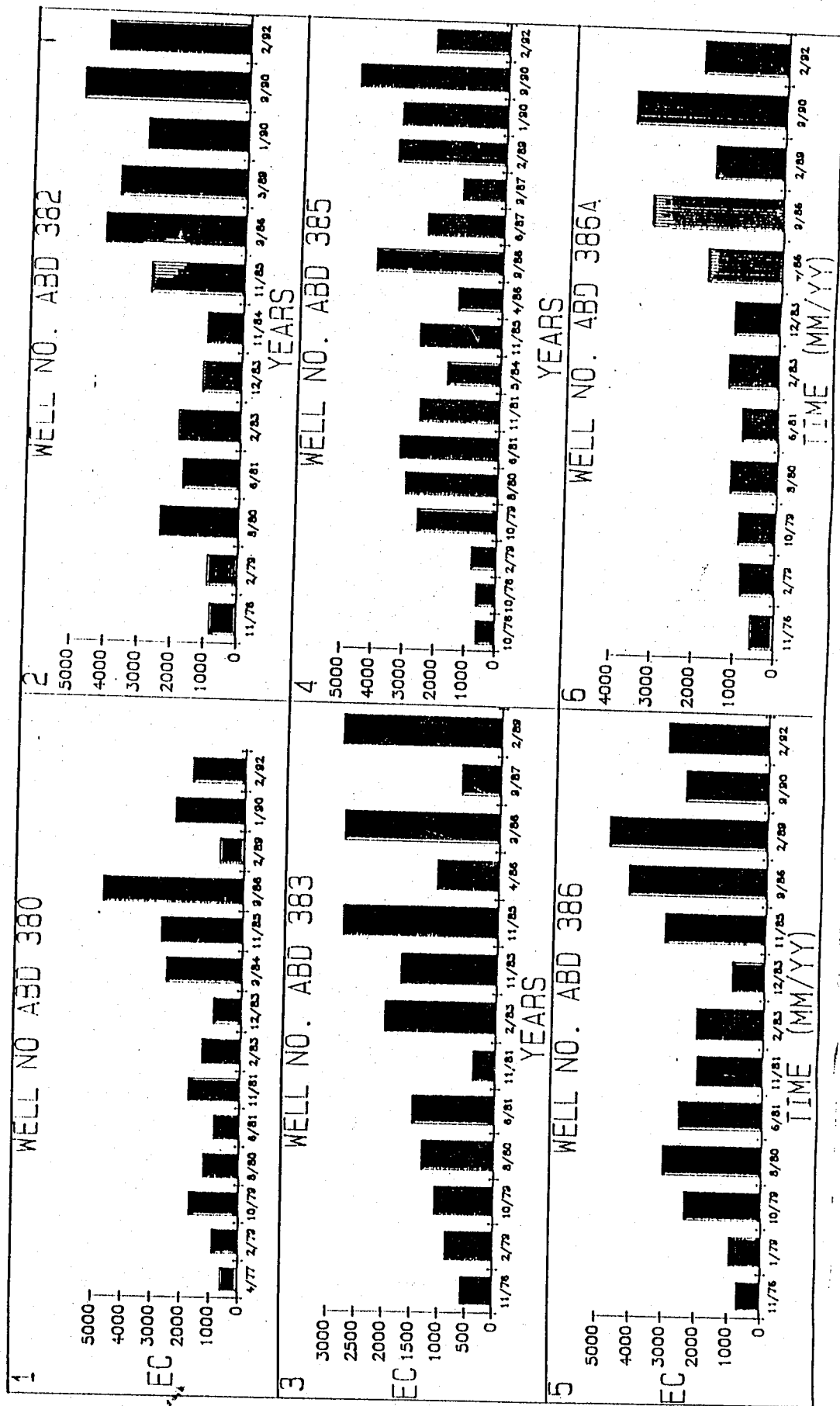
FIG: 3.7 EC CHANGES OVER A PERIOD OF 16 YEARS IN SOME SELECTED WELLS IN THE SEQUENCE DATA WAS COLLECTED.
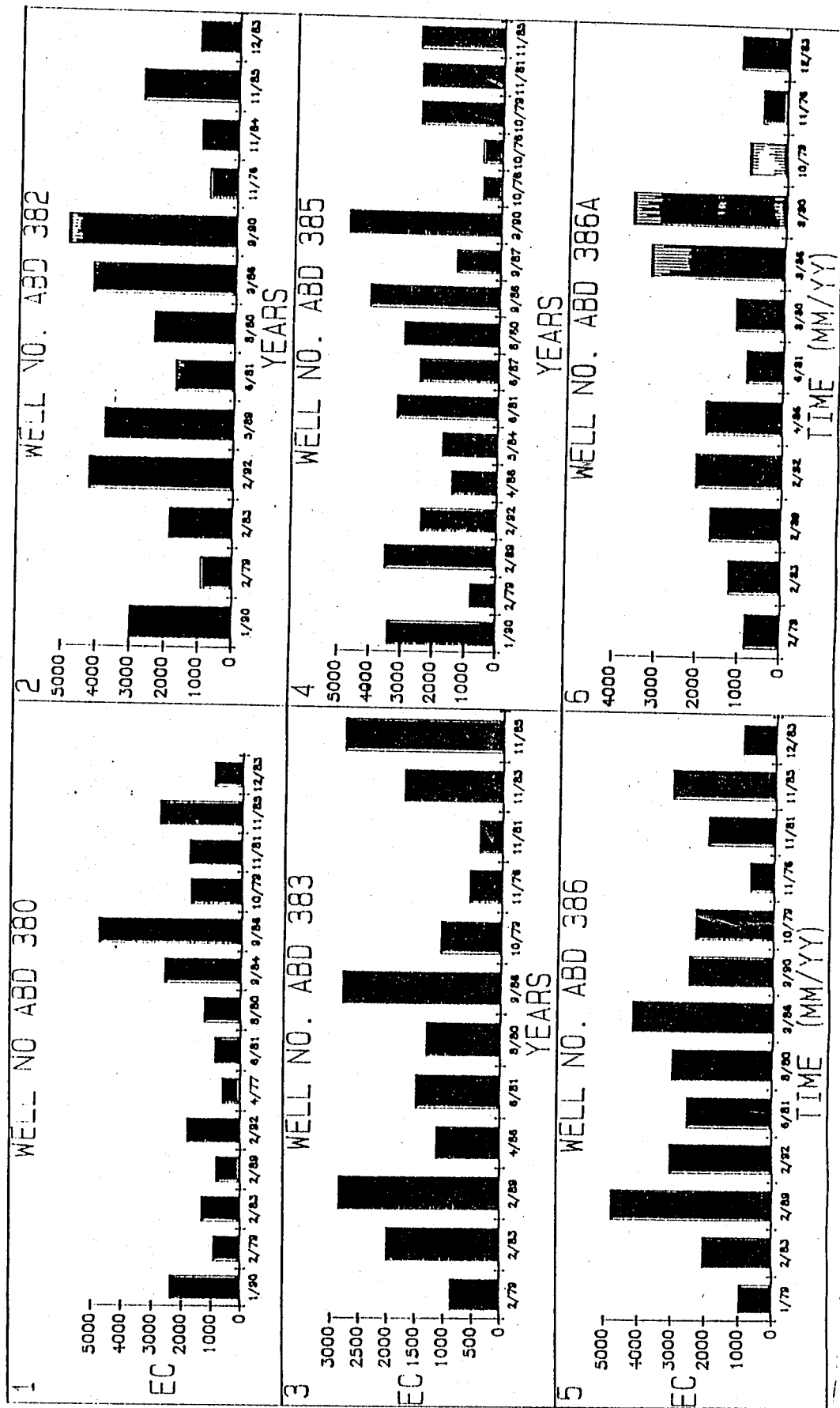
FIG:3-8 EC CHANGES OF SOME SELECTED WELLS PLOTTED