KINGDOM OF THE NETHERLANDS
MINISTRY OF FOREIGN AFFAIRS
DIRECTORATE GENERAL OF
INTERNATIONAL COOPERATION
DAL/ZZ

GOVERNMENT OF INDIA
MINISTRY OF AGRICULTURE
DEPARTMENT OF RURAL DEVELOPMENT
—
GUJARAT WATER SUPPLY &
SEWERAGE BOARD

INDIA

HYDROGEOLOGICAL INVESTIGATIONS FOR THE SANTALPUR AND SAMI-HARIJ RWSS

RURAL WATER SUPPLY AND SANITATION

REGIONAL WATER SUPPLY SCHEMES GUJARAT STATE

January 1992

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REPORT OF HYDROGEOLOGICAL INVESTIGATIONS SANTALPUR AND SAMI-HARIJ REGIONAL WATER SUPPLY SCHEMES

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LIST OF ABBREVIATIONS

AC	Asbestos cement
AE	Assistant Engineer
AEF	Assistant Executive Engineer
ARDC	Agricultural Refinance and Development Corporation
BGL	Below Ground Level
BLC	Branch Line Committee
CE	Chief Engineer
CGWB	Central Ground Water Board
CHETNA	Centre for Health, Education, Training and Nutrition Awareness
CI	Cast Iron
CRU	Community Relations Unit
CPHEEO	Central Public Health & Environmental Engineering Organization
CT	Cattle Trough
DG	Diesel Generator
DRD	Department of Rural Development
EE	Executive Engineer
EEC	European Economic Community
ESI	Environmental Sanitation Institute Ahmedabad
ESR	Elevated Storage Reservoir
FC	Faecal Coli
FPI	Foundation for Public Interest
FSWD	First Secretary Women in Development
FSWS&S	First Secretary Water Supply & Sanitation
GEB	Gujarat Electricity Board
GOI	Government of India
GOG	Government of Gujarat
GON	Government of The Netherlands
GWSSB	Gujarat Water Supply and Sewerage Board
GWRDC	Gujarat Water Resources Development Corporation
GU-XX	Mission no. XX to Gujarat
HGLR	High Ground Level Reservoir
hp	Horse Power
HW	Head Works
IBRD	International Bank for Reconstruction and Development
IHE	International Institute for Hydraulic and Environmental Engineering
IMD	Indian Meteorological Department
IRC	International Reference Centre for Community Water Supply and Sanitation
ISI	Indian Standard Institute
ITW	Irrigation Tube Well
KAP	Knowledge, Attitudes and Practices
LPCD	Litres per Capita per Day
mg/l	Milligrams per litre
MIS	Management Information System
MLD	Million Litres per Day
MCM	Million Cubic Metres
MSL	Meters above Sea Level
NABARD	National Bank for Agriculture and Rural Development
NEERI	National Environmental Engineering Research Institute, Nagpur
NGO	Non Governmental Organisation

LIST OF ABBREVIATIONS cont'd

O&M	Operation & Maintenance
ORG	Operations Research Group Baroda
PP	Paani Panchayat (Village water committee)
PPM	Parts per million
PZM	Piezometer
RCC	Reinforced (cement) Concrete
RNE	Royal Netherlands Embassy
RSF	Rapid Sand Filtration
RSM	Review and Support Mission
RWS	Rural Water Supply
RWSS	Regional Water Supply Scheme
SE	Superintending Engineer
SEU	Socio-Economic Unit
SEWA	Self Employed Women's Association
SOR	Schedule of Rates
SPI	Sardar Patel Institute
SSF	Slow Sand Filtration
TAG	Technology Advisory Group
TDS	Total Dissolved Solids
TOR	Terms of Reference
TW	Tube Well
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
WHO	World Health Organisation

1. GENERAL

1.1 Introduction

During subsequent review and support missions of the Santalpur and Sami-Harij regional water supply schemes in the State of Gujarat, the mission expressed its concern regarding the contamination of the groundwater with fluoride and the continuously descending groundwater levels. In the GU-23 mission this concern resulted in the advise to carry out a complementary hydrogeological study to the phenomena described above. A proposal for this study was prepared and handed over to the Directorate General for International Cooperation (DGIS-DAL/ZZ) in November 1990. Approval of the study was given by DGIS and the Water Coordinator of the Royal Dutch Embassy in India and it was decided to mobilise in the second half of February 1991.

This report contains in chapter 1 the setting of the hydrogeological conditions and the outline of the investigations. Chapter 2 is dedicated to a literature survey and evaluation of existing groundwater studies. Chapter 3 comprises the investigations on the Shihori well field whereas chapter 4 is focused on the Kamlivada well field. In chapter 5 and 6 the conclusions and recommendations are formulated.

This report contains many tables and figures. The figures are presented at the end of each chapter.

1.2 Problem setting

The State of Gujarat is known for its high fluoride contents in natural groundwater and the deeper groundwater in particular. So far, the district of Banaskantha, in which the Santalpur RWSS is located (fig. 1 and fig. 2), has not been mentioned with respect to the fluoride problem. However, monitoring of the fluoride content revealed that locally the permissible limits are being exceeded. The district Mehsana, in which the Sami-Harij RWSS is located, is known since long for its fluoride problems. However, these were mainly limited to the Taluka's to the east and the south of the district. More detailed maps of the region around the well fields is given in Annex I.

Although several studies have been made of the occurrence of fluoride in groundwater [12], [17], [20], the cause of excessive fluoride content and the distribution is not yet fully understood. A discussion on the possible causes of fluoride in the groundwater of the project area is given in Annex II.

Overdraw of the aquifers occurring in the Mehsana district and more recently also of the aquifers in the Banaskantha district is recognized by the mission as a serious problem. The cause of the problem is most likely to be found in the extensive use of groundwater for irrigation purpose. The seriousness of the problem of the falling groundwater levels and its impact in future is not being realised by the competent authorities.

The aim of this report is to quantify the extend of the problems for the two well fields of Shihori (Santalpur RWSS) and Kamlivada (Sami-Harij RWSS) and its surrounding areas being the Kankrej Taluka and the Patan Taluka of the Banaskantha and the Mehsana districts respectively.
At the same time the report presents an inventory of hydrogeological work executed in this area.

1.3 Background of the problems

As mentioned before, both problems of excessive fluoride content of deeper groundwater and descending of the groundwater table have been studied earlier.

1.3.1 Groundwater levels

District-wide observations revealed that groundwater levels are continuously dropping in both the Banaskantha and the Mehsana districts and in other parts of the State of Gujarat. This might lead to a further deterioration of the quality of the groundwater through invading and upconing of brackish groundwater. In addition recirculation of irrigation water may badly affect the quality of the groundwater. It has already been noticed that salinity tends to increase with continuing exploitation of the aquifers and consequently lowering of the groundwater table.

Already in the report of the UNDP [16] in 1976 it has been mentioned that exploitation of water for irrigation purposes in the project area should be reduced with 25% to prevent further declining of ground water levels. The project area of this UNDP project is located between the Banas and the Sabarmati river. The Kamlivada well field is located in this area and the Shihori well field is located just outside this area, on the opposite bank of the Banas river (Annex 1).

Regional observations also indicate that water levels are declining over a very large area. In the west of Banaskantha towards the Ran of Kutch, several artesian wells up to 300 m depth used to exist around Santalpur and Radhanpur. Due to over-exploitation, these sources lost their artesian conditions. In the region of Shihori the following declines in water levels in the unconfined aquifer have been observed between 1977/78 and 1988/89:

Shihori	18.4 m
Umbari	7.6 m
Kuvarva	15.1 m
Chekhala	12.4 m

In Banaskantha the water levels are dropping at a rate of several meters per year. For example, in a small regional water supply scheme in the north of Banaskantha, Bhabhar, water levels are dropping with 1 to 1.5 m per year. More to the east in Deesa where wells are located for a large RWSS, water levels are dropping with 1.5 to 2 m per year.

In the region of the Kamlivada well field, the waterlevels have dropped below the bottom of the phreatic aquifer for a large part of the year.

Water levels in the deeper confined aquifers are also declining which is illustrated by the following data:

Village	Period of Measurement	Decline (m/year)
Walam	1986 - 1990	2.5 - 2.6
Bhandu	1986 - 1990	0.8 - 3.2
Charassan	1986 - 1990	0.85
Pasna	1981 - 1990	1.5

It was recognised that limitation of the irrigation with groundwater was necessary in order to reduce the decline of the ground water table.

In the State of Gujarat, the Bombay Irrigation Act (Gujarat Amendment) [9] is active. This amendment obliges the holder of land to apply for a licence for any tube well, artesian well, borewell or dugwell exceeding 5 m depth in coastal area, exceeding 45 m in a specified area (not a coastal area where an overdraw of confined aquifers has been notified) exceeding a depth of 25 m in an area other than a coastal or a specified area. The control of the latter limitation is the responsibility of the GWRDC. In order to obtain financing for the construction of a tube well and the required power supply connection, approval of GWRDC is required. However, in practice control is difficult and still possibilities exist to realise new tube wells for irrigation purposes.

An extensive explanation of the regional hydrogeology is given in Annex III together with some illustrative maps and cross-sections.

1.3.2 Fluoride levels

Several mechanisms have been suggested to explain the excessive fluoride content in the groundwater in Gujarat. Fluoride might have originated from the seawater which in earlier geological periods covered large parts of Gujarat. It also might originate directly from the sediments. These sediments are partly weathered products from hilly areas situated more to the north and the east, consisting of igneous rocks that contain fluoride minerals. Also direct leaching of fluoride from these igneous rocks by rain water and subsequent infiltration and percolation through the aquifers has been mentioned as a source of the present fluoride. Although the vertical occurrence of fluoride has not yet been investigated in detail sofar, it was presumed that excessive fluoride levels do not occur in the deeper aquifers ("B") and beyond. Since high fluoride concentration may originate from any of the above mentioned sources, logical patterns in distribution so far could not be recognized and the distribution appeared impossible to predict.

Trends in fluoride levels that are found are only local. Tube wells tapping the same aquifer and situated at short distance can give complete different fluoride values. A phenomena which has been observed is the increase of fluoride content during and after monsoon. Yet, also several exceptions are known. Another phenomena is that it seems that fluoride levels are increasing when the waterlevels decline.

1.4 Directives

The directives for fluoride and other components in groundwater for the purpose as drinking water are not uniform. Directives in general are given in a range of desirable limits and a maximal permissible limit. The guidelines given hereafter are from the World Health Organisation (WHO), the European Community (EC) and the Indian Standards Institution (ISI).

Table 1 Guidelines of the WHO [23]

Water Quality Parameter	Unity	Desirable level	Maximal permissible level
Nitrate	mg/l	50	100
Chloride	mg/l	200	600
Sulphate	mg/l	200	400
TDS	mg/l	500	1500
Fluoride	mg/l	1.0	1.5*

(*) Less than 0.8 and more than 1.5 are harmful.

Table 2 Guidelines of the EEC [3]

Water Quality Parameter	Unity	Desirable level	Maximal permissible level
Nitrate	mg/l	25	50
Chloride	mg/l	250	--
Sulphate	mg/l	25	250
TDS	mg/l	--	--
Fluoride 8°-12°	mg/l	--	1.5
25°-30°		--	0.7

-- has not been specified in the guidelines

Table 3 Guidelines of the Indian Standards Institute [8]

Water Quality Parameter	Unity	Desirable level	Maximal permissible level
Nitrate	mg/l	45	--
Chloride	mg/l	250	1000 (*)
Sulphate	mg/l	150	400 (**)
TDS	mg/l	500	3000 (*)
Fluoride	mg/l	0.6 - 1.2	1.5 (*) (***)

(*) Maximal permissible level if no alternative sources are available.
(**) If Mg content does not exceed 30 mg/l.
(***) If the fluoride content is lower than 0.6 mg/l, the water should not be rejected but suitable public health measures should be taken.
-- Has not been specified in the guidelines.

The previous tables illustrate the differences in desirable and acceptable limits. In general the maximal permissible level according to the Indian Standards Institute are higher than those according to the other standards. For this report we will refer to the standards which are most appropriate, the standards of the Indian Standards Institute.

In hot and arid regions of the world, the need of drinking water per head per day is higher. As already indicated in table 2, the permissible limits therefore should be related to the climate of the area under consideration. Galagan & Vermillion [3] presented the following widely-used formula for the calculation of the "optimum" level of fluoride in mg/l:

Optimum level = 0.34/(0.0062*x - 0.038)

with x as the mean maximum temperature in degrees Fahrenheit ($T_f = 32 + 1.8 * T_c$).

In temperate climates (T_f=61 °F) this means an optimum value of 1.0 mg/l whereas in hot and arid climates (T_f=95 °F) this means an optimum value of 0.6 mg/l. The foregoing illustrates to which degree permissible limits should be looked at in relation to the climate of the area under consideration.

1.5 Outline of the programme

Roughly, the activities of the hydrogeological investigations initiated by the RSM, can be divided into three parts being a literature survey and data collection, sampling and chemical analysis programmes and study of the ground water levels.

The first two weeks were used to carry out an extensive literature survey and an inventory of data available, resulting in large quantities of available material on different aspects concerning the sources of the RWSS's.
The third week was used to study the water level behaviour from the data obtained. The fourth week was used to study the chemical aspects of the Shihori well field more closely. A large amount of samples for several purposes has been taken from the water supply tube wells, irrigation tube wells surrounding the well fields and from tube wells in the region used for drinking water supply. Also specific tests were carried out, samples were sent to the laboratory of GWSSB in Palanpur and a sampling programme for the coming period was set up. In this period construction of piezometers in both well fields started. GWSSB division offices carried out surveys of existing tube wells surrounding the well fields of Kamlivada and Shihori and carried out a sampling programme in both well fields.
The fifth and the sixth week have been used to complete the chemical analysis on site, assembling of the latest data, reporting and discussions with GWSSB on the preliminary results.

Piezometers have been completed later on by GWSSB. The results of the drillings, water levels and chemical analysis were available during GU-25. Subsequently the report on the hydrogeological investigations has been finalised.

1.6 Detailed investigations

1.6.1 Literature search and data collection

During the first two weeks GWSSB, GWRDC and CGWB were contacted in order to make an inventory of literature and data available on the area of investigation. During this period inventories were initiated of irrigation tube wells and drinking water tube wells situated in the vicinity of the well fields of Shihori and Kamlivada.

Since reliable data on the water levels around the well fields were not available, sites were selected for measurements during the study and in the future to monitor the local hydrogeological conditions.

1.6.2 Chemical analysis

Chemical analysis of several samples were carried out both in India and The Netherlands. Prepared sample bottles have been used for the samples to be analyzed in The Netherlands. The samples have been taken shortly before leaving Gujarat.

Sample analysis in India was carried out by the GWSSB laboratory in Palanpur. During a visit their methods of sampling, storage and preservation of the samples and the actual analysis were discussed. The impression obtained from the functioning of the laboratory was good. The laboratory was sober but sufficiently equipped. Samples are thoroughly being stored and analysis is executed within 48 hours upon arrival. The laboratory demands delivery of samples within 24 hours after the actual sampling and samples older than 72 hours are refused. As a guide for the analysis techniques, "Standard methods for the examination of water and wastewater" [2] is being used.

Not only the lateral differences but also the vertical differences in chemical characteristics have been tested. Because at the time of the investigations only 2 single piezometers tapping the deep aquifers in Kamlivada and Shihori were available to take samples from a specific depth, groups of tube wells were chosen which tap aquifers up to different depths. Comparison of the results would then indicate characteristics of the non-commonly tapped aquifers. Later on in both well fields, all piezometers have been installed up to several depths. The Shihori well field comprises 8 piezometers, tapping different aquifers. The Kamlivada well field comprises 12 piezometers. More details are given in Chapter 1.6.5, 3 and 4 with the discussion of both well fields.

1.6.3 Fluoride analysis

In order to carry out fast analysis of the fluoride content of the ground water on site, a fluoride measuring set has been provided. This set consisted of a multi purpose meter applicable for several electrodes and able to convert concentration to redox potential and ion-activity, a fluoride selective electrode, a temperature electrode and a pH electrode. Because the concentration of fluoride to a certain extend depends on pH and calibration of both electrodes requires temperature data, the latter two electrodes were necessary to complete the set. The set has been handed over to the GWSSB in Radhanpur with instructions to the use of the set.

The fluoride analysis was executed with an ion selective electrode. This electrode is only sensitive for fluoride ions. The measured redox-potential is directly converted to concentration after executing a calibration with prepared standard solutions. The accuracy of the method is around 0.01 ppm. From fluoride it is known that the concentration may vary with the pH of the sample.

In case of excessive pH (high as well as low) or high background concentration of other ions which might interfere with the actual concentration, a stabilising complex should be added. However, this was not found to be necessary regarding pH and background concentrations of interfering ions in the samples tested.

The fluoride analysis in the laboratory in Palanpur was executed by using Spans method [2]. With this method a stable complex is formed with a metal ion. The solution is tested by means of photometry. The intensity of light transmitted through the solution is indicative for the fluoride concentration. The accuracy of the method is around 0.05 ppm.

1.6.4 Isotope analysis

Isotope analyses were carried out to obtain information about the isotopes present in the groundwater of the area. Isotope studies concern the abundances and behaviour of isotopes of elements participating in the hydrological circle. This concerns radioactive as well as stable isotopes. The elements of primary importance are hydrogen, carbon and oxygen. Isotopic analyses related to groundwater aim to give response to questions as "What is the origin of the groundwater", "How does the groundwater move" and "What geochemical processes operate underground". The following isotopes are considered to this extent: ^{18}O (Oxygen- 18), ^{2}H (Hydrogen-2), ^{3}H (Tritium), ^{13}C (Carbon-13), ^{14}C (Carbon-14). ^{13}C and ^{14}C are used to indicate the (relative) age of the water. In case of relative young water and to study possible mixture of older and younger water, information of the isotope ^{3}H is required. ^{3}H, ^{2}H and ^{18}O are used to study processes of transpiration, evaporation, infiltration velocity and infiltration rate.

Samples were taken in special bottles which prevent sun light to enter changing the characteristics of the sample. Because about 30 l of sample is required to extract the amount of ^{14}C necessary for analysis, preparation of the sample was done on site in order to reduce the volume of water to be analyzed to 250 ml. The analysis was done by the Institute for Isotope Research of the University of Groningen in The Netherlands.

1.6.5 Piezometers new wells

During mission GU-23 the RSM suggested to install piezometers tapping the different aquifers in order to determine the most optimal location for the new wells. It was planned to install piezometers in all aquifers known. GWSSB executed the piezometers in separate boreholes.

The RSM introduced the idea of multiple piezometers in one borehole which would save enormous costs for reduced drilling and shorter construction time. This means that all piezometer tubes are installed at the same time and the aquifers are separated by an impermeable seal. However, since GWSSB does not have any experience with the construction of multiple piezometers, this method could not be taken up. It was consequently decided to install single piezometers.

The method for the construction and installation of multiple piezometer or piezometer nests is as follows. A hole is drilled up to the required depth. The hole is widened to the required diameter, while the walls are maintained through the mud. Individual piezometer tubes are prepared for the required depth on the surface. All piezometers are tied up together and lowered down into the borehole. After lowering, a gravelpack is applied and the separation of the different aquifers is carefully restored by clay seals. The piezometers consist preferably of small diameter (1 inch) flexible plastic pipes.