IN MONTH WISE SEQUENCE STARTING FROM JANUARY TO DECEMBER.
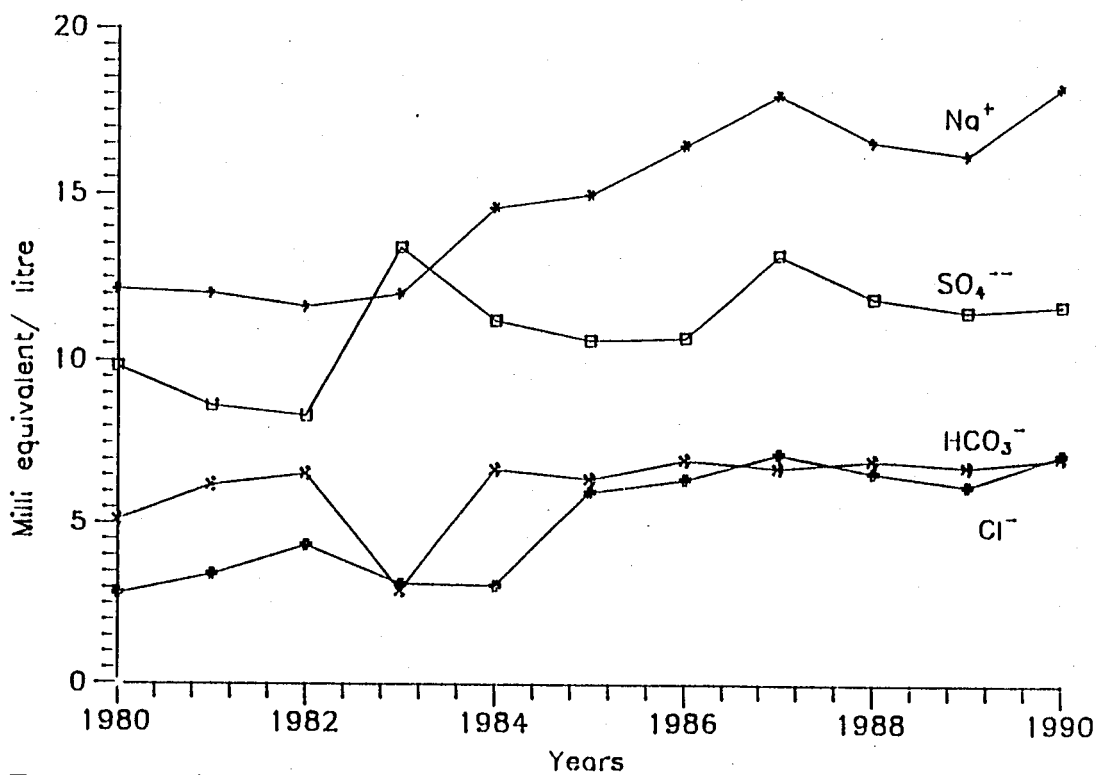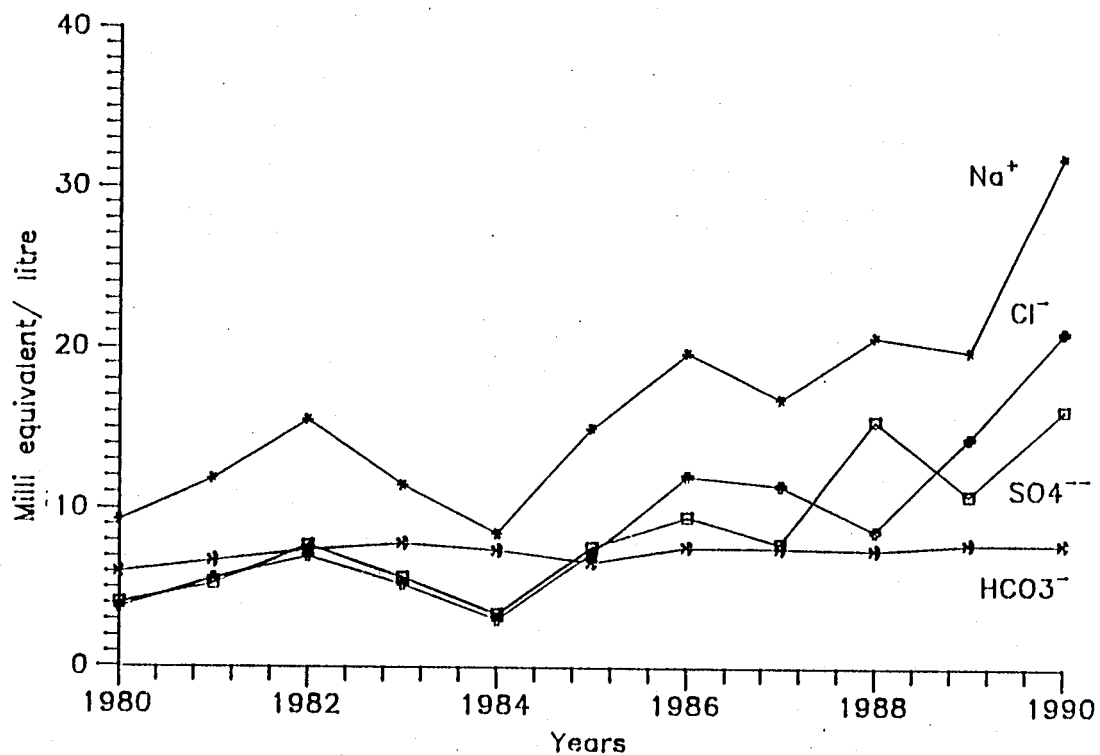
FIG. 3·9 YEARWISE VARIATION IN NA, HCO3, CL AND SO4
         IONS IN TUBEWELLS 503 & 507.

4.0 CONCLUSIONS

i) The variation of water quality in the aquifer appears to be mainly from the saline water lying in the lower part of the aquifer. The intrusion is lateral as well as vertical.

ii) Both recharge and pumping patterns in the aquifer are contributing to the water quality changes observed in the piezometeric data.

iii) The interface as well as the transitional zone appears to be moving in response to pumping and recharge patterns. The range of variation is about 50 ft in the vertical direction.

iv) Where large water quality variation is observed, it appears that the interface is very close to the well screen i.e well is located close to the saline water body.

v) Where changes are relatively small, the well is taking water from the fresh zone.

vi) The SMO water quality map indicate that along south-eastern boundary gradual salinization is taking place and extending towards the central part, hazardous water is found along this boundary. The piezometers are installed mainly along the saline wedge intruded into the fresh zone. This

means that the movement of the wedge towards the fresh zone
can be detected easily.

vii) Only two sets of monitoring wells are selected in the
hazardous water zone and the rest are located in the fresh
water zone, therefore these wells fail to capture the exact
location of saline interface.

It would be appropriate If these monitoring wells are
installed at three or four different location along the
south-eastern boundary in a straight line extending into the
fresh water zone. The layout of piezometer can be greatly
helpful in monitoring the movement of the saline interface.

5.0 RECOMMENDATIONS

i)   The pumping patterns of the aquifer should be carefully defined based on recharge estimated and strictly followed otherwise the wells will gradually start pumping saline water especially in the eastern part of the aquifer.

ii)   The crop water requirements should be carefully determined to minimize pumping and to avoid excessive disturbance caused to saline water body by the pumps.

iii) The monitoring of the wells should be continued on long term basis. Atleast four readings should be recorded to monitor the movement of the saline water in the area.

iv) The monitoring of these existing network of wells by SMO should be carefully planned to provide useful data. It is suggested that the total number of wells monitored in the area should be reduced to a minimum. But the number of observation should be increased to atleast four in a year. The layout of the monitoring well should be such that it gives a clear picture of saline water movement in the area.

v)   The data base prepared by SMO should be updated on regular basis (annually or bi-annually)