Another, more costly method, is by installing a large diameter casing which is slotted continuously. In the interior of the casing, piezometers are lowered with screens embedded in gravelpacks and separated by clay seals.

All piezometers in the Shihori well field as well as in the Kamlivada well field have been completely installed as single piezometers in August 1991. During GU-25 the first result have been discussed between GWSSB and the RSM.

1.7 Acknowledgements

The consultant wishes to express its appreciation of the full support and close collaboration that was extended by the GWSSB during its stay in Gujarat. The close collaboration resulted in a valuable exchange of data, literature and ideas.

The consultant also wants to thank the GWRDC and the CGWB for their cooperation and time made available.

HYDROGEOLOGICAL INVESTIGATIONS SANTALPUR + SAMI HARIJ RWSS

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FIG. NO. 1

MAP OF INDIA
INDICATING THE STATE
OF GUJARAT

DATUM	GET.	CORR.

SCHAAL

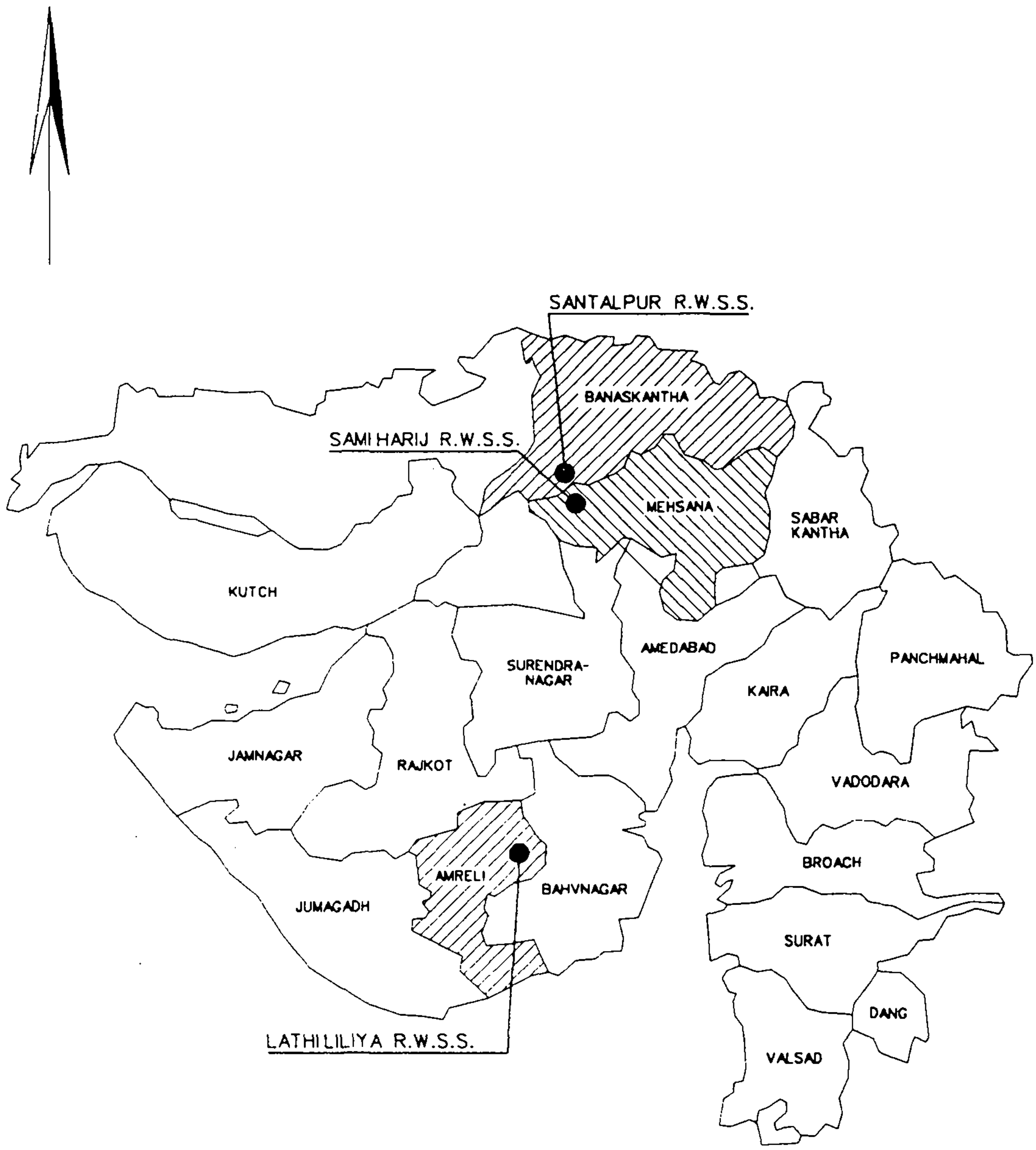

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FIG. NO. 2

MAP OF GUJARAT STATE INDICATING DISTRICTS AND LOCATION OF SCHEMES

DATUM	GET.	CORR.

SCHAAL

2. EXISTING REGIONAL GROUNDWATER STUDIES

The reports discussed hereafter were encountered during the literature survey in the first two weeks of the investigations. They can be separated in water balance studies and hydrogeological reports.

2.1 Ground water balance studies

2.1.1 Ground water estimation methodology, a report of the Ground Water Estimation Committee, 1984 [7]

For the assessment of replenishable ground water resource potential, several methodologies were being adopted by the different States and the CGWB before the year 1979. In order to project a unified methodology for assessing the ground water resources on scientific lines, the Ground Water Over Exploitation Committee (GWOEC) was constituted in november by ARDC (currently NABARD). Their methodology was adopted by ARDC for Credit II and IV projects. The National Bank for Agriculture and Rural Development (NABARD) approached the Government of India (GOI) to contribute material for inclusion in its approach paper for availing the World Bank assistance under NABARD-I project (1984-1985). The CGWB to whom the matter was referred, prepared an approach paper with a revision of the methodology suggested by the GWOEC for estimation of the ground water potential. It was felt necessary that a committee, the Ground Water Estimation Committee (GWEC), constituted by the GOI, went into all aspects of the problem and made its recommendations. In March 1983, recommendations were discussed and adjusted and in march 1984 the final version of their findings was published.

The report first gives an overview of the occurrence of ground water in India. Thereafter a review is given of existing methodologies and norms for ground water resource evaluation. These include norms for the approximate evaluation of ground water potential (from the Ministry of Irrigation, GOI) and norms for ground water resource evaluation (from GWOEC). In addition, the status of recent studies on ground water resource evaluation is given. The final recommendations of the report are that when sufficient data are available, ground water potentials in India should be calculated according to the "water level fluctuation and specific yield approach" which are not explained in the report. If no sufficient data are available, ad hoc data may be introduced for which the norms are given. These norms for ground water resource evaluation include recharge from rainfall, recharge due to seepage from canals, return from irrigation fields, seepage from tanks and net recoverable recharge. The norms given for the factors mentioned coincide with data from the literature [18].

2.1.2 Report of the group on the estimation of groundwater resource and irrigation potential from groundwater in Gujarat State, 1986 [8]

A "Group on the estimation of ground water resource and irrigation potential from groundwater in the State of Gujarat" constituted on the request of the Ministry of Irrigation and Power of the Government of India has reported on potential groundwater resources in 1986. Meetings and research of the group was carried out between june 1985 and december 1985 and data used in the report are from 1984. The GWSSB participated in this group and provided demand figures for drinking water for households and industries. Other organisations involved were CGWB, GWRDC, NABARD and Gujarat Electricity Board (GEB).

The main objective of the group was to estimate the present level of ground water development and to recommend a programme for investigation and development of groundwater resources.

The total dynamic groundwater resources from unconfined aquifers in Gujarat are estimated at 20,377 MCM/yr. In addition, total groundwater resources of 2,175 MCM/yr are estimated from the confined and semi-confined aquifers of alluvium and semi-consolidated rocks.

The Taluka-wise estimates of phreatic aquifers revealed in five Talukas in Gujarat, an overall annual draft which exceeds recharge; in one Taluka the present (1984) level of ground water development is > 85% and in 13 Talukas the level of ground water development varies between 65% and 85%. In Mehsana district the over-exploited Talukas are:

- Mehsana;
- Sidpur;
- Patan.

The Talukas Vijapur and Kalol have an aquifer development of 65% to 85%.

The ground water estimation committee has recommended that 15% of the total ground water resources should be kept reserved for drinking and industrial purposes. This has been based on the methodology set up by the GWEC of which an outline is given under 2.1.1. It is further stated that based on the resource estimates, large ground water potential is still available for development in the State of Gujarat.

It is concluded that financial inputs are required to increase the number of tube wells for irrigation in order to come to development of the stated ground water reserves.

Relevant data from the report have been summarized in the following tables:

Table 4 Ground water potential of the phreatic aquifer

District	Total gw. res. (MCM/yr)	Provision dom. + ind. (MCM/yr)	Utilisab. gw. res. (MCM/yr)	Total gw. dev. %
Banaskantha	1450.14	217.53	1232.64	33
Mehsana	864.3	129.64	734,66	66

Table 5 Ground water potential (semi) confined aquifers

District	Total gw. res. (MCM/yr)	Provision dom. + ind. (MCM/yr)	Utilisab. gw. res. (MCM/yr)	Total gw. dev. %
Banaskantha	420.00	63.00	357.00	40
Mehsana	611.86	91.78	520.08	88

2.2 Hydrogeological studies

2.2.1 Report of the groundwater surveys in Rajasthan and Gujarat, for the United Nations Development Programme, 1976 [16]

This project is one of 4 subsequent UNDP assisted projects in India of which two are partly covering areas in Gujarat including or related with the region on the Shihori and the Kamlivada well fields. These are the projects Ind 71-614 "Ground water resources in Rajasthan and Gujarat" described hereafter and Ind 78-033 "artificial recharge studies - Mehsana area and coastal Saurashtra, Gujarat". The latter will be discussed in paragraph 2.2.2.

The main objectives of the project under discussion were to:

- investigate and evaluate ground water potentials and ground water quality in the project areas;
- appraisal the technical and economical feasibility of ground water development;
- form a strong counterpart team that would be qualified to carry out ground water resources exploration and evaluation in the future.

Activities undertaken in this project included geological mapping, drilling programme for different types of wells, execution of a wide range of well tests, well inventories, establishment of an observation well network, analysis of ground(water)samples, data collection within a wide range of disciplines, ground water modelling and pedological and landuse studies.

Relevant conclusions on the Gujarat project area are:

- Effects of excessive ground water exploitation are noted in both the phreatic and the uppermost confined aquifer in the central and south-eastern part of the project area where the ground water is fresh. In these areas pumping has to be reduced by about 25% in order to prevent further decline of ground water levels.

- Other important groundwater resources are located in the south-western and western part of the project area where soil conditions are unfavourable for agriculture. About 80 MCM of water is available with TDS varying between 2000 and 5000 and 40 MCM is available with TDS below 2000.

- Operational runs of the mathematical models made of the project area after thorough calibration led to similar conclusions as have been made after field observations.

- Additional wells can be drilled in the foothill zone (Aravalli hills), where natural recharge is high. It is predicted that an additional 50 MCM can be pumped without significant influence of the water levels in most part of the aquifer. This prediction is made for the 5 year following the project period, which has been covered by the modelling study.

- In the modelling studies also artificial recharge has been taken into account. 30 MCM has been assumed to be injected in the foothill area, which would have a beneficial effect on the continued exploitation of the area.

- It was further more recommended that a feasibility study should be made of artificial recharge in the area between the Banas river and the Saraswati river.

- The project finally urged the necessity of continuation of monitoring relevant data and parameters in order to maintain modelling studies for future well fields and for artificial recharge.

In this report for the first time a schematised model for the several aquifers (A-H) has been developed and has been consequently used in recent UNDP projects in Gujarat. The identification of the separate aquifers has been done in cooperation with CGWB and consequently has been introduced as the official classification of the existing aquifers. It is now widely used in hydrogeological studies and reports whenever appropriate.

2.2.2 UNDP report. Artificial recharge studies Mehsana and coastal Saurashtra, 1986 [15]

Artificial recharge studies Mehsana and coastal Saurashtra, 1986. This project, UNDP/IND-87-033, was carried out from 1981 to 1985.

The main objectives for the Mehsana area are to examine the feasibility of storing surface water of the Banas and the Sabarmati river in a groundwater reservoir for utilisation during the lean period for agriculture in the Mehsana area. This would include a cost benefit analysis with study of short and long term socio-economic effects, determination of the optimal method for recharge and the environmental implications caused by the recharge.

The development objectives of the project were to find ways and means to increase groundwater resources so as to sustain accelerated agricultural production in the country.

The project was carried out in close cooperation with the CGWB and with the GWRDC.

In addition to the hydrogeological work carried out previously by UNDP and CGWB, detailed investigations were carried out in the proposed area of recharge. These included drilling for various purposes, several types of well tests, the establishing of a network of observation wells and the construction of several hydraulic works for the recharge experiments (spreading channels, recharge pits and recharge ponds). As source water for the injection wells and the surface water recharge structures, respectively tail-end releases from the Dharoi canal system and ground water from phreatic aquifers was used.

The conclusions which were made, are:

- In central and central-east Mehsana, regional decline of groundwater levels of both phreatic and confined aquifers is taking place due to over-exploitation.

- In addition to the surface run off to the extend of about 100 MCM per annum in the Saraswati river and 50 MCM per annum in the Rupen river, the flood plain aquifers of the rivers contain 13 MCM and 2 MCM of ground water resources, respectively within shallow depths of 3 to 8 m.

- The Dharoi canal system will increase the availability of surface water for irrigation purposes. This will reduce the ground water draft and will provide excess surface water for recharging the depleted confined aquifers in the Central Mehsana area.

- Among the most significant findings of the artificial recharge project is that the injection of water from the phreatic aquifer into the semi-confined A2 and A3 aquifers (at a recharge rate of 3 to 5 LPS) is feasible in parts of the Saraswati and Rupen river valleys.

- Project findings also indicate that recharge at the semi-confined aquifer units in the over exploited area is primarily from relatively local downward leakage from the overlying phreatic aquifer zone due to a difference in hydraulic head of 10 to 20 m.

- Artificial recharge to the phreatic aquifer is practicable by spreading methods (recharge rates of 1.2 m^3/m^2 to 2.8 m^3/m^2 and infiltration rates of around 96 cm/day) and limited recharge through injection wells (1.5 LPS for long duration) is also feasible in the common recharge zone at the foothills.

The following recommendations were made:

- Augmentation of groundwater resources of the phreatic aquifers in the project area should be taken up to utilise 59 MCM of storage from ponds/-tanks, 150 MCM of surplus run-off from the Saraswati and Rupen river systems and the tail-end releases from the canals.

- Recharge of the semi-confined aquifer may be increased with the help of injector/connector wells. These wells should also be used as extraction wells to make them economic viable and to avoid periodic cleaning.

- Artificial recharge of the phreatic aquifers can take place by ponds and pits, the latter being more economic and easier in maintenance.

- To capture the flash-flood run off from the Saraswati and Rupen river, bends or levies should be constructed in the river courses.

- Priority should be given to artificial recharge of the phreatic aquifer. Availability of ground water from the phreatic aquifer should decrease overdraft of the semi-confined aquifers and should increase the recharge of these aquifers through leakage.

2.2.3 Geohydrology of Gujarat State, West Central Ground Water Board, Ministry of Water Resources, Government of India [21]

This report gives an overview of hydrogeology in Gujarat up to 1988 in a very broad sense. The report goes into detail in geology, pedology, landuse, hydrogeology, climate and water resources of Gujarat State. Furthermore an extensive discussion of artificial recharge is given.

The relevant conclusions are:

- The fresh water alluvial areas have limited ground water resources on account of depthwise quality deterioration and poor storage coefficient due to poor soil conditions.
- The percentage of irrigation by groundwater is 73%. This is likely to come down in near future with the completion of the Sardar Sarovar Project on the Narmada River, the lining and modernisation of existing irrigation canals and the construction of several proposed minor an medium irrigation schemes. Regarding the foreseen tremendous increase of surface water irrigation there is no need of construction of artificial recharge structures except in drought prone areas.
- Surface water irrigation has been observed to be beneficial for saline areas. Water logging of small proportions of all canal command areas will be kept under control by lining of canals and conjunctive use of ground water and surface water, forming essential parts of command area development.
- The awareness for enhancing the annual ground water replenishment is going to help in the effective water management in the vast drought prone areas. The 1985 - 1987 drought has proved to meet the requirements of domestic water supply. The several water harvesting schemes carried out under different programmes are likely to considerably enhance the ground water recharge and extend its adequacy for irrigation purposes also during subsequent droughts.

Recommendations which have been made are:

- Compulsory conjunctive use of ground water and surface water in canal command areas.
- Provision of water harvesting structures to increase the ground water potential of overexploited areas.
- Construction of tidal regulators on all streams/rivulets/rivers in coastal areas.
- Exploitation of surplus ground water from major flood plain deposits with the help of connector/recharge tube wells.
- Ground water exploitation plans for drought prone areas only in view of proposed large scale development of surface water resources with the help of canals.

A last but most important suggestion given is that the renovation of existing ponds and tanks diminishes the need for the construction of new artificial recharge structures.

2.3 Evaluation of ground water balance and hydrogeological studies

2.3.1 General

Looking at the tendency of the conclusions and recommendations of studies discussed in paragraph 2.1 and 2.2, a clear distinction can be made between studies carried out by UNDP and organisations such as GWEC, GWOEC and CGWB. The studies carried out by the UNDP tend to be precarious in estimating ground water resources in Gujarat State and are more critical in reviewing current groundwater management. GWEC, GWOEC and CGWB however admit that some problems of declining ground water levels are present but still tend to be very optimistic with respect to available ground water resources.

UNDP stated already in 1973 that irrigation in the project area should be reduced with at least 25% in order to prevent further decline of ground water levels. Compensation for lowering of ground water levels before this period is even not taken into account in this 25%. With increasing ground water exploitation of especially the deeper aquifers and consequently continuously declining ground water levels in the Banaskantha and the Mehsana districts, still several organisations insist on continuing and even increasing ground water development in considerable parts of these districts.

UNDP refers to introduction of irrigation with high TDS level ground water, of high TDS resistant crops and introduction of land preservation measures and soil condition optimisation by combined use of irrigation, fertiliser and special crops to decrease the use of ground water from the over exploited aquifers. UNDP also is positive about artificial recharge of the over exploited aquifers but mentions that considerable investments have to be made and that thorough operation and maintenance of structures for artificial recharge is required to come to positive results.