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APPENDICES

MONTHWISE BEHAVIOUR OF AQUIFER AROUND TUBEWELL NO. 2-A IN ELECTRICAL CONDUCTIVITY AND WATER LEVELS
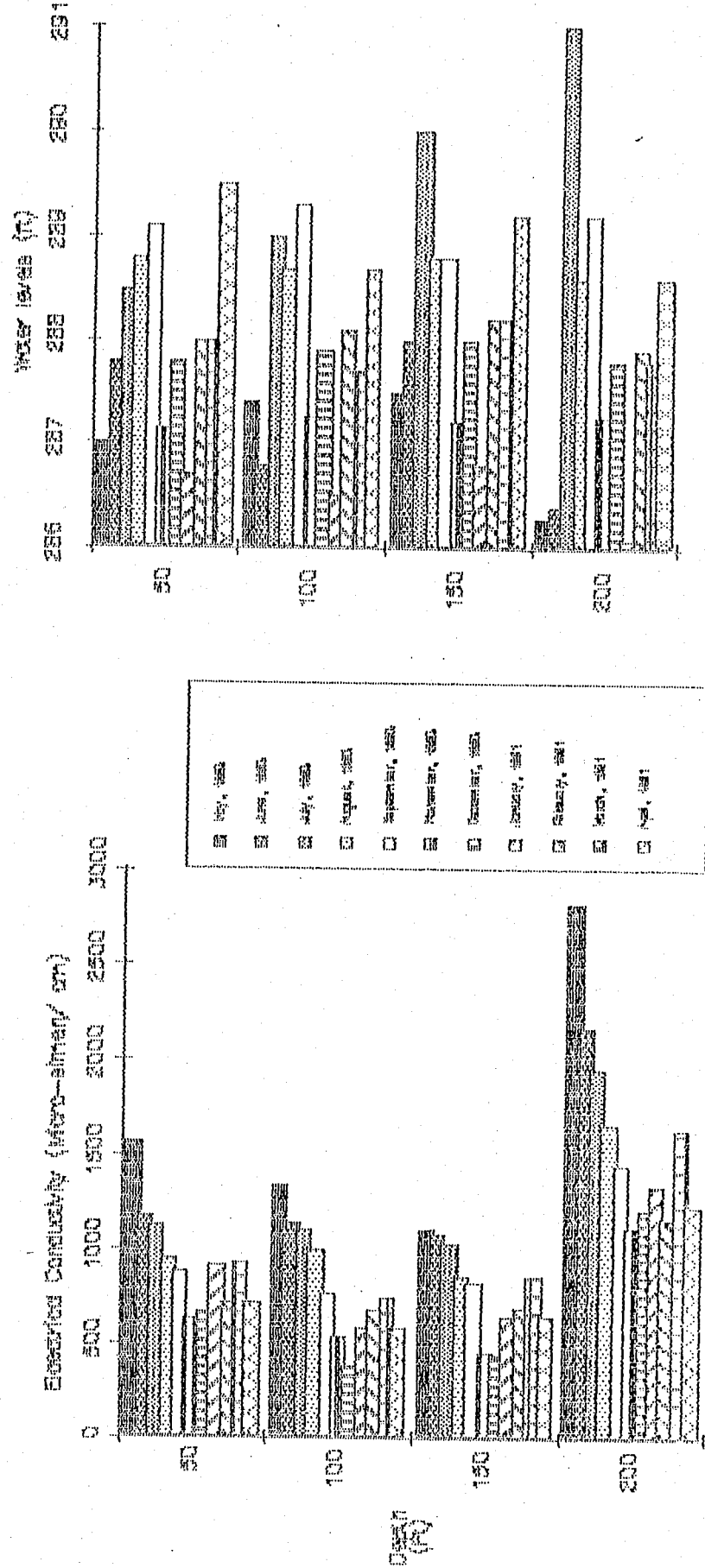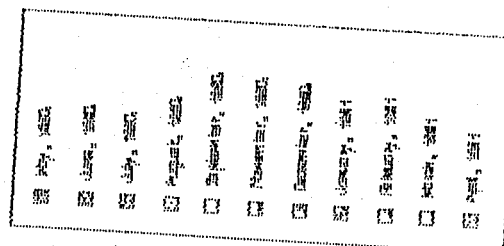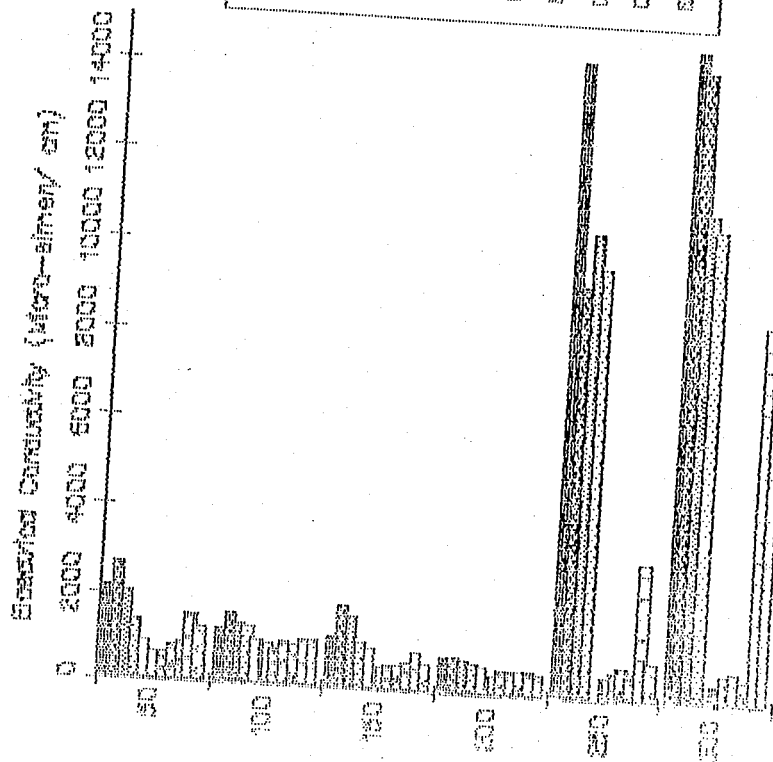