The reports of the GWEC, Committee on the estimation of the ground water resources and irrigation potential, tend to be more positive on the available ground water resources, future development of irrigation and artificial recharge. They suggest that still enough ground water resources are available and construction of tube wells should continue to come to optimal exploitation. Only a relative small area is mentioned to be over-exploited. They also suggest that with proper operation and maintenance of existing structures for artificial recharge, no new structures have to be realised. They expect water level problems to be solved with the realisation of the Sardar Sarovar project, giving access surface water to decrease exploitation of ground water. However, the Narmada canal project is still in the preparatory phase and many technical problems will have to be overcome. On the short and medium term other solutions have to be provided. The Narmada canal system will mainly cover western parts of the Banaskantha and Mehsana districts. Ground water exploitation in these areas may decrease due to relative high costs of the tube well operation whereas surface water from the canal system is available. It is however doubtful if this is of sufficient benefit for the severely over-exploited aquifers more to the east of these districts where the Shihori and Kamlivada well fields are located.

2.3.2 Methodology

The method for assessing available ground water resources used by the UNDP clearly differs from those used by GWOEC, GWEC and CGWB. UNDP uses modelling and calibration with existing data to check the accuracy of the model.

As already discussed in paragraph 2.1.1, GWEC, CGWB etc. are using the "fluctuating water table" concept. Although the concept may be correct, the relevance of the result depends completely on the data which have been used. This means that in the case of this area where a relative complex and irregular aquifer system is present, much irrigation is taking place and infiltration of rainfall is irregular. Due to frequently changing soil characteristics it is extremely difficult to estimate infiltration, withdrawal, run off etc. A few percent increase in infiltration can considerably change the available water resources making the water balance irrelevant.

The main difference with working with models is that with models, comparison with real data is required to come to a correct model. However, the norms suggested by the GWEC are indicators, often not given as one figure but as a range of figures.

It appears that Normal Monsoon Rainfall over the period 1901 to 1950 is high compared to monsoon rainfall of 1951 to 1990 for the taluka's considered (Kankrej and Patan). In general the data for 1951-1990 are 15 to 25% lower than data for 1901-1950. This causes structural overestimation of the recharge. Because officially it is not allowed to use more recent averages for rainfall, calculations of water resources are still being made with these relative high figures. It is however mentioned that corrections are being made to compensate for the high averages.

It is not likely that the incoherence of the normal monsoon/average monsoon rainfall has been consequently made since it is evident that the factor should be reversed. However, the use of old data as indicated above can lead to severe overestimation of the annual recharge.

2.3.3 Quantitative wise comparison

Comparison of the several studies quantitative wise is difficult since different methods and data have been used, different assumptions have been made whereas the area covered by the studies is not the same.

When comparing the CGWB report of 1988 [21] with the GWEC report of 1984 [7] it appears that all data have been used while more recent data of draft and available ground water resources are not available. CGWB however changed the percentage of the gross draft forming the nett draft. Whereas the GWEC [7] assumes that 30% of the water used for irrigation purposes will return to the ground water level, the CGWB [21] uses 25%. UNDP uses 35% in their calculations and still comes to a lower amount of available ground water resources.

The results of a comparison between the UNDP report from 1976 [16], the GWEC report from 1984 [7] and the CGWB report from 1988 [21] are given in table 6.

The 5 talukas mentioned in this table are: Deesa, Palanpur, Vadgan, Danta and Kankrej. These talukas are the only talukas covered by the UNDP report in the Banaskantha district.

Table 6 Comparison of nett annual draft

		Nett draft MCM/yr		
		Report		
District	Taluka	UNDP (1973)	Group... (1986)	CGWB (1988)
Banaskantha	Deesa Kankrej Total 5 Tal.	10.23 5.92 153.76	84.88 45.68 257.25	
	Total Banaskan-tha*		407.60	438.92
Mehsana	Patan Sidhpur Sami	46.41 57.02 5.78	34.34 65.58 2.67	
	Total Mehsana*	532.90	483.42	520.60

* Including other Taluka's

Table 7 Irrigation tube wells in study area

District	Report	Dug Wells	DCB Wells	Tube Wells
Mehsana	UNDP (1976) Group... (1986)	37.612 20.008	25.268 34.467	2.362 4,384
Banaskantha	Group... (1986)	15.806	31.150	874

It must be mentioned here that dug wells usually are not equipped with motor pumps and have a very low discharge whereas dug-cum-bore wells (DCB wells) and tube wells are equipped with motor sets or deep well pumps and have high discharges when operated.

The tables 6 and 7 presented above indicate that a considerable increase has taken place in the construction of motorised wells and in the yearly draft. It also indicates that Mehsana is having an extreme high amount of irrigation wells compared to the Banaskantha district. In Mehsana the increase in construction of motorised wells is accompanied by a decrease of draft according to the Taluka wise and the district figures, which is a clear incoherence.

The Dantivada canal system, realised in the late eighties, covers a considerable part of the northern and eastern part of the Mehsana district. Due to the low costs of the water supplied by this system compared to the cost of operating tube wells, the number of tube wells has strongly reduced in the area. Because no information is available on the area irrigated by water from the Dantivada canals, it is not clear whether the incoherence of data demonstrated in Tables 6 and 7 can be explained with the presence of this canal. However, observations in the Patan and Sidhpur Talukas indicate that high concentrations of tube wells for irrigation purposes still exist. Therefore, compared to the data of UNDP, the data of the GWEC are considered to be very optimistic.

3. THE SHIHORI Well field

3.1 Existing situation

3.1.1 General

The Shihori well field supplies water to the Santalpur RWSS which currently covers 98 villages and in future will supply about 120 villages through 2 extension phases. The well field consists of 6 tube wells, spread over a distance of 8 km between the head works and the Banas river, and a radial well which is situated next to the floodplain of the Banas river.

3.1.2 Production

The tube wells in this field, having a design capacity of 1.6 MLD, have been completed in 1979 and taken into production in 1986. The production per well has been recorded since 1987 (see figure 3.1, 3.2 and 3.3). The radial well was completed in 1988 and is yet to be taken in production. However, with the testing of the well, it appeared that the yield stayed below expectations (3 MLD against the planned 11 MLD).

Since 1986 the water level (static and dynamic) and since 1987 also the quality of the water of the six producing wells has been monitored on a regular basis on request of the mission.

Due to the severe drought during three successive years, 28 villages have been connected to the water supply scheme in relative short period of time. Therefore the production capacity had to increase suddenly. It was necessary to install higher yield pumps (1.6 MLD instead of 1 MLD). Only tube well no. 2 remained equipped as designed since high fluoride levels have been encountered in this well. Between April and June 1988 production was increased from 6.5 MLD to 8 MLD (per tube well from 1.2 to 1.5 MLD). As a consequence the water levels showed an initial drop. However, after some time, the impact of the increased production on the waterlevels diminished (fig. 5.1 and 5.2) while the general trend of decline in water levels continued.

In the end of 1988 again production had to be increased (2 MLD instead of 1.6 MLD per tube well) to in total around 11 MLD due to the connection of more villages to the scheme. This lead again to a sudden drop in the groundwater levels which, on the long term, did not have a significant impact on the general trend in declining water levels. In both cases, the increase of production was necessary to face the higher demand caused by the connection of more villages.

Due to the overdraft of the aquifer, the possible relation between the high fluoride levels and the descending ground water table and the high losses in the scheme, GWSSB decided at the end of 1990 to decrease the production from 11 to 8 MLD. This led to an initial rise of the waterlevels in the tube wells after which the general decline continued.

The capacity of the water resources at present is under the present operational conditions insufficient to supply for the Santalpur RWSS in the ultimate stage. During GU-23 it was however stated that the production capacity of the sources is already above the designed capacity (1.6 MLD).

The production at the time of GU-23 was around 11 MLD whereas from a rough estimate the consumption appeared to be in line with the design criteria (5.85 MLD). This might indicate important losses between the resources and the tap points.

As a consequence, if confirmed by more accurate measurements by GWSSB, reduction of supposed losses could contribute to reduce the need for extension of the production capacity (quantitative wise) as well.

It is recalled here that it was proposed by GWSSB to construct 9 additional tube wells. Immediate construction of five wells should compensate for the lack of production of the radial well. The remaining four wells were to be constructed to meet the demand for the implementation of the augmentation scheme (third phase) which will increase the demand to 18.92 MLD for all three phases.

Mission GU-23 suggested to construct piezometers prior to the realization of production wells.

3.1.3 Description of resources

The Shihori well field consists of 6 tube wells and 1 radial well. The tube wells are tapping the A2, A3 and B aquifers at depths between 159 and 174 m. The radial well is tapping the phreatic aquifer upto a depth of 18 m below ground level. A cross section of the area, based upon the results of the drillings, is given in fig. 4. More detailed data on the piezometers is given in Annex IV. As can be clearly seen, the wells are tapping all aquifers encountered below the phreatic aquifer. Because no separate tests of the aquifers have been carried out and because borehole logging was not executed as a standard practice when the wells were constructed in 1979, it can not be confirmed whether the different aquifers are in hydraulic contact nor can be confirmed which layers belong to the A2, A3 or B aquifer. It is however assumed that the aquifer system at Shihori is semi-confined and leaky.

The transmissivity of the wells varies between 850 and 1150 m^2/day. The more shallow aquifers mainly consist of medium to fine sand and clayey sand. They contain sometimes kankar and are sometimes interlaid with clay lenses (up to 1.5 m). The deeper aquifers have a higher content of coarse sand and contain gravel. Still clay lenses occasionally are present. The clay layers consist of yellow to brown clay, occasionally sandy with a thickness varying up to 20 m.

Compared to the hydrogeological situation around the Kamlivada well field (see chapter 4), aquifers are thicker and less frequently interlaid with clay layers. The aquifer therefore has a higher transmissivity.

3.1.4 Water levels

The water levels of the Shihori well field have been monitored since 1986 (fig. 5.1 and 5.2). A gradual but steady descent can be observed.

The RSM established monitoring practices to study the decline. During the last years a continuous drop of 3 m/year is observed which even tends to go towards 4 m/year. The increase in production levels as previously discussed is noticeable but has no significant influence on the general decline in waterlevels. The influence of the dry season and the abundant monsoon of 1990 are very pronounced.

The remarkable rise in water levels after the monsoon of 1990 is completely lost within 5-8 months time after which the general observed decline is continued.

In order to prevent damage to pumps in case of declining waterlevels, lowering of the pumpsets is regularly required, based on the dynamic levels (fig. 6.1 and 6.2). Striking is the clearly stronger decline in dynamic water levels of 4-5 m/year. As can be seen also in the dynamic water levels, the subsequent increases of production are more distinct as in the static levels, which was to be expected. The influence of the drought and the abundant monsoon are less significant as in the static water levels. Since the pumps can be lowered entirely to the bottom of the tube wells, ample space is present for lowering these pumps.

Remarkable is the behaviour of tube well no. 1 which is located 150 m from the riverbed. The dynamic waterlevel of this well is declining in a similar way as those of TW2 to TW5. However, the static water level of TW1 over the last three years (figure 5.1) has remained relatively constant around 65 m. The reason for this could be found in the effect from the type of irrigation. Since water levels in the phreatic aquifer are relatively high in the area near to the river, irrigation is still taking place from shallow wells (upto 25 m below ground level) whereas tube wells elsewhere are tapping water from 50-160 m below ground level and occasionally deeper. However, it might also be possible that the screen resistance has increased and that the well needs to be redeveloped. The behaviour of the waterlevel of tube well 2 is very irregular due to discontinuous production.

It was observed that over several years of records, waterlevels in the tube wells rise somewhat earlier than the waterlevel in the radial well. Wether this phenomena is due to hydraulic loading of the aquifer through early rains in the Aravalli mountains or due to reduced irrigation activities in view of the coming monsoon, is not yet clear. The hydraulic gradient between wells 1 and 6 under static conditions is presented in figures 7.1 and 7.2. It appears that it considerably increased from 2.0 m/km in 1986 to 4.4 m/km in 1991. The high hydraulic gradient can only be caused by the withdrawal of ground water through surrounding tube wells mainly at the south-west part of the field (downstream side). The same can be concluded when comparing the hydraulic gradient of the field with the regional gradient (1.7 m/km, Annex III, fig. III-4). Large scale ground water withdrawal around the Shihori well field causes a local hydraulic gradient 2.5 times larger than the regional gradient. Figures 8.1 and 8.2 present the hydraulic gradient between wells number 1 and 6 under dynamic conditions. Under these conditions the hydraulic gradient is less pronounced.

3.1.5 Water quality

All production wells have regularly been sampled for standard analyses. The water is potable. Elements that may endanger the potability in future, are discussed hereafter.

3.1.5.1 Nitrate

On some locations in the project area, the advised limits of nitrate content in the drinking water are exceeded. However, this mainly occurs in the samples obtained from shallow wells. In the south-west of Gujarat the problem of high level of nitrates is well known. There it is associated with irrigated land and excessive use of fertilizer.

The degree in which the advised limits are exceeded in the Shihori well field and the absence of an increasing trend, do not require any remedial measures in the near future. Still monitoring is advised to continue.

3.1.5.2 Chloride and TDS

The chemical analysis data, obtained since 1984, indicate a slightly increasing level of chloride content (see figures 9.1 and 9.2). If the ascending trend will be continued, the permissible limits of 250 mg/l will not be reached within the coming 15 to 20 years, tube well 3 excluded. Due to the mixing of the water from the different tube wells, the chloride concentration of the produced water remains considerably below the permissible limits.

Also the TDS content of the tube wells, indicative for the salinity, remains well within the permissible limits (fig. 10.1 and 10.2). From several neighbouring Talukas and Districts, saline groundwater caused by upconing or intrusion has been observed. For example, the water resources of the regional water supply scheme in Tharad have been degraded to such an extent that this water supply scheme had to be connected to the Deesa RWSS. The TDS level increased from 2000 ppm to about 4000 ppm. Also from the water resources of the Bhabhar RWSS it is known that they are deteriorating with an increasing TDS value.

Regarding the geographical position of the Kamlivada and Shihori well fields compared to the position of the Tharad and Bhabhar well fields, it is not excluded that in the future the level of chloride and TDS of the well fields will increase. Therefore, monitoring of the chloride content of the water has to be continued but remedial measures are not yet required.

3.1.5.3 Fluoride

The fluoride level in the tube wells of the Shihori well field are the main point of concern of the RSM with respect to the water quality. As has been mentioned, the whole region and more in particular, the south (Mehsana), suffers from excessive fluoride content. The analysis of the fluoride content carried out since 1988, shows an ascending trend of 0.2 to 0.7 ppm per year (fig. 11.1 and 11.2). During the 4 years of monitoring, the fluoride level in all wells approached the permissible limit of 1.5 ppm and in some wells even exceeded this limit. Since there is no indication of stabilisation or decrease of the fluoride content, the permissible limits will most probably be exceeded in the near future.

The GWSSB determined the location of the 5 proposed wells required for extension on the basis of the analysis of the fluoride content in surrounding wells. However, regarding the highly unpredictable distribution of the fluoride concentration (vertical as well as lateral), it is a considerable risque to implement the boreholes in this way. Therefore, a more thorough investigation is desirable to determine the distribution of fluoride in the groundwater. This will enable a more secure implementation of borehole locations which will increase the lifetime of the well field.

3.2 Detailed investigations

3.2.1 Chemical analysis

3.2.1.1 Outline

The aim of the sampling campaign was to determine the chemical characteristics of the water in and around the well field. Possible differences between the water from the different sources of the samples in the surroundings of the well field and the Shihori tube wells can be determined and a better understanding of the aquifer system underlying the Shihori area can be obtained.

Samples from irrigation wells surrounding the Shihori well field within a radius of 5 km have been inventarised and some have been selected for chemical analysis. Also samples from tube wells used for drinking water in villages in the Kankrej Taluka have been analyzed. Some selected samples were cross checked by a laboratory in The Netherlands.

3.2.1.2 Results

Results of the chemical analysis of samples from the Shihori well field and the surrounding area are given in table 8.

Table 8 Results of Chemical Analysis Shihori Area

Piper nr.		Depth m bgl	NO^{3-} mg/l	$SO^{4}2-$ mg/l	CL^- mg/l	K^+ mg/l	Na^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	HCO^{3-} mg/l	F^- mg/l
1.	Shihori Headwork site	N.A.*	4.5	36	100	1.3	160	30	16	290	1.4
2.	Tail-end village	N.A.*	2.5	32	100	1.2	150	23	13	290	1.6
9.	Shallow well Umbri	12	38	51	180	3.8	170	66	24	360	1.2
4.	Radial well	18	2.9	12	20	3.9	56	29	11	230	1.1
3.	Irrigation well	15	19	39	130	1.8	410	34	29	280	1.1
5.	Shihori TW 5	159	5.0	33	110	1.8	160	35	20	290	1.5
6.	Irrigation TW 35	183	<0.3	14	84	1.4	150	12	6.7	270	1.9
7.	Irrigation TW 36	130	1600	22	93	0.75	140	23	13	270	1.9
8.	Piezometer P8	190-204	0.8	21	68	2.1	150	16	6.1	290	1.7

* N.A.: not applicable

In figure 12, the results from table 8 have been presented in Piper diagrams. Results of chemical analysis can be represented in Piper diagrams. Piper diagrams are trilinear diagrams. In these diagrams the chemical composition of water with respect to cations is indicated by a point plotted in the cation triangle, and the composition with respect to anions plotted in the anion triangle. The coordinates at each point add to 100%.

The points are then extended into the diamond shaped central plotting field by plotting them along lines parallel to the upper edges of the central field. The intersection of these projections represents the composition of the water.

Results of the chemical analysis of samples from the piezometers in the Shihori well field are given in table 9. These results could not be plotted in Piper diagrams since results of the analysis of some constituents are lacking.

Table 9 Results from the chemical analysis of the piezometer samples Shihori well field.

	Depth m bgl	NO^{3-} mg/l	SO_4^{2-} mg/l	Cl^- mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	F^- mg/l	$CaCO_3$ mg/l	TDS mg/l
Piezometer 1	27-60	13.29	31	154	76	38	0.86	190	608
Piezometer 2	68.5-76	6.64	0	126	28	15	3.75	346	650
Piezometer 3	95-115	0	25	60	7	12	1.50	240	368
Piezometer 4	120-126	0	0	56	11	4	2.04	224	548
Piezometer 5	130-137	0	0	50	15	6	1.30	208	324
Piezometer 6	140-166	2.2	0	76	14	6	1.50	244	410
Piezometer 7	170-180	8.86	10	86	13	7	1.50	280	530
Piezometer 8	190-204	4.43	10	102	17	7	1.76	268	470

3.2.1.3 Discussion

From the results it appears that the sample taken at the source is identical to a sample taken from the taps in a village at the tail-end of the distribution system. Except for the slightly elevated fluoride level, the water which reaches the consumers is of excellent chemical quality.

The chemical analysis of the samples taken in the Shihori area indicates that $NaHCO_3$ waters are dominant and that all components stay within the permissible limits, except fluoride. The analysis of the piezometer samples taken at different depths reveals we can distinguish three sub-systems. The water from the phreatic aquifer has relative high nitrate-, sulphate-, chloride- and TDS levels. These relatively high values are most likely caused by human, notably agricultural activities (the use of fertilizers in combination with irrigation). Since these contaminations remain restricted to the upper layer we may conclude that the irrigation return flow does not infiltrate deeper than 80 m. Below this depth different hydrogeological conditions prevail.

The deeper waters (140 m and deeper) tend to be enriched in Cl^-, NO^-_3 and TDS. The reason for this is the fact that the sediments are of marine origin and that desalinization has not yet fully been completed. Consequently the intermediate layers (90-130 m) give the best quality water.

The above is confirmed by the Piper diagram (fig. 12). The samples from the shallow wells (no's 4 and 9) are located towards the area of the rainwater (A). The samples from the intermediate layers are grouped together and can be clearly distinguished from the samples from the deeper layers (no's 6 and 8). The process can be described as the desalinization of the deeper layers and enrichment of the water by $NaHCO_3$ caused by cation exchange at the contact of sweet infiltrating water with originally marine formations. The position of seawater in the Piper diagram is represented by "B".

3.2.2 Fluoride analysis

3.2.2.1 Outline

To discover possible patterns in the distribution of fluoride, lateral or vertical, an extensive sampling campaign was carried out, local as well as regional. In the whole Taluka, samples of tube wells were taken. Towards the Shihori well field the numbers of sampled wells increased and numberous tube wells in the direct surroundings of the well field (0-5 km) were sampled.

Data of chemical analysis of piezometers samples became available at RSM GU-25. Fluoride has been monitored from the date of construction (initial measurement) upto November 1991.

Another test carried out was the analysis of samples of TW no. 6 of the Shihori well field taken every hour during 48 hours. The aim of this specific test was to determine whether there is any short term fluctuation in the fluoride content of the water from the tube well.

3.2.2.2 Results

Not all samples obtained during the fieldwork period could be tested on their fluoride content due to problems encountered during the testing. However, many samples have been tested in this period and thereafter by the laboratory in Palanpur.

The results of the 48-hours test were striking. It appeared that the fluoride content varied with 0.26 mg/l.

Table 10 Fluoride levels of the piezometers samples

	PZM 1	PZM 2	PZM 3	PZM 4	PZM 5	PZM 6	PZM 7	PZM 8
Depth m bgl	27-60	68.5-76	95-115	120-126	130-137	140-166	170-180	190-204
Date								
Initial	0.86	3.75	1.5	2.04	1.5	1.5	1.5	1.76
20/9	0.88	1.2	2.1	3.75	1.12	1.5	2.24	1.5
30/9	0.62	2.86	1.5	0.94	0.88	1.5	0.74	2.14
25/10	0.50	1.74	0.56	0.6	0.8	1.34	0.4	0.44
1/11	0.50	2.30	0.5	0.7	0.8	1.3	0.6	0.76

The data from table 10 show high initial values for all piezometers. The values then strongly decrease to a clearly lower level.

Some observations on the vertical occurrence of fluoride are that the samples of the upper piezometer have relative low fluoride levels. Samples of the second piezometer give very high fluoride levels. Fluoride levels of samples from piezometers between 80 m and 140 m are relatively low whereas samples of the piezometers between 140 m and 204 m show relatively high values.

Results of the lateral spreading given in fig. 13 and 14 show varying levels of fluoride. This may be due to the fact that these wells tap multiple aquifers. In general wells up to an intermediate depth are presented. The pattern is scattered with low level fluoride wells located in between high level fluoride wells. However isolated areas with rather high level of fluoride can be identified.

Comparing the samples from 1989 and 1991 indicates that fluoride levels tend to increase in the time, which also has been found in the tube wells of the Shihori well field. Measurements from 6 observation wells in the surroundings of the well field (fig. 15) indicate a considerable rise of the fluoride levels in 1989 and in some cases a decrease thereafter.

3.2.2.3 Discussion

Although much is known about fluoride origin and occurrence, in this particular area the mechanism causing a high fluoride content of groundwater appears to be very complex and can not be related to certain areas or depths.

From the 48-hours test and regular tests over longer time, it appears that fluoride levels are varying in time. Apparently more shortterm processes (fluctuating groundwater table and the flow of groundwater) have a considerable impact on fluoride which is considered to be a relative stable cation [2], [20], [24]. From several measurements, it is clear that groundwater level fluctuations have an important influence on the fluoride levels in groundwater. Analyses over several years indicate increasing fluoride levels while in the whole area groundwater levels are dropping considerably. Detailed measurements over a shorter period tend to show an increase of fluoride levels after a good monsoon and initial rising groundwater levels.

A trend which can be observed from the samples of different depth is that at very shallow depth in the phreatic aquifer, the fluoride level is low whereas at the lower part of the phreatic aquifer relative high levels of fluoride are found. This is most likely the reason for the high fluoride levels in the tube wells near to the river which are mainly subtracting water from the lower part of the phreatic aquifer upto 80 m. This means that the fluoride level of a well is merely influenced by the depth of the tube well instead of its geographical location.

High initial fluoride levels in the piezometers may have several causes. First, there is the fact that a situation in relative rest is disturbed by the construction of the piezometer. A temporary connection between layers is created and the water from the enclosed aquifer is permanently exposed to the open air. Second, there is the mud which is used to stabilise the walls of the hole during the construction phase and which partly invades the aquifers. The clay minerals of the mud may influence the geochemical conditions in the underground and fluoride may be exchanged in contact with the groundwater.

Which processes are actually taking place is not yet clearly understood and needs more specific scientific research which goes beyond the aim of the present investigations. A summary of the theoretical background is given in Annex II.

3.2.3 Isotope analysis

3.2.3.1 Outline

Several samples have been taken for this analysis. Because only one piezometer was finalised, clusters of wells tapping aquifers at different depths were chosen for the sampling in order to be able to determine characteristics of the different aquifers.

3.2.3.2 Results

The results of the isotope analysis of samples around the Shihori well field are displayed in table 11.

Table 11. Results on isotope analysis Shihori.

Location	Depth m bgl	O-18 ‰	H-2 ‰	C-13 ‰	C-14 ‰	H-3 TU
Tube well 5	40-153	-4.36	-28.6	- 9.18	57.8 ± 1.1	1.3 ± 0.1
Irrigation Tube well 35	40-175	-4.66	-30.7	- 8.76	57.4 ± 0.9	0.4 ± 0.1
Irrigation Tube well 36	40-123	-4.75	-30.3	- 8.36	49.0 ± 1.0	0.5 ± 0.1
Tube well survey no. 52	10- 20	-4.54	-28.5	-10.16	*	2.8 ± 0.1
Piezometer	190-207	-4.14	-28.4	- 8.57	15.4 ± 0.5	2.4 ± 0.2

* Not measured since the well is shallow and thus the water is very recent.

3.2.3.3 Discussion

As can be clearly seen from the above table, in general the values are uniform, indicating one type of water. A clear distinction from the values from the samples from the Kamlivada well field (see chapter 4) can be made.

O-18 (Oxygen 18)
The O-18 values are around -4.5. The 0-18 value of precipitation in the region of the well fields is -5.7 ‰ ± 0.2. New Delhi gives in general O-18 values of -6‰. Values for extreme dry and hot areas would be around -1 ‰ while values in cold and humid conditions would be around -16 ‰. Bombay is -2.5 ‰ and Mirzapur is -7.5 ‰.

H-2 (Deuterium)
The deuterium values can be compared with the O-18 values. The deviation of the O-18/H-2 pair of data from the relation, $H^2 = 8O^{18} + 10$ gives a considerable evaporation while the water was stagnant, which was already indicated by the actual O-18 values.

C-14 (Carbon 14)
The C-14 values of the samples differ substantially. Tube well 5 and irrigation tube wells 35 and 36 are more or less comparable. The C-14 value of the piezometer however, is much lower, indicating an older age. Since the other samples are mixed samples from a depth of 40-170 m water of different ages has been mixed. Regarding the low value of the water from the piezometer, the C-14 value for surface water should be around 80% to come to an average value of the mixed water of ±55%. From these data it is not possible to deduct an absolute age of the water.

H-3 (Tritium)
The relative low tritium levels of TW5 and ITW 35 and 36 indicate relative older water. However, the tritium level of the piezometer is relatively high which is in contradiction with the C-14 level. Probably this indicates mixing of younger water. At the same time this would mean that the actual C-14 value is lower than the value measured, since mixing with recent water has taken place.

Very often a positive relation is present between the tritium level and the nitrate content. A higher tritium level means young water with often a high nitrate content due to human activities (urban areas) or due to the presence of animals and the use of fertilizers (rural areas). This has already been discussed in paragraph 3.1.5.

C-13 (Carbon 13)
The C-13 levels for Shihori are around -8.5‰. These values are more positive than could be expected on the basis of all the data. This points in the direction of the presence of enriched lime from the younger sediments which migrates with the percolating groundwater.

3.2.4 Piezometers new wells

As mentioned before, instead of multiple piezometers single piezometer were installed in the Shihori well field of which only one was realised at the period of investigation. The piezometers are installed up to 205 m depth and are located west of TW no. 3, annex I. Samples from these piezometers have been extensively tested. Data of the piezometers are given in table 12.

Table 12. Data of the piezometers installed in the Shihori well field near Umbri Village

	PZM1	PZM2	PZM3	PZM4	PZM5	PZM6	PZM7	PZM8
TOTAL DEPTH m bgl	63,50	80,00	119	129,50	139,50	170,00	186,00	210,00
DIAMETER m bgl	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
DEPTH RANGE OF FILTERS m bgl	26,80 - 60,05	68,55 - 76,33	95,05 - 115,62	120,6 - 126,3	130,10 - 137,15	140,38 - 165,61	170,15 - 180,15	190,05 - 204,45

3.2.5 Water levels

3.2.5.1 Outline

During the investigations, waterlevel measurements have been carried out in several irrigation tube wells in and around the Shihori well field. After mission GU-25, data of waterlevels in the recently constructed piezometers became available.

3.2.5.2 Results

Results of waterlevel measurements from the piezometers is given in table 13.

Results from the measurements of groundwater levels around the well field and a isohypse map are given in fig.16.

Table 13 Results of waterlevel measurements of piezometers in the Shihori well field

	PZM 1	PZM 2	PZM 3	PZM 4	PZM 5	PZM 6	PZM 7	PZM 8
Depth (m msl)	27-60	68.5-76	95-115	120-126	130-137	140-166	170-180	190-200
Date								
04/09/91	72,61	71,45	64,45	64,37	64,49	65,13	65,32	65,85
12/09/91	72,61	71,43	64,06	64,07	64,08	64,83	65,13	66,42
20/09/91	72,53	71,33	63,78	63,72	63,81	64,61	64,91	66,2
27/09/91	72,48	71,38	63,01	62,92	63	63,98	64,48	65,65
04/10/91	72,43	71,21	62,66	62,52	62,63	63,46	63,75	65,2

3.2.5.3 Discussion

From the measurements of the waterlevels in the piezometers, it appears that we can distinguish two (of the three) sub-systems. The first sub-system upto a depth of 80 m bgl is separated with a relative thick layer of low permeability (19m) from the second aquifer sub-system between 95 m and 205 m bgl. From the isohypse map it appears that the Shihori well field and the surrounding area show a similar flow direction of groundwater (from NE to SW) as the whole region (annex III, fig.III-4) but with a considerably higher hydraulic gradient than the regional hydraulic gradient. The most significant fall in hydraulic gradient is found between tube well no. 1 and 2 (20m).

The deviation of the hydraulic gradient of the groundwater flow in the (semi)-confined aquifers is apparently due to subtraction of water around the well field used for irrigation.

3.3 Conclusions

In the Shihori well field and the surrounding area, groundwater levels are dropping dramatically and progressively, causing an increasing hydraulic gradient of the well field which is currently 2.5 times higher than the regional gradient. However, strong deviation from the groundwater flowing pattern is not observed.

The groundwater chemistry around the Shihori well field is quite clear. We can distinguish three aquifer sub-systems with distinct geochemical characteristics. The upper most first aquifer, up to 80 m, is strictly phreatic. The nitrate content is high which indicates an irrigation return flow which is thus restricted to this upper aquifer and is caused by the presence of human activities (livestock).

The second aquifer sub-system, between 80 m and 140 m, in general has a better quality water. The results of the chemical analysis of samples from different locations are also more uniform than those from the upper aquifer.

The third aquifer sub-system, between 140 and 200 m, contains water with a higher salt content. Hydrogeologically we can state that the groundwater circulation in the first aquifer sub-system is more or less separated from the second and third. Looking to the waterlevels in the piezometers, we see that piezometers 1 and 2, tapping the aquifer up to 80 m bgl, give water levels which are less deep than the waterlevels of piezometer 3 to 8 which indicates a clear distinction in chemical and hydraulic conditions between sub-system 1 and 2.

The general picture is that we have to do with a phreatic aquifer which has a distinct groundwater regime and to which the irrigation return flow is limited. The waterquality in this aquifer in general is below the standards for drinking water and is likely to become more deteriorated. Also regarding the decline of the waterlevels, this aquifer in the area around Shihori is not suitable for groundwater development and should be avoided in the construction of future tube wells for drinking water purposes.

The deeper aquifer sub-systems can be distinguished chemically but not hydrogeologically, which means that the separation between sub-systems 2 and 3 is not very important. This is confirmed by the chemical analysis plotted in Piper diagrams. Water from these aquifers has an increasing salinity with the depth caused by cation exchange with the sediments of marine origin.

The second sub-system, between 80 and 140 m has thus a good quality water with slightly elevated fluoride levels and is suitable for extraction for drinking water. The groundwater of the third sub-system might also be suitable for drinking water production but also has a slightly elevated fluoride level. The salinity is still well within the permissable limits.

The concentration of fluoride in groundwater under the given circumstances is not as stable as believed. Due to disturbance of the deeper groundwater while constructing new tube wells, initially high fluoride levels may occur.

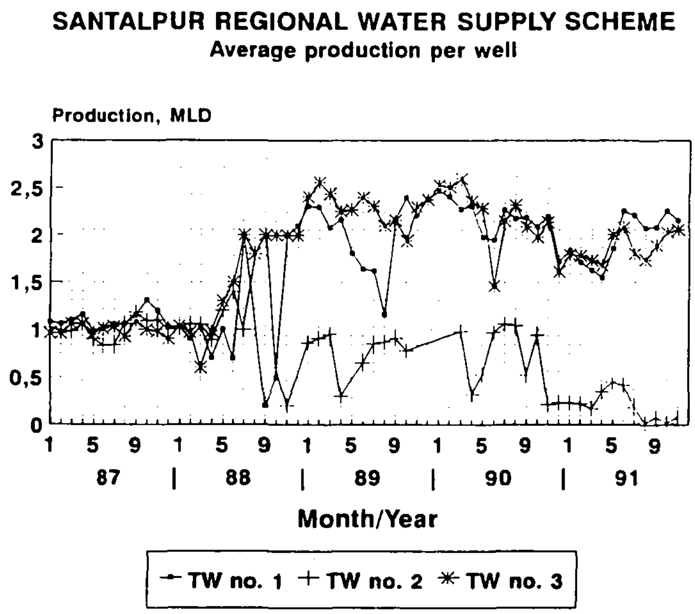


Fig. 3.1

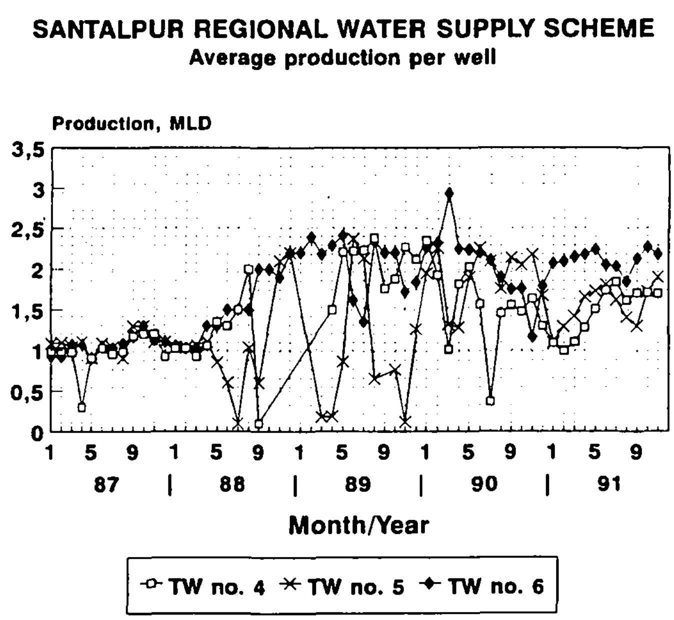


Fig. 3.2

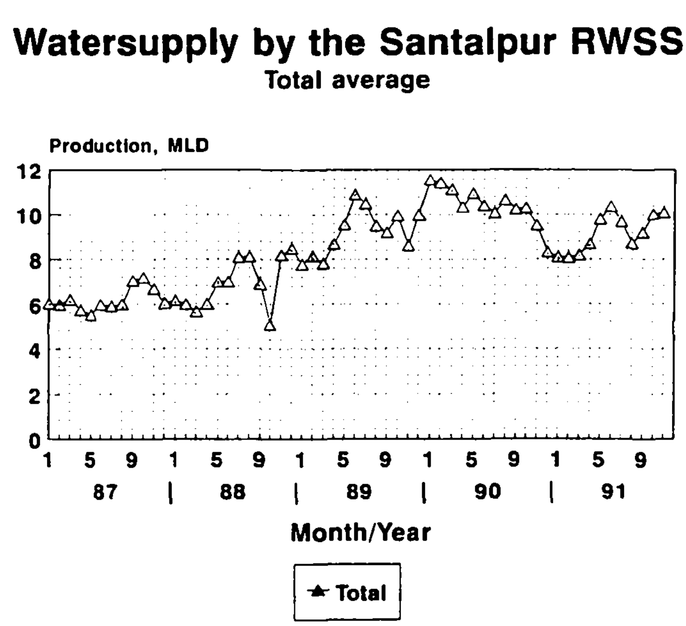
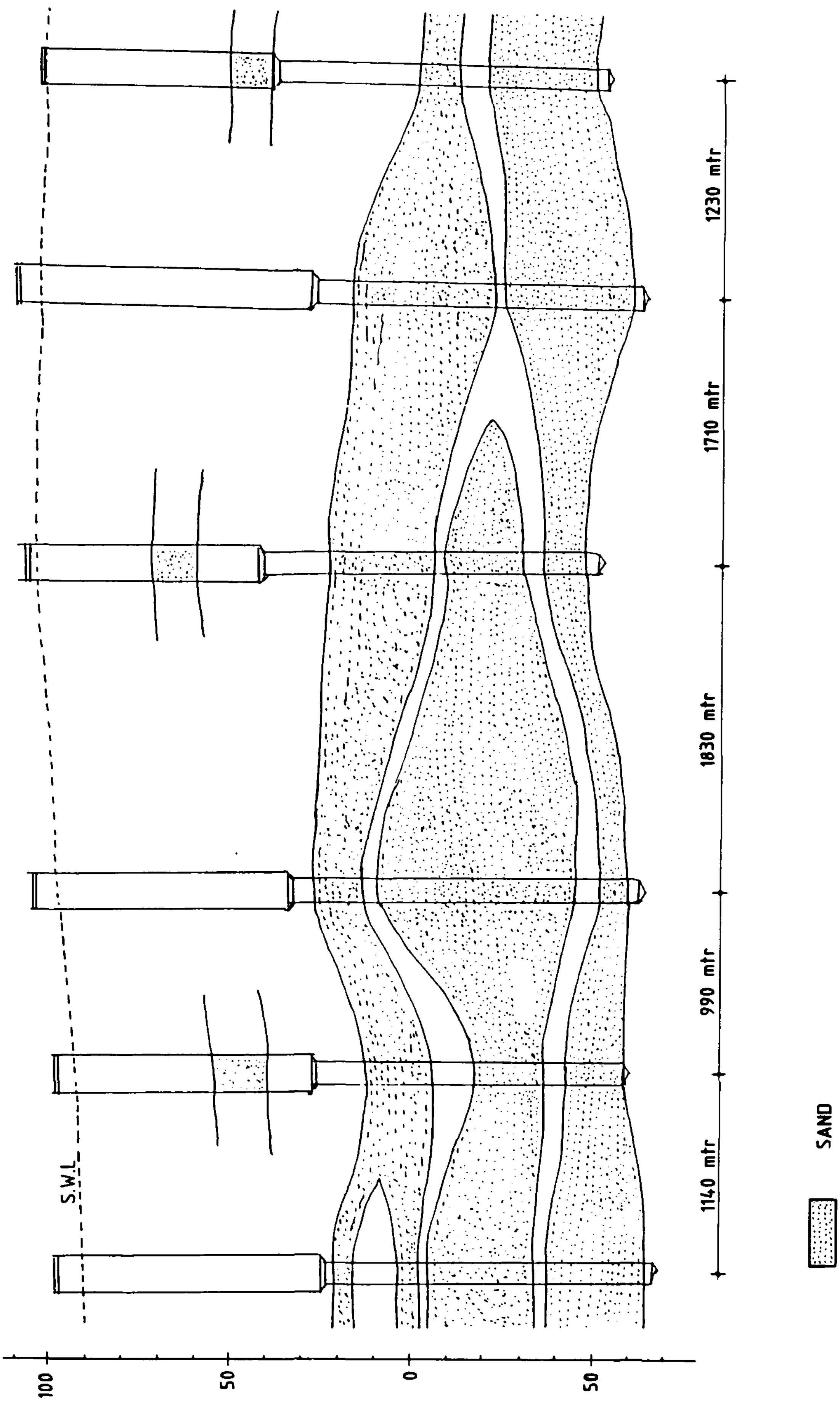