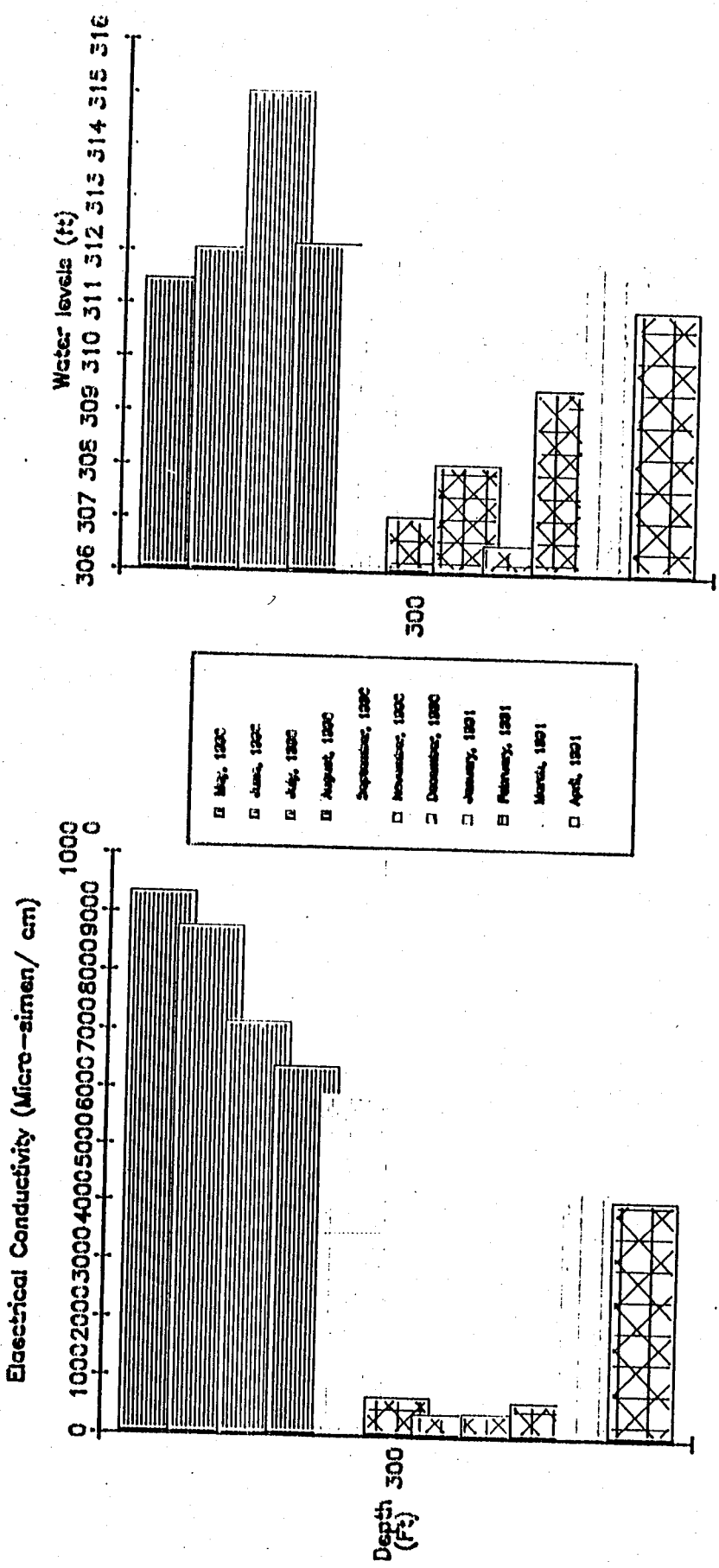
FIG-1: MONTHWISE BEHAVIOUR OF AQUIFER AROUND TUBEWELL NO. 98 IN ELECTRICAL CONDUCTIVITY AND WATER LEVELS
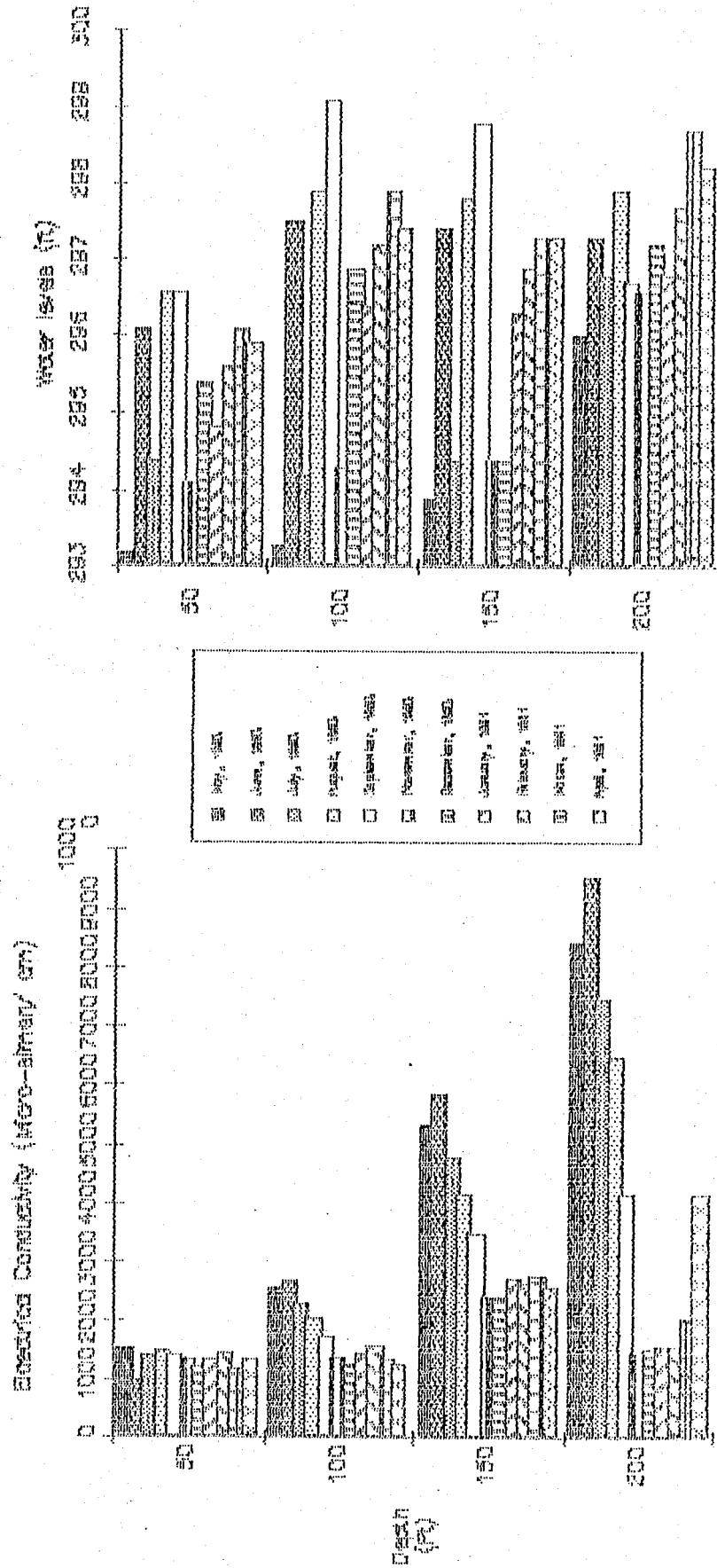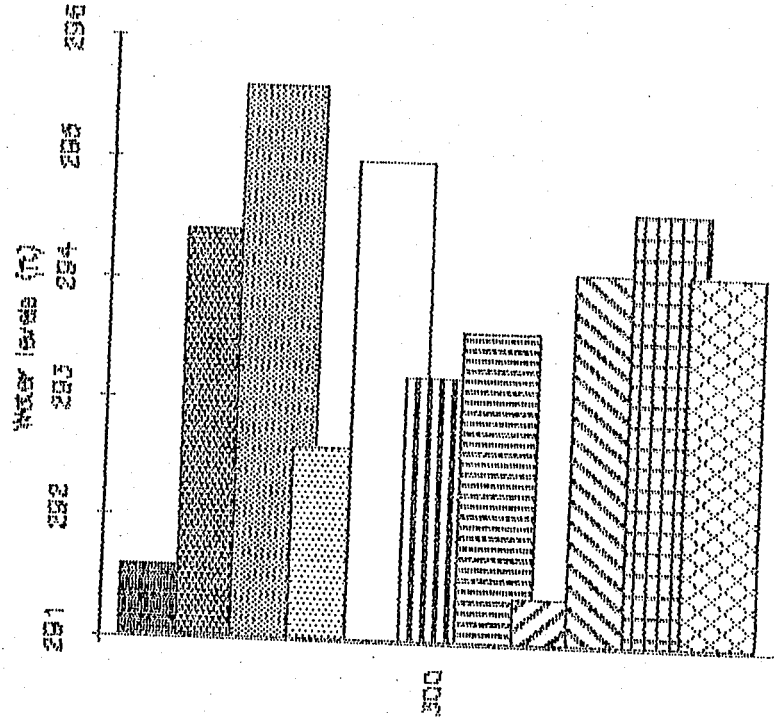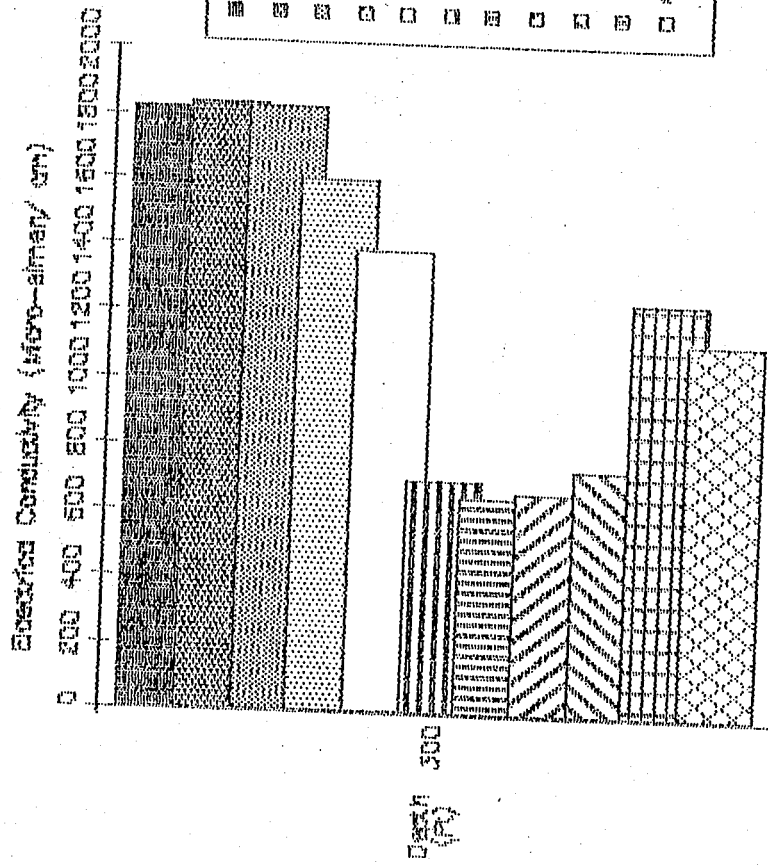