Fig. 3.3



HYDROGEOLOGICAL INVESTIGATIONS SANTALPUR + SAMI HARIJ RWSS		SCHEMATISED CROSS-SECTION THROUGH THE SHIHORI WELL FIELD
HASKONING Royal Dutch Consulting Engineers and Architects	FIG. NO. 4	

03-03-92

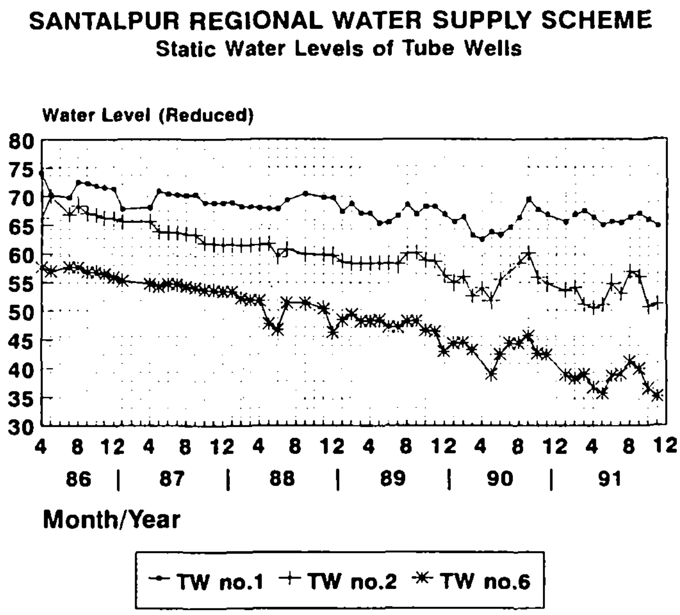

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Static Water Levels of Tube Wells
Water Level (Reduced)
80
75
70
65
60
55
50
45
40
35
30
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12
86 | 87 | 88 | 89 | 90 | 91
Month/Year
TW no.1
TW no.2
TW no.6

Fig. 5.1

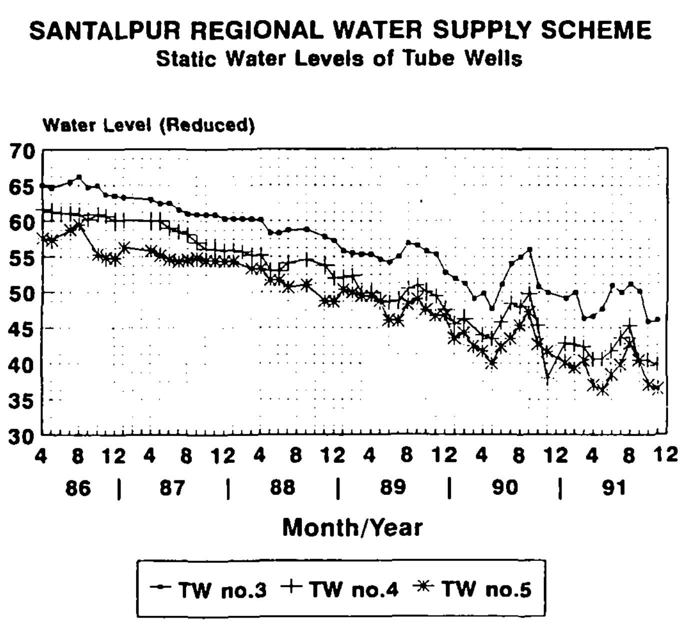

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Static Water Levels of Tube Wells
Water Level (Reduced)
70
65
60
55
50
45
40
35
30
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12
86 | 87 | 88 | 89 | 90 | 91
Month/Year
TW no.3
TW no.4
TW no.5

Fig. 5.2

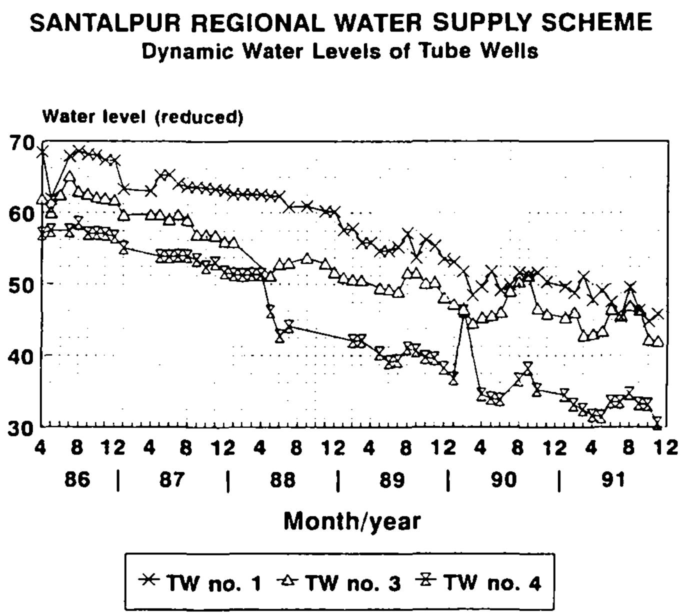

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Dynamic Water Levels of Tube Wells
Water level (reduced)
70
60
50
40
30
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12
86 | 87 | 88 | 89 | 90 | 91
Month/year
TW no. 1
TW no. 3
TW no. 4

Fig. 6.1

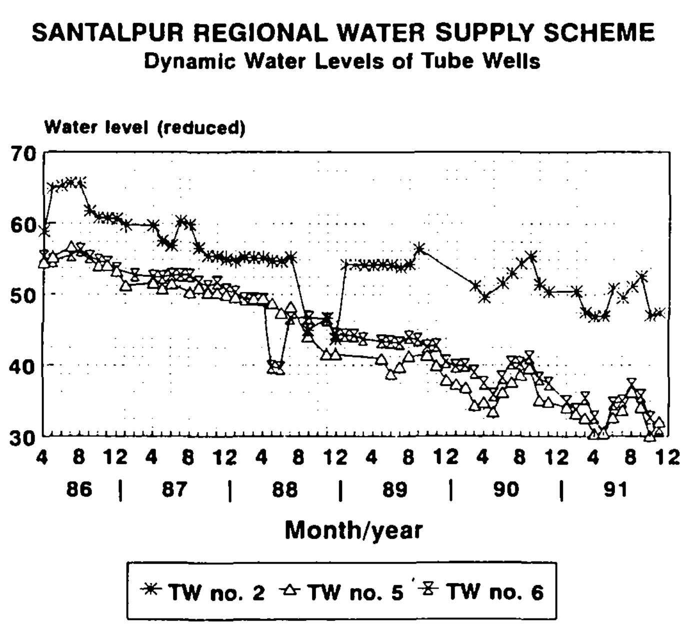

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Dynamic Water Levels of Tube Wells
Water level (reduced)
70
60
50
40
30
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12
86 | 87 | 88 | 89 | 90 | 91
Month/year
TW no. 2
TW no. 5
TW no. 6

Fig. 6.2

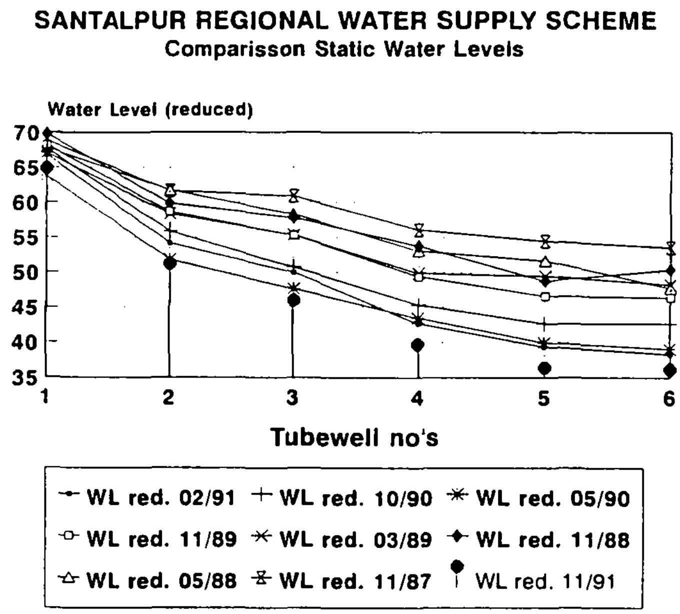

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Comparisson Static Water Levels
Water Level (reduced)
70
65
60
55
50
45
40
35
1
2
3
4
5
6
Tubewell no's
WL red. 02/91
WL red. 10/90
WL red. 05/90
WL red. 11/89
WL red. 03/89
WL red. 11/88
WL red. 05/88
WL red. 11/87
WL red. 11/91

Fig. 7.1

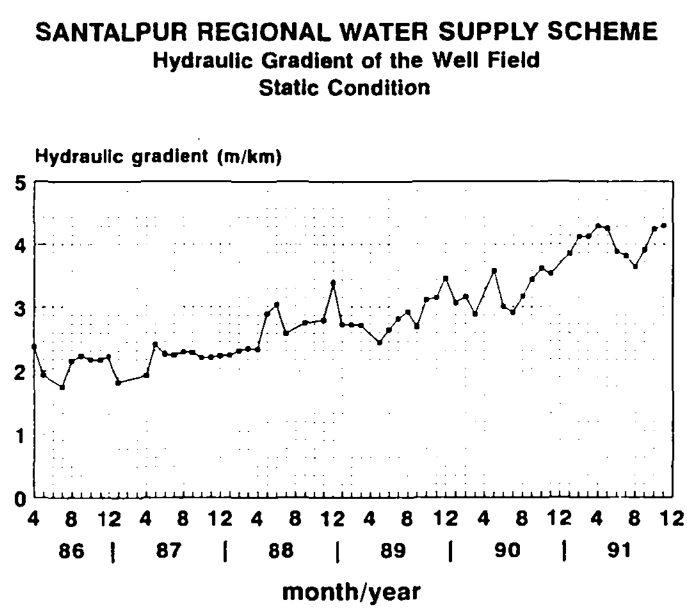

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Hydraulic Gradient of the Well Field
Static Condition
Hydraulic gradient (m/km)
5
4
3
2
1
0
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12
86 | 87 | 88 | 89 | 90 | 91
month/year

Fig. 7.2

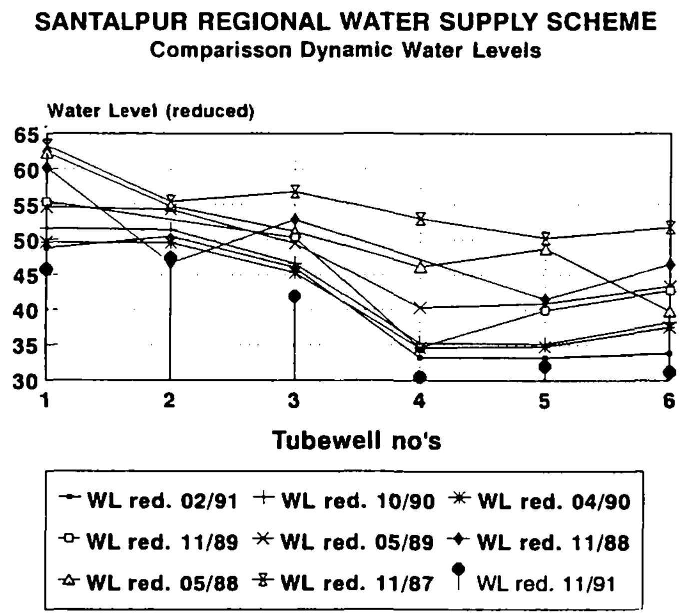

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Comparisson Dynamic Water Levels
Water Level (reduced)
65
60
55
50
45
40
35
30
1
2
3
4
5
6
Tubewell no's
WL red. 02/91
WL red. 10/90
WL red. 04/90
WL red. 11/89
WL red. 05/89
WL red. 11/88
WL red. 05/88
WL red. 11/87
WL red. 11/91

Fig. 8.1

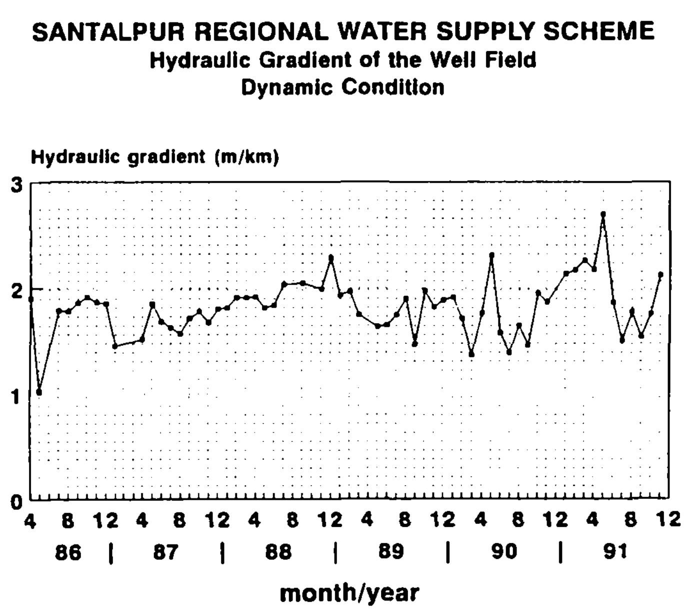

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Hydraulic Gradient of the Well Field
Dynamic Condition
Hydraulic gradient (m/km)
3
2
1
0
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12
86 | 87 | 88 | 89 | 90 | 91
month/year

Fig. 8.2

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Chloride Content Tube Well Water

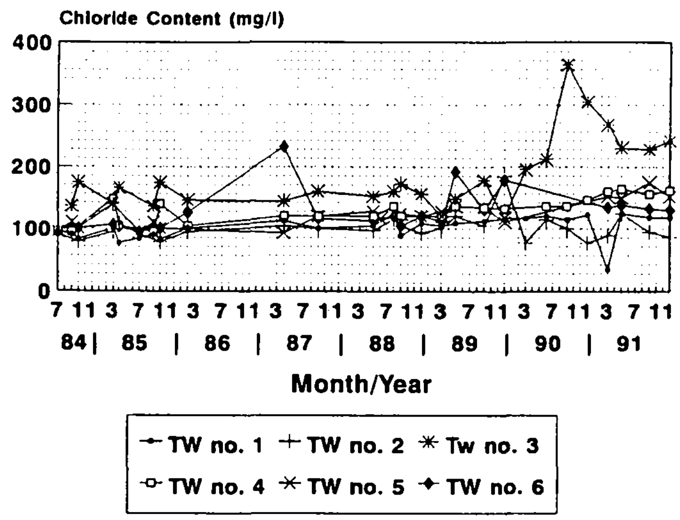


Fig. 9.1

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Trend in Chloride Content Well Field

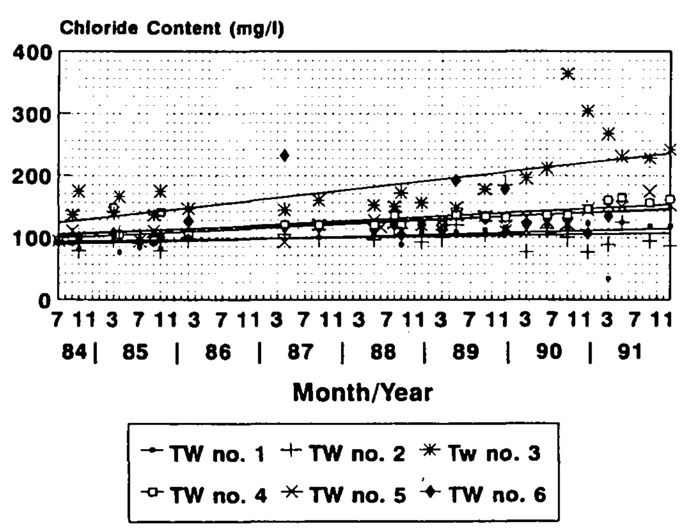


Fig. 9.2

SANTALPUR REGIONAL WATER SUPPLY SCHEME
TDS Content Tube Well Water

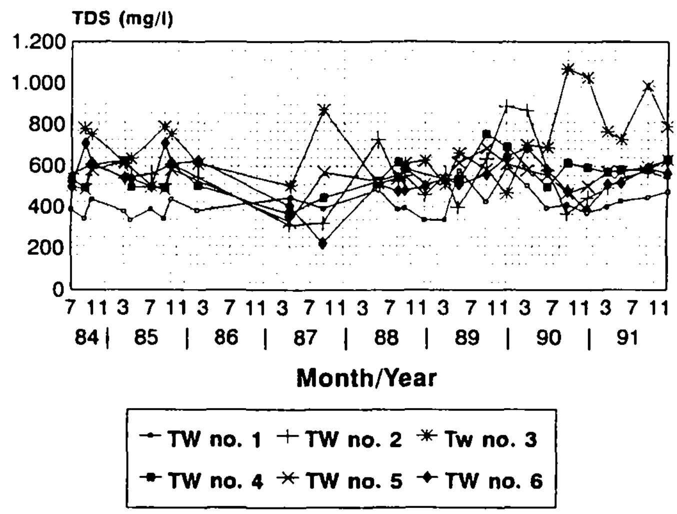


Fig. 10.1

SANTALPUR REGIONAL WATER SUPPLY SCHEME
Trend in TDS Content Tube Well Water

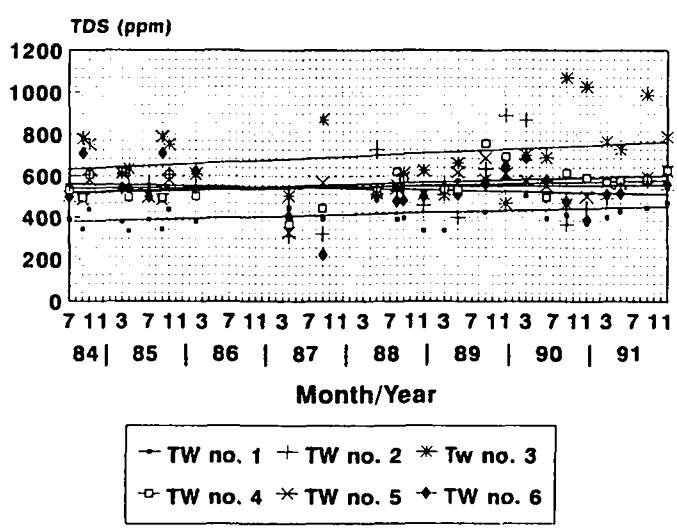


Fig. 10.2

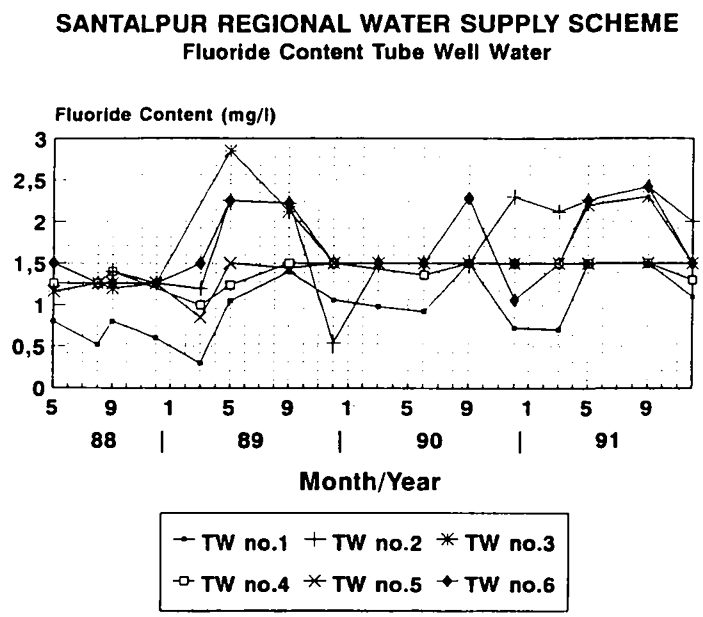


Fig. 11.1

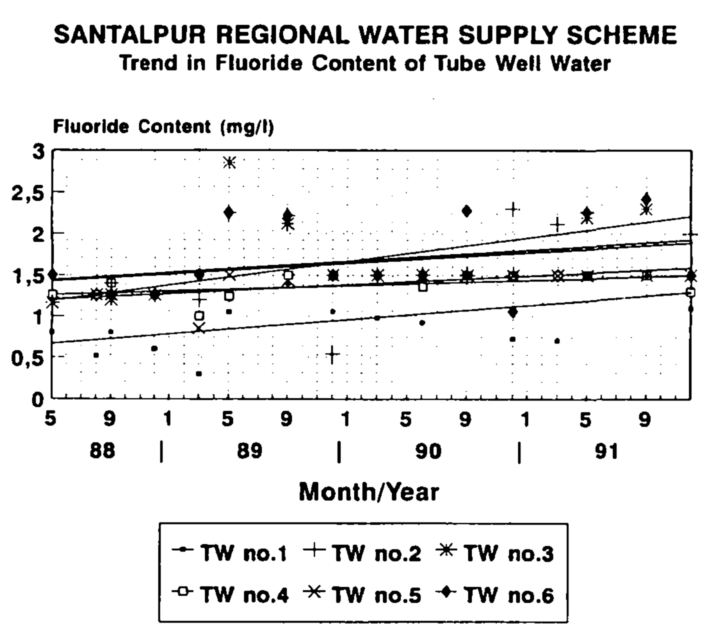


Fig. 11.2

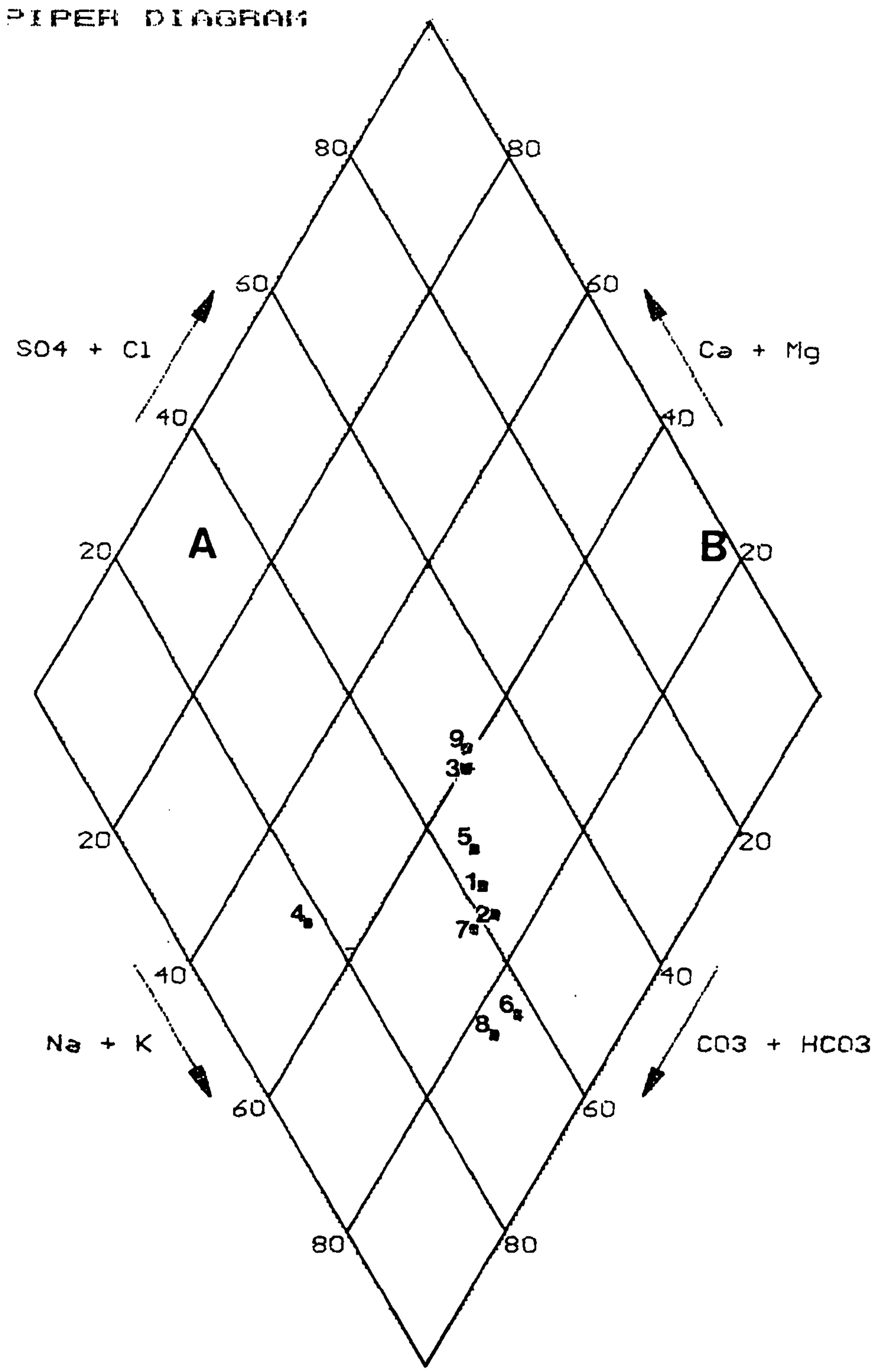


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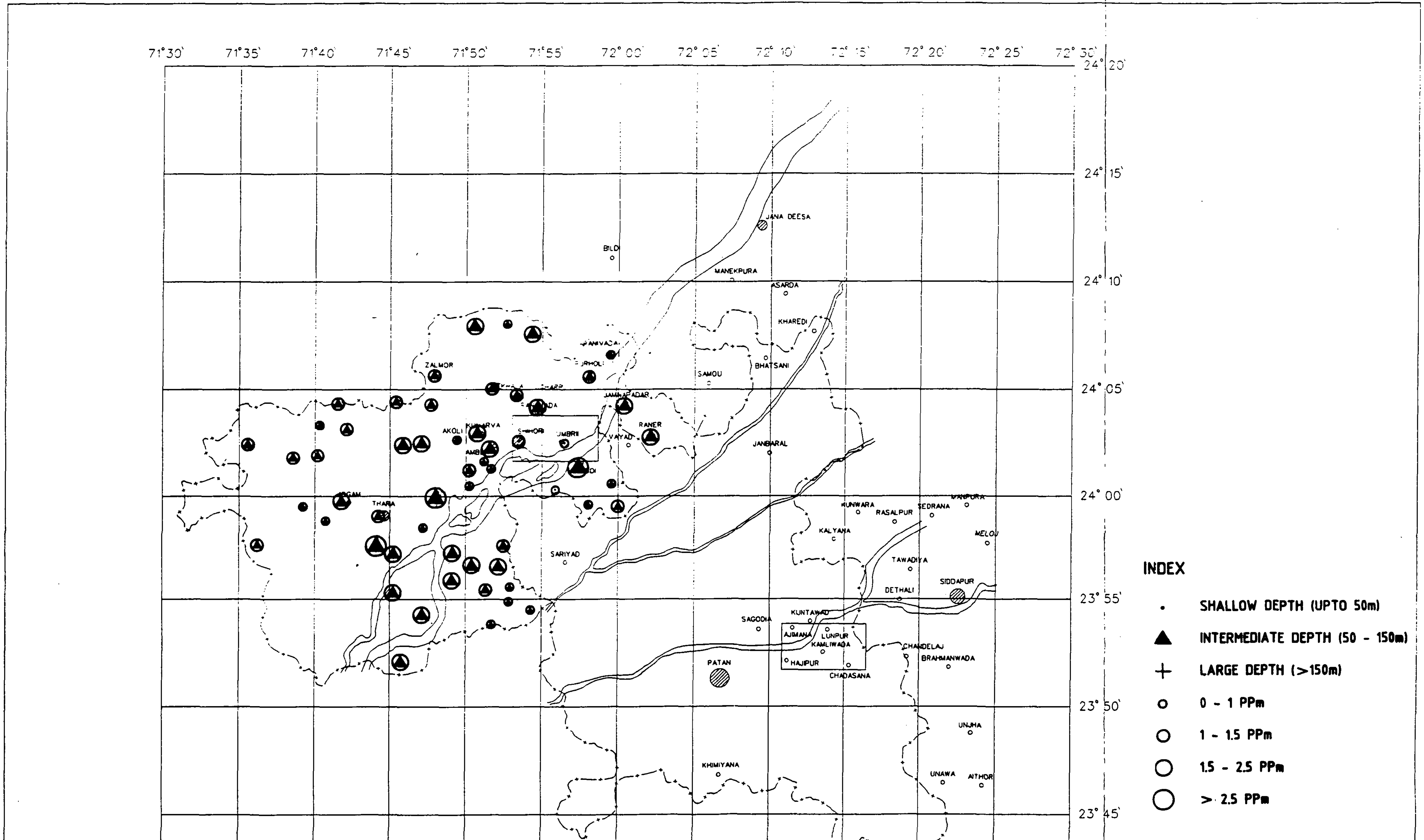
FIG. NO. 12