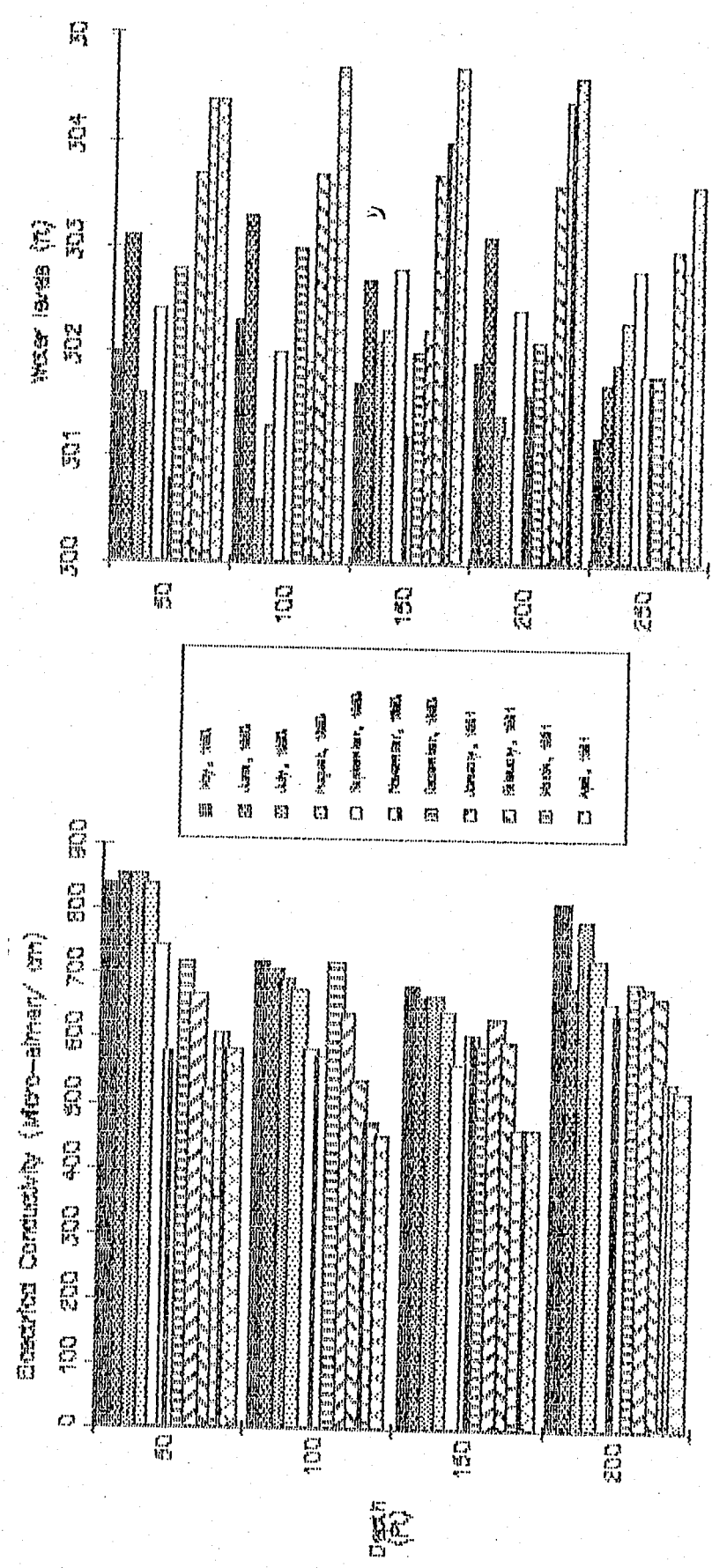
MONTHWISE BEHAVIOUR OF AQUIFER AROUND TUBEWELL NO. 24-A IN ELECTRICAL CONDUCTIVITY AND WATER LEVELS
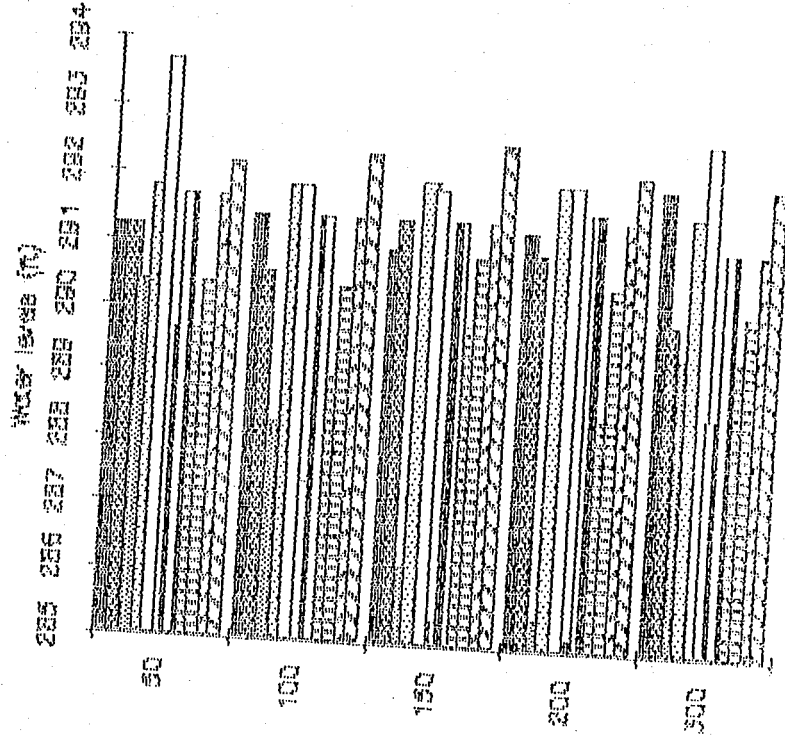
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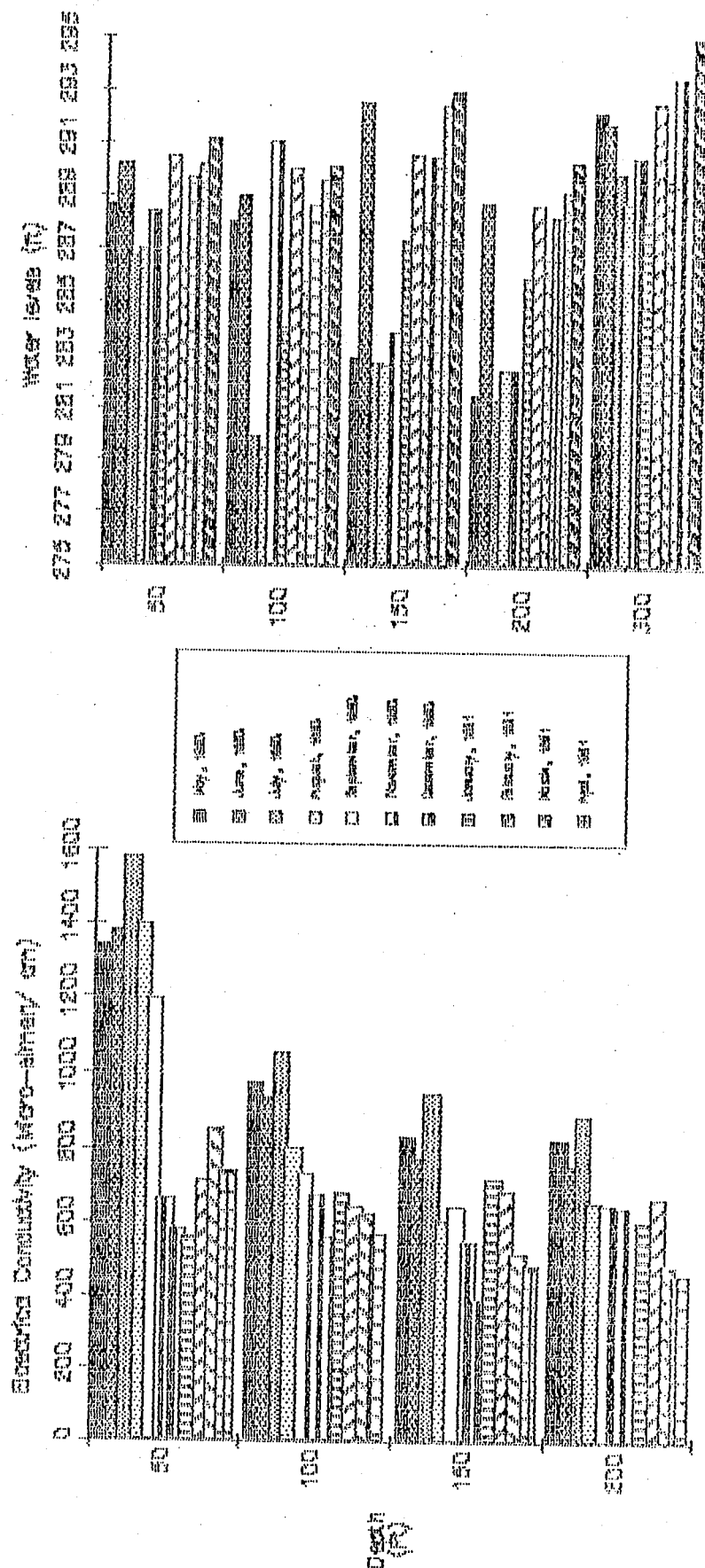