RESULTS CHEMICAL ANALYSIS OF SAMPLES FROM SHIHORI

Date	Drawn	Check



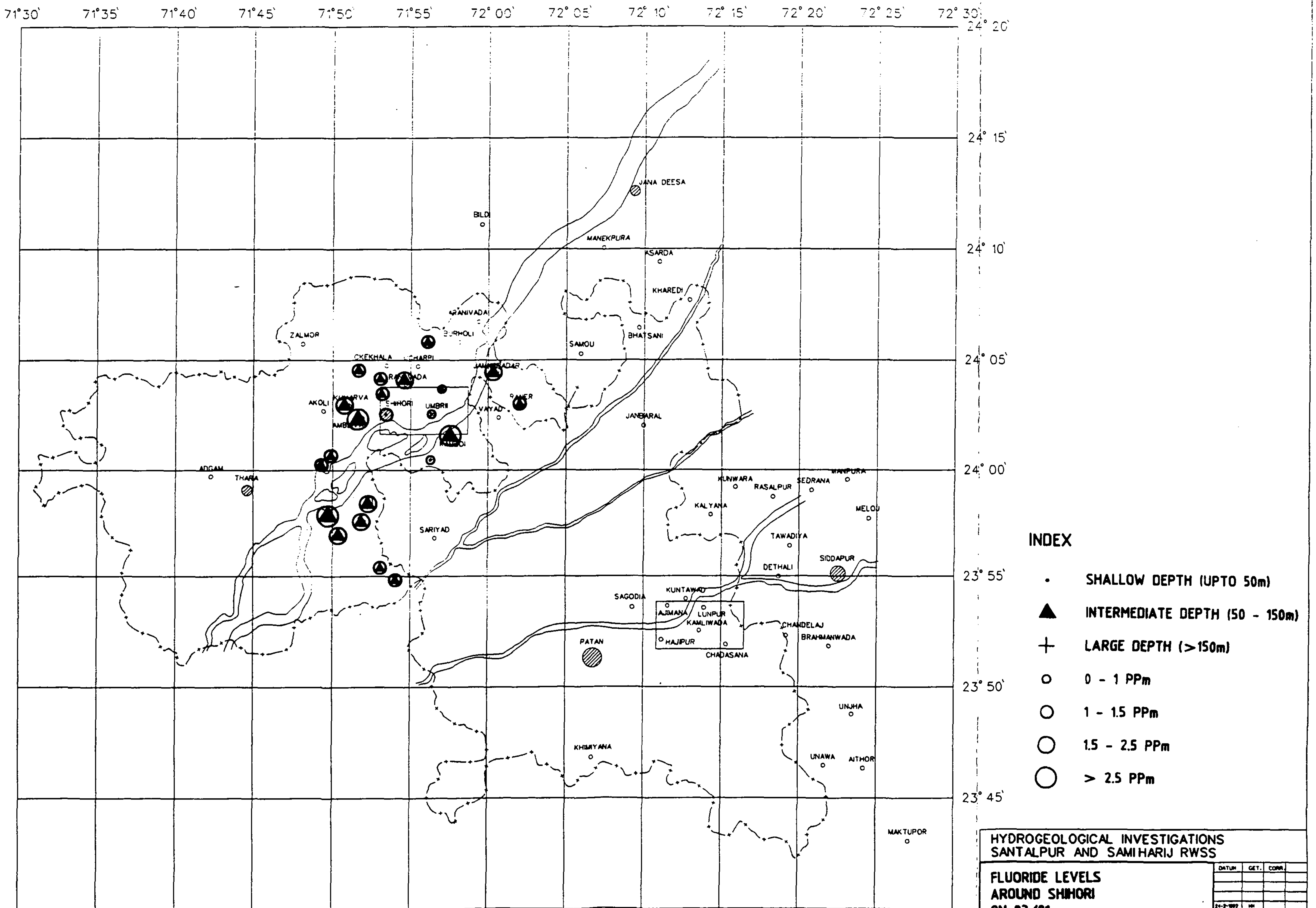
HYDROGEOLOGICAL INVESTIGATIONS
SANTALPUR AND SAMIHARIJ RWSS

FLUORIDE LEVELS AROUND SHIHORI ON 05/89

SCALE 1:350.000

HASKONINO
ROYAL DUTCH CONSULTING ENGINEERS AND ARCHITECTS

FIG. NO. 13



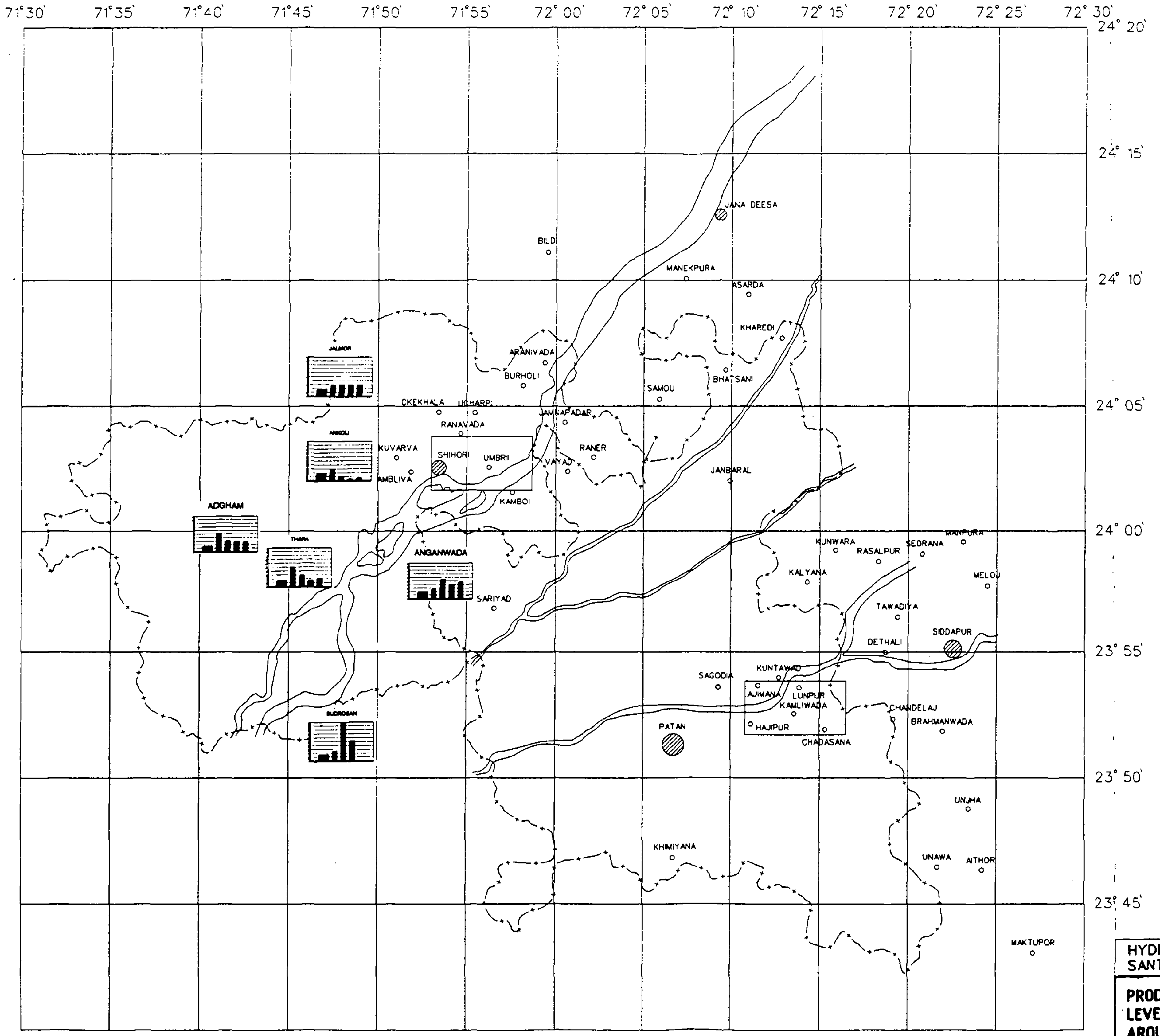
HYDROGEOLOGICAL INVESTIGATIONS
SANTALPUR AND SAMIHARIJ RWSS

FLUORIDE LEVELS AROUND SHIHORI ON 03/91

SCALE 1:350.000

HASKONING
ROYAL DUTCH CONSULTING ENGINEERS AND ARCHITECTS
BARBAROSSASTRAAT 35 6522 DK NIJMEGEN

FIG. NO. 14



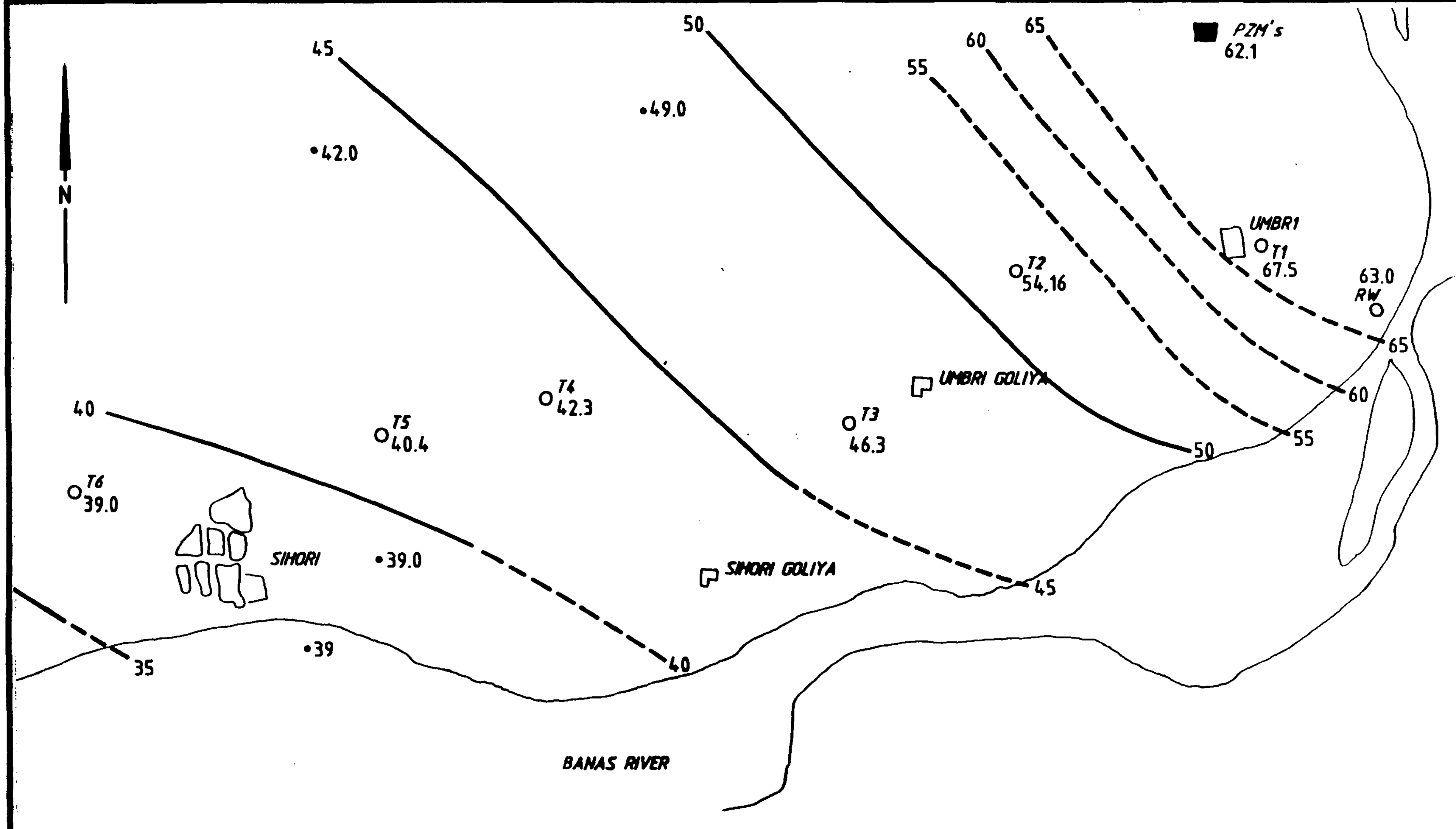
HYDROGEOLOGICAL INVESTIGATIONS
SANTALPUR AND SAMIHARIJ RWSS

PRODUCTION FLUORIDE LEVELS IN TUBEWELLS AROUND SHIHORI

DATUM	GET.	CORR.
SCALE	1:350.000	A/

HASKONING
ROYAL DUTCH CONSULTING ENGINEERS AND ARCHITECTS
BARBAROSSASTRAAT 35 6522 DK NIJMEGEN

FIG. NO. 15



HYDROGEOLOGICAL INVESTIGATION SANTALPUR + SAMI HARIJ RWSS

HASKONING
Royal Dutch Consulting Engineers and Architects

FIG. NO. 16

STATIC WATER LEVELS
SHIHORI
ON 03/91

Date	Drawn	Check
12-03-92		

Scale 1 : 30,000

4. THE KAMLIVADA WELL FIELD

4.1 Existing situation

4.1.1 General

The Kamlivada well field has been constructed to supply the Sami-Harij RWSS in the district Mehsana. It consists presently of 13 wells which have all been realised now. Pumping has already started, but only from the connected wells and for the purpose of testing of pipelines and reservoirs. The well field as a whole has not been in production yet. Eight wells have been constructed by GWSSB and five wells were handed over from CGWB to GWSSB. These wells have been used as production wells (1) and observation wells (4) for a artificial recharge project carried out by CGWB in cooperation with UNDP. From these wells, two have been rejected for reasons of shallow depth (depth of tube well no. 1 is 39 m) and excessive fluoride content (tube well no. 5 : 2.98 mg/l). This leaves 11 tube wells for the water supply of the scheme serving 112 villages. In the future three additional tube wells will be realised to supply for phase II.

4.1.2 Expected production

As already mentioned, the well field will supply 13.82 MLD in future to the Sami-Harij scheme by means of 14 tube wells which means an average production of 1 MLD per tube well. The difference in save yield and installed capacity of the pumps per well, may cause differences in the actual production per well.

4.1.3 Description of resources

The Kamlivada well field consists of 13 wells tapping the phreatic aquifer A1 and the more confined aquifers A2, A3 and B. In one tube well the C aquifer has been encountered but it is not being tapped. A cross section through the well field is give in fig. 17. Only the confined aquifers, are being exploited. This means that the depth of the productive wells ranges between 130 m and 239 m below ground level (bgl). The transmissivity of the wells varies between 35 and 441 m^2/day with average value around 270 m^2/day. The rather low transmissivity is caused by the frequent interbedding of clay layers. Depending on the tube well, 7 to 10 different aquifers have been identified by means of cuttings and electric logging. The UNDP made a simplified cross section of the area around Kamlivada showing 3 to 4 aquifers (annex III, fig. III-2).

The upper part of the aquifer system at Kamlivada, the phreatic A1 aquifer up to 30 m bgl, consists of medium to coarse grained sand interlaid with yellow-brown clay, gravels and occasionally kankar. The deeper more confined aquifers A2 and A3, situated between 50 and 120 m bgl, consist of alternated bands of fine to medium grained sands, gravels, sandy clay and kankar. The less permeable layer between the A and the B aquifer consists of yellow clay with lenses of sandy clay. The B aquifer situated between 130 and 220 m consists of a mixture of layered sandy clays, sands, gravels and kankar.

It is mentioned that the A aquifer is a leaky aquifer. Seasonal fluctuations in the phreatic aquifer are between 1 and 6 m. In the Kamlivada area seasonal variations up to 15 m are observed in the more confined aquifers.

4.1.4 Water levels

The monitoring of the water levels of the Kamlivada well field takes place since 1989. Therefore, long time series are not yet available. In addition the well field is not yet productive which means that water levels are under static conditions. Figure 18.1, 18.2 and 18.3 present the measured water levels. The overall rise which can be observed is due to excessive monsoon rains of 1990. The latest readings of April 1991 show a remarkable drop in levels of most wells that cannot be explained. Ample space is available for pump-setting at adequate depth if regional water levels will drop at a rate of 2-3 m/y. The distance of the wells to each other is relative small regarding the low transmissivity which is reflected by the relative high drawdowns (6-26 m) obtained from pump test data.

4.1.5 Water quality

Since water quality monitoring only started recently with the pumps not yet in operation, not enough data are available to draw any conclusions on the trends. An aspect which has to be taken into account is the fact that the tube wells in the Kamlivada well field tap more aquifers and with a larger depth range (129 m to 235 m) than is the case in the Shihori well field (159 m to 174 m). Because it was already known that the region (Mehsana district) copes with high fluoride levels, the RSM asked during GU-22 for an inventory of tube wells within a radius of 5 km of the well field. The wells mainly serve irrigation purposes and are usually screened in each aquifer. As a consequence they do not provide information on the chemical quality of specific layers.

4.1.5.1 Nitrate

From the chemical analysis of water from tube wells in and around the Kamlivada well field, it appears that the nitrate concentration does not significantly exceed the required limits. Although monitoring will be continued as routine, remedial measures are not expected in the near future.

4.1.5.2 Chloride and TDS

On the chloride content, there are not sufficient data to identify trends. However, some chemical analysis from tube wells in and around the Kamlivada well field show excessive chloride contents up to 600 mg/l. The TDS levels in the Kamlivada well field show some elevated levels (fig. 19.1, 19.2 and 19.3).

Due to the blending of the water from the different tube wells which takes place in the large storage tanks, TDS levels still remain within the permissible limits.

4.1.5.3 Fluoride

The fluoride content in this area, analyzed since one year only, is relatively high. From the tube wells in and around the well field it appeared that the fluoride concentration approached the permissible limits (figures 20.1, 20.2 and 20.3). From the chemical analysis of the water from the observed wells outside the well field, it may be expected that the maximal permissible limits will be reached in the near future. Therefore monitoring is necessary while balanced production from wells with different levels of fluoride may keep the fluoride level of the blended water within the permissible limit. However, it must be realized that most probably the fluoride levels will pass beyond this level.

4.2 Detailed investigations

4.2.1 Chemical analysis

4.2.1.1 General

A sampling campaign has been carried out to determine the chemical characteristics of the ground water. Many data were available from the studies carried out by UNDP in 1971-1973 [14] and 1981-1983 [13]. The present campaign was carried out to update the existing data and to determine whether the tube wells from the Kamlivada well field would fit within the regional pattern.

4.2.1.2 Results

In table 12 the results are given of the chemical analysis of samples in and around the Kamlivada well field.

Table 12: Results of Chemical Analysis Kamlivada Area

PIPER DIAGR. nr.	SAMPLE	Depth of screen m bgl	NO_3^- mg/l	SO_4^{2-} mg/l	Cl^- mg/l	K^+ mg/l	Na^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	HCO_3^- mg/l	F^- mg/l
10	Hajipur Shallow Well	0- 15	8.1	18	56	19	81	44	21	340	11
11	Hajipur ITW ITW #357	0- 99	18	55	113	10	170	60	48	500	0.9
6	" " " #172	50-106	0.7	20	88	1.5	170	22	20	410	1.1
1	" " " #217	50-116	20.3	18	85	1.6	160	30	28	420	2.0
8	Kamlivada Tube well TW # 8	50- 90	2.0	32	190	1.1	130	52	41	350	0.9
4	" " " # 10	50-130	20.3	14	80	1.2	130	28	25	380	1.0
2	" " " # 13	45-115	20.3	17	72	1.2	140	25	21	410	1.6
5	Kamlivada ITW ITW #142	50- 91	1.1	130	260	2.1	410	27	23	590	2.1
9	" " " #323	50-111	8.9	69	270	1.4	400	17	16	630	3.3
12	" " " # 52	50-183	12	150	270	1.4	150	48	33	610	1.9
3	Village Panchayat/ Kamlivada Tube well	40-219	4.5	84	260	1.6	400	18	14	450	3.0
7	Piezometer PZM10	234-240	32	340	260	4.8	390	100	51	380	1.1

Samples from the piezometers, located next to tube well 8 and 9 of the well field, have been analyzed as well. However, only Cl^- and TDS were as table 15 presents the values of fluoride.

From the UNDP report [16] some data are available from the tube wells tapping the deeper aquifer down to 550 m below ground level. Some of these tube wells, located in the area of Kamlivada are listed in table 14.

Table 13: Results from the Chemical Analysis of the Piezometer Samples (15/10/91)

Location	Depth m bgl	Cl^- mg/l	TDS mg/l
PZM1B	34.68 - 46.68	230	678
PZM1A	50 - 62	232	562
PZM1	77.15 - 85.96	176	700
PZM2	93 - 111	166	608
PZM3	118 - 130.03	168	590
PZM4	134.6 - 140.6	158	502
PZM5	145.56 - 154.86	154	436
PZM6	160 - 172.06	194	648
PZM7	178.41 - 190	136	532
PZM8	194.80 - 220.14	116	480
PZM9	223.15 - 229.05	88	358
PZM10	234.08 - 239.98	280	802

Table 14: Data from deep drillings in the surroundings of the Kamlivada well field [16]

Village	Elevation m above MSL	Depth drilled m bgl	zone tapped m bgl	Designation of the aquifer	TDS mg/l	Cl^- mg/l
Kamlivada	67.64	613	465-508	F	1464	N.A.
Khimiyana	69.95	594	343-413	C	840	285
Sariyad	72.32	330	265-270	C	1484	680
Khimiyana	67.64	214	186-205	C	3734	1160
Sariyad	72.54	517	404-429	D	2480	1050
Bhatson	67.02	305	268-298	D	1972	900
Khiniyana	126.85	609	446-464	E	356	90
Sariyad	72.41	614	515-545	E	3844	1975
Sariyad	43.96	453	401-422	F	1342	600

4.2.1.3 Discussion

The hydro-chemical characteristics of the groundwater in the Kamlivada area are more complex than in the Shihori area. No clear distinction can be made on the basis of complete chemical analysis of the samples. If the data are displayed in a Piper diagram (figure 21), the chemical composition reflects a Na(K) HCO_3 - type of water. No distinction can be made between the different wells. The piezometer, tapping the deepest aquifer of the Kamlivada well field has a clearly higher salinity than the other samples.

The piezometers that are grouped together, show however a similar trend as observed in the Shihori area. The phreatic aquifer upto 65 m below ground level gives a rather high chloride content. Below this aquifer the chloride and TDS content decreases steadily down to a depth of 160 m below ground level. At 160 m both Cl^- and TDS show a sharp increase and again gradually decrease down 230 m below ground level. At 235 m bgl again an increase in Cl^- and TDS occurs. Data from larger depths are only on a regional scale available (table 14).

Geochemical data from tube wells around Kamlivada tapping deeper aquifers reveal TDS and Cl^- levels that are in some cases lower than could be expected on the basis of the geological history of the region. In general the water from these aquifers is rather saline (figure 22), but aquifers with fresh water may be encountered as well. A deep tube well (613 m) drilled at Kamlivada encountered 1464 mg/l TDS in the F aquifer at 465-508 m. The exact location of this well is, however, unknown.

4.2.2 Fluoride analysis

4.2.2.1 General

An inventory of tube wells for irrigation purposes, carried out in 1989, enabled to determine local distribution of fluoride within a radius of 5 km around the well field and samples were tested in 1989 and 1991.

Vertical occurrence of fluoride has been tested by taking samples from the piezometers and from several tube wells tapping aquifers up to different depths.

4.2.2.2 Results

Table 15 gives the results of the fluoride levels of samples from the piezometers.

Table 15: Fluoride levels of the piezometer samples

	PZM 1B	PZM 1A	PZM 1	PZM 2	PZM 3	PZM 4	PZM 5	PZM 6	PZM 7	PZM 8	PZM 9	PZM 10
Depth m bgl	34.68 - 46.68	50 - 62	77.15 - 85.96	93 - 111	118 - 130.03	134.6 - 140.6	145.56 - 154.86	160 - 172.06	178.41 - 190	194.80 - 220.14	223.15 - 229.05	234.08 - 239.98
Date												
Initial	1.46	1.50	5.10	3.50	2.14	2.58	2.04	4.85	5.65	2.80	1.50	1.50
28/08	1.65	1.05	1.50	1.95	1.65	2.25	1.25	2.25	3.15	2.85	1.05	1.40
17/09	1.50	1.50	1.50	1.50	1.50	1.36	1.50	2.30	2.48	2.10	1.20	1.30
27/09	1.50	2.36	1.50	1.50	1.36	1.24	0.12	1.24	2.60	5.10	1.20	1.20
07/10	1.34	1.50	1.40	1.30	1.10	1.20	0.84	0.80	2.24	1.30	1.36	1.30
16/10	1.14	0.94	1.24	1.10	1.00	1.00	0.66	1.50	2.20	1.50	0.80	0.80

A certain distribution of fluoride in depth can be observed from the above table. This distribution is not exactly conform the other chemical parameters and the waterlevels. The first sub-system consists of the piezometers 1B and 1A up to 62 m depth. In this system, fluoride levels decrease with depth. The second system comprises the piezometers 1 to 6. In this system the fluoride levels decrease with depth also. However, piezometer no. 6 shows already a higher level of fluoride, probably due to the fact that it taps partly the third sub-system, to which belong piezometers 7 to 10. In the piezometers 7 to 10, the fluoride levels decrease again with increasing depth.

With all piezometers, initial fluoride levels directly after construction tend to be quite elevated but decrease in the samples which were taken more recently.

On the long term, as can be seen from the observations on the water supply tube wells, fluoride levels are increasing which is confirmed by the analysis of samples from irrigation tube wells in the region tested in 1989 and 1991, fig. 23 and 24.

It appears that the Kamlivada well field has been constructed on an area of relative low level fluorides. However, regarding the above mentioned development of fluoride levels in the region, increase of fluoride levels in the tube wells of the well field can be expected.

4.2.2.3 Discussion

The vertical distribution of fluoride seems to be related to the chemical and hydrogeological characteristics. Striking in the vertical distribution is the stepwise decreasing trend in fluoride in separate aquifer sub-systems. This trend may be induced by the layer of low permeability containing clay and clay minerals, which separates the three aquifer sub-systems. As mentioned earlier, fluoride (from clay minerals) may be exchanged in cation exchange processes between clay layers and groundwater. However, other processes may play a role as well (annex II).