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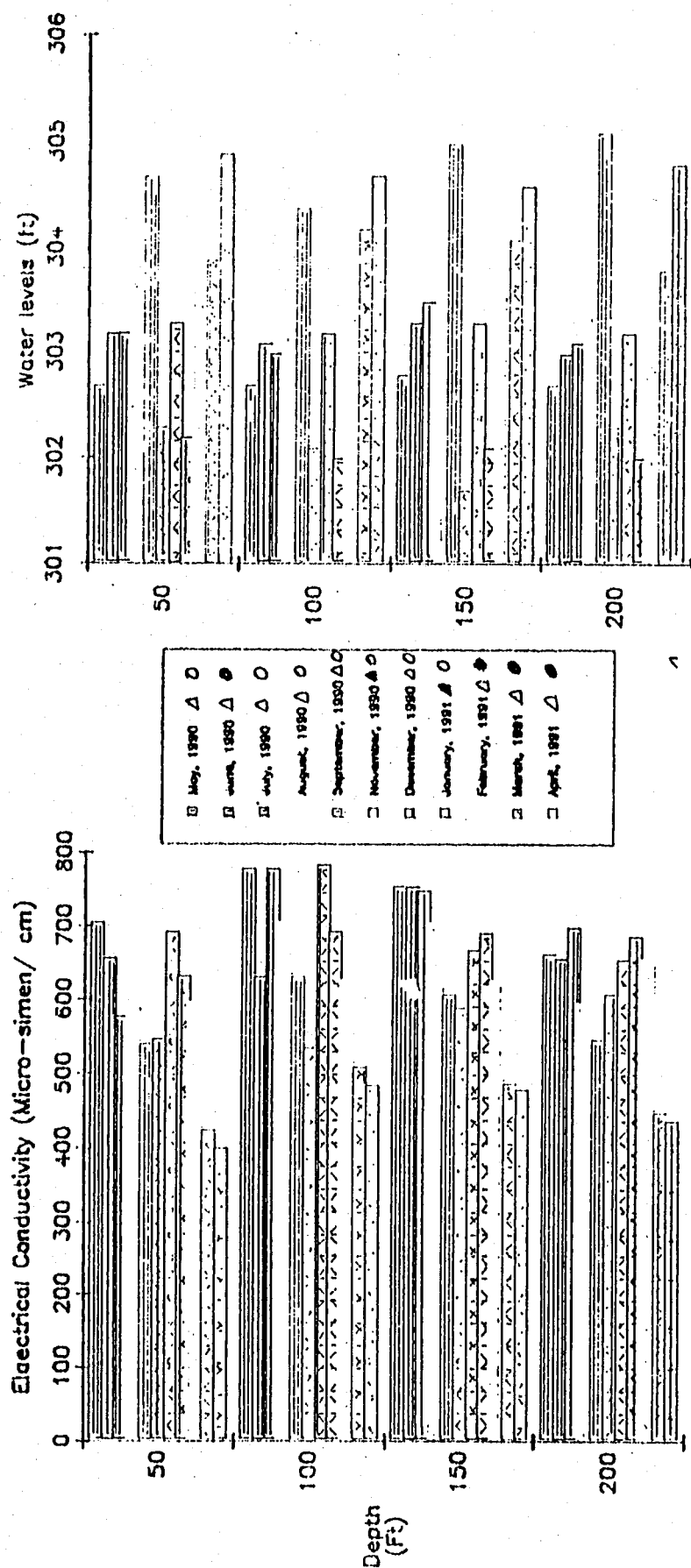
MONTHWISE BEHAVIOUR OF AQUIFER AROUND TUBEWELL NO.54 IN ELECTRICAL CONDUCTIVITY AND WATER LEVELS

MONTHWISE BEHAVIOUR OF AQUIFER AROUND TUBEWELL NO. 217-A IN ELECTRICAL CONDUCTIVITY AND WATER LEVELS

MONTHWISE BEHAVIOUR OF AQUIFER AROUND TUBEWELL NO. 1/2 KM FROM 54 IN ELECTRICAL CONDUCTIVITY AND WATER LEVELS

MONTHWISE BEHAVIOUR OF AQUIFER AROUND TUBEWELL NO. 1/2 Km from 2-A IN ELECTRICAL CONDUCTIVITY AND WATER LEVELS