The increase in fluoride content over a longer period observed around the Kamlivada well field most probably is caused by the dropping groundwater tables. Compared to the tube wells in the region, fluoride levels in Kamlivada are relative low.

The high initial levels of fluoride found in the piezometers and the decreasing trend thereafter must be caused by the disturbance of the underground by the construction of the piezometer, as mentioned earlier.

4.2.3 Isotope analysis

4.2.3.1 Outline

Isotope analysis was carried out on several samples from the well field and surrounding wells. Because only one piezometer was realised at the time of the fieldwork, clusters of wells were chosen tapping aquifers down to different depths. Comparison would enable determination of characteristics of the different tapped aquifers.

4.2.3.2 Results

The results of the isotope analysis of samples around the Kamlivada well field are displayed in table 16.

Table 16: Results on isotope analysis Kamlivada

Location	Depth m bgl	O-18 ‰	H-2 ‰	C-13 ‰	C-14 ‰	H-3 TU
TW-8	40-156	-3.31	-22.1	-9.66	83.6 ± 1.2	2.2 ± 0.1
TW-10	49-173	-3.32	-21.5	-9.54	75.3 ± 0.7	1.0 ± 0.1
TW-13	43-156	-3.10	-22.8	-9.10	71.8 ± 1.0	2.4 ± 0.1
Haijpur Shallow well	20- 25	-4.36	-28.6	-9.18	*	*
Piezometer PZM 10	233-245	-3.14	-20.8	-5.05	52.1 ± 0.9	< 0.2

* Not measured since the well is shallow thus the water is recent.

4.2.3.3 Discussion

The results show that the values from these samples do not vary in a significant way. However, there in a clear difference with those from the Shihori well field.

O-18 (Oxygen 18)
The values of O_{18} are around -3.25‰ while the 0-18 value of the precipitation in the region around the well field is -5.7‰ ± 0.2. This average is clearly less negative than with the Shihori samples which means a higher evaporation before the infiltration caused by a larger period of stagnation for the Kamlivada samples. The value of the Haijpur shallow well indicates a relative higher evaporation than the other samples.

H-2 (Deuterium)
The H-2 values are uniform except for the Haijpur Shallow well. However, the latter value coincides very well with the values from the Shihori well field. This indicates that at shallow depth the water in Kamlivada and Shihori is of the same type. Mixing of older water from larger depth with more recent water results in clearly different types of water for both well fields. The reason for this difference is that the Kamlivada well field is closer to the infiltration area.

C-14 (Carbon 14)
The C-14 values in Kamlivada are quite uniform and clearly higher than at Shihori. This could mean a higher age for the water at Kamlivada. However, regarding the fact that both well fields have a common source area and their lateral distance is not more than 30 km in relative homogeneous unconsolidated sediments, this is not an obvious reason. The relative high C-14 values compared to Shihori could be caused by the local presence of enriched lime which could reach the deeper and older water by percolating groundwater in the leaky aquifer system in combination with the numerous irrigation tube wells that are continuously screened. This would mean that the underground around Kamlivada contains more enriched lime than at Shihori. The chemical composition of the water around the Kamlivada well field indicates higher levels of Ca^{2+}, Mg^{2+} and HCO^{-}_{3}. Another possibility is that the soil characteristics around both well fields are comparable, but the rate of mixing and percolation and the depth to which mixing takes place at Kamlivada is higher.

This could be explained by the higher density of irrigation tube wells around Kamlivada and upstream of the well field. This density causes a larger drawdown, a deeper percolation of the infiltrating groundwater and more vertical connections between different aquifers causing more mixing. In this specific area it indicates more irrigation with a larger irrigation return flow causing in its turn more dissolution of enriched lime percolating to deeper layers.

The sample from the piezometer at Kamlivada is clearly older. Especially the fact that hardly any tritium has been found (<0.2 TU) indicates that the water is old and no mixing with recent surface water has taken place.

C-13 (Carbon 13)
For carbon 13 the same can be said as for C-14. Kamlivada shows generally more negative values than Shihori. Also this is most likely caused by a larger irrigation return flow and more intensive mixing of water. Since cation exchange also influences C-13 values, high cation content (as is the case with the samples from the piezometer) can induce more positive C-13 values.

H-3 (Tritium)
The tritium levels in Kamlivada are generally higher which also indicates more intensive mixing with recent water caused by a larger irrigation return flow as mentioned before.

4.2.4 Piezometers new wells

Piezometers have been installed in each layer (12 in total), the deepest at a depth of 240 m. During the field work only one piezometer was realised. After realisation of the other piezometers, samples have been taken and extensively tested. Data of all piezometers are listed in table 17.

Table 17: Data on the piezometers in the Kamlivada well field

	PZM 1B	PZM 1A	PZM 1	PZM 2	PZM 3	PZM 4	PZM 5	PZM 6	PZM 7	PZM 8	PZM 9	PZM 10
DEPTH m bgl	58,0	65,0	93,0	133,0	113,0	142,0	155,5	175,0	199,0	222,5	234,8	241,0
DIAMETER m bgl	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
DEPTH RANGE OF FILTERS m bgl	34,7 - 46,7	50,0 - 62,0	77,2 - 85,9	93,0 - 111,0	118,0 - 130,0	134,6 - 140,6	145,6 - 154,8	160,0 - 172,1	178,4 - 190,0	194,1 - 220,1	223,2 - 229,05	234,1 - 240,0
STATIC WATER LEVEL AT 24/9/91	23,15	23,05	42,74	45,74	46,51	45,55	49,36	65,58	69,04	70,18	44,41	71,67

4.2.5 Water levels

4.2.5.1 Outline

Waterlevels in the Kamlivada well field have been monitored since 1989. Since the well field has not yet been taken in production results from measurements in productive situation should be awaited before drawing any conclusions on the longer term.

4.2.5.2 Results

The available data of the Kamlivada well field are given in fig. 25.
Table 18 gives the water levels of piezometers between August 8, 1991 and December 1991.

Table 18 Water levels piezometers in the Kamlivada well field

	PZM 1a	PZM 1b	PZM 1	PZM 2	PZM 3	PZM 4	PZM 5	PZM 6	PZM 7	PZM 8	PZM 9	PZM 10
Depth m bgl	50-62	35-42	77-86	93-111	118-130	135-141	146-155	160-172	178-190	194-220	223-229	234-240
Date												
19/08/91	22.85	22.93	40.1	42.95	43.94	43.25	47.35	66.22	69.5	70.5	47.5	73.4
28/08/91	22.92	23.5	43.5	46.62	47.6	46.9	49.45	66.3	69.9	71	47.5	73.4
17/09/91	22.96	23	40.5	43.46	44.45	43.55	47.42	64.75	68.25	69.05	44.1	71.5
24/09/91	23.05	23.15	42.74	45.74	46.51	45.55	49.36	65.58	69.04	70.18	44.41	71.67
29/09/91	23.15	23.2	43.18	47.94	48.91	48.12	56.86	66.43	70.47	71.02	44.56	73
07/10/91	23	23.35	48.26	52.91	54	53.42	55	69.73	74.38	74.76	52.08	76.13
14/10/91	23.05	23.42	52	57.17	58.27	57.21	58.25	72.91	77.9	76.9	57.17	79.9
25/10/91	23.64	23.53	53.85	58.85	60.23	59.56	61.74	77.7	82.92	80.98	59.09	85.12
01/11/91	23.26	23.65	55.74	60.9	62.1	61.12	62.39	79.17	84.21	85.32	58.5	86.71
05/12/91	23.55	23.91	58.39	64.59	65.94	64.3	68	88.23	93.36	94.09	65.52	96.33

4.2.5.3 Discussion

With the available data, a water level contour map can not yet be established. The water levels in the different layers are varying most likely due to the intensity of groundwater withdrawal of irrigation tube wells around the well field.

Once the field is taken into full production, some tube wells in the area around the Kamlivada well field should be selected to serve as observation well, in order to see wether the well field influences the surrounding tube wells.

The tube wells in the Kamlivada well field are screened at all aquifers. Also, in general, the irrigation tube wells tap all aquifers which are encountered. This means that deterioration of certain aquifers on the long term will spread to other aquifers. Also the possibility of dosed mixing of tube well water with high and with low level deterioration to ensure a final product which falls within the permissible limits for drinking water, is not present due to the continuous screening of the tube wells.

4.3 Conclusions

In Kamlivada, the underground has a more complex hydrogeology than Shihori. In the Kamlivada well field, three separate aquifer sub-systems can be distinguished on basis of hydrogeological and geochemical characteristics including fluoride.

A phreatic aquifer is present upto 65 m with a slightly elevated chloride level and relatively shallow groundwater levels of 24 m bgl. This aquifer is almost exhausted and consequently irrigation mainly takes place from the deeper aquifers. Irrigation return flow is mainly restricted to the upper aquifer, but same water is leaking to the deeper aquifers as well.

The second aquifer sub-system from 75 to 150 m shows intermediate waterlevels around 65 m bgl. Irrigation tube wells are mainly tapping aquifers in this aquifer sub-system, but frequently continue tapping permeable layers beyond this depth.

The quality in general is reasonable and especially towards the bottom of the aquifer, good quality drinking water may be found.

The third aquifer sub-system from 155 m to 240 m bgl and possibly beyond, has deep water levels around 90 m bgl except for piezometer no. 9, which shows different levels, comparable to those of the second aquifer sub-system. Groundwater quality in this aquifer sub-system is reasonable, in particular in the middle part of the aquifer sub-system.

Waterlevels around Kamlivada are dropping fast but measurements from the tube wells of the well field in productive situation have to show whether the tube wells reinforce to this regional patten.

Fluoride levels in groundwater around the Kamlivada well field have increased in time which most likely caused by the dropping groundwater levels. It is to be expected that fluoride levels of the tube wells in the well field will increase in future as well. Two distinct levels of relatively low fluoride can be indicated: 145 - 155 m bgl and 223-229 bgl. Future wells should preferably tap these aquifers only.

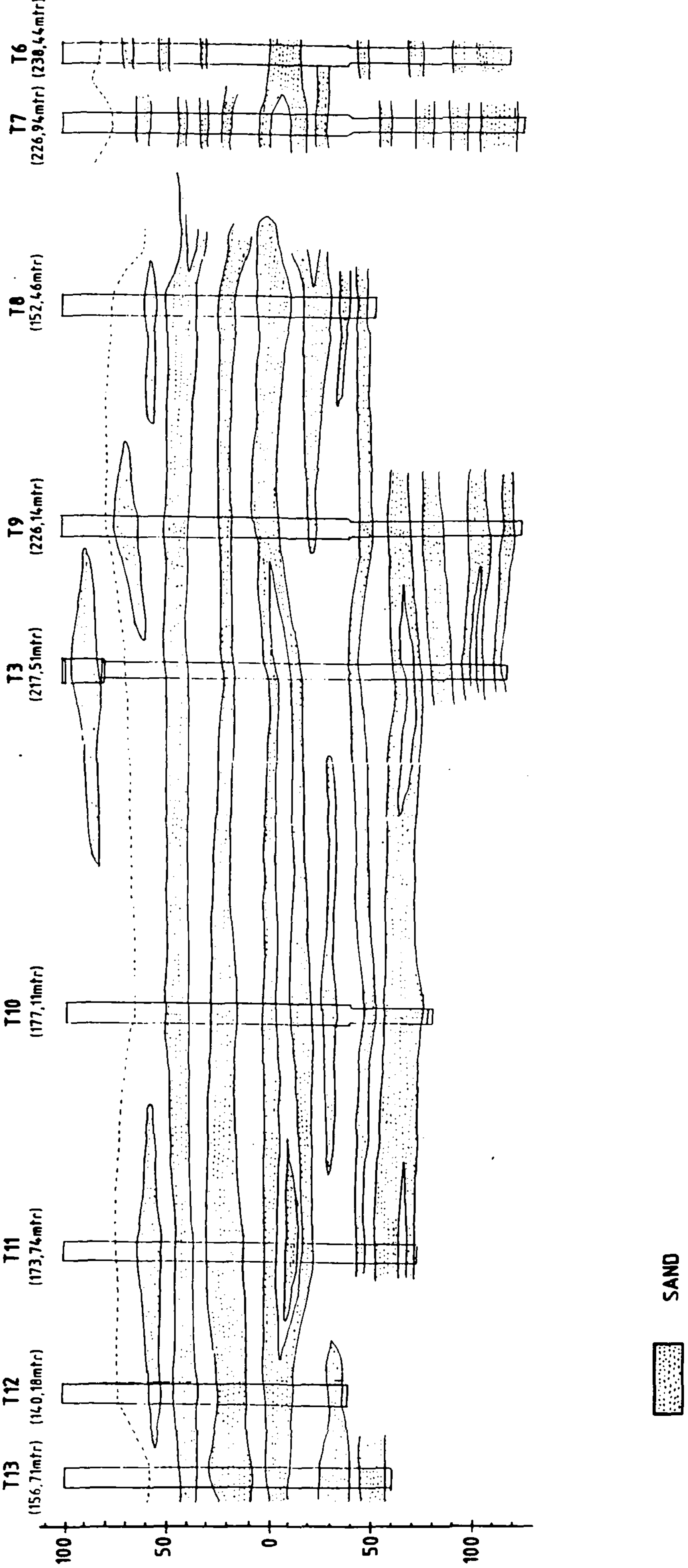


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FIG. NO. 17

SCHEMATISED CROSS-SECTION THROUGH THE KAMLIVADA WELL FIELD

Date	Drawn	Check
03-03-92		
Scale		

SAMI-HARIJ REGIONAL WATER SUPPLY SCHEME
Static Water Levels Tube Wells

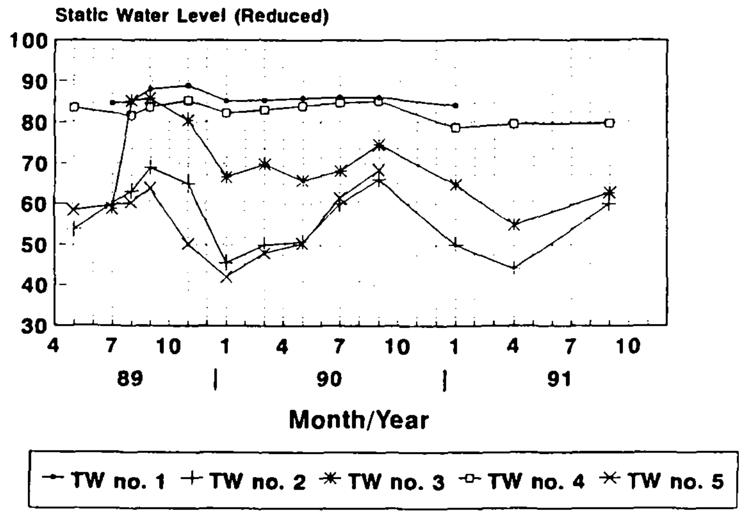

Fig. 18.1

SAMI-HARIJ REGIONAL WATER SUPPLY SCHEME
Static Water Levels Tube Wells

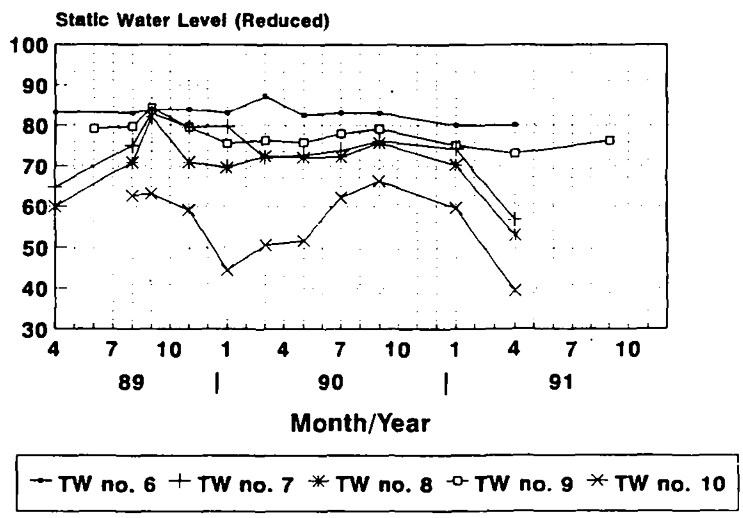

Fig. 18.2

SAMI-HARIJ REGIONAL WATER SUPPLY SCHEME
Static Water Levels Tube Wells

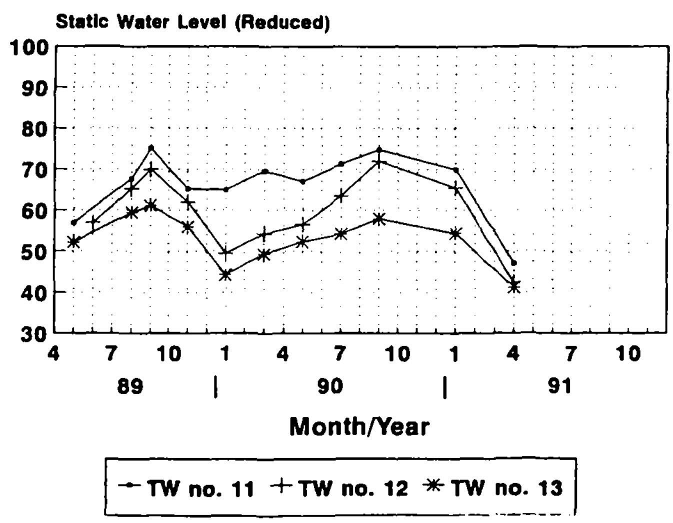

Fig. 18.3

SAMI-HARIJ REGIONAL WATER SUPPLY SCHEME
TDS Content Tube Well Water

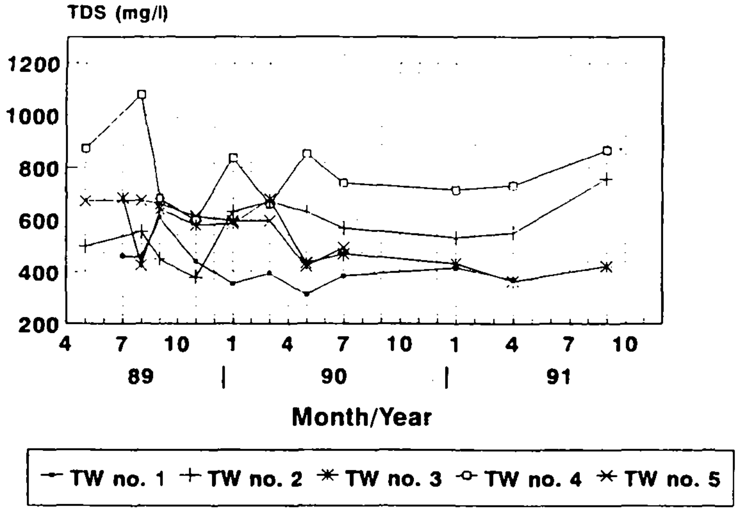

Fig. 19.1

SAMI-HARIJ REGIONAL WATER SUPPLY SCHEME
TDS Content Tube Well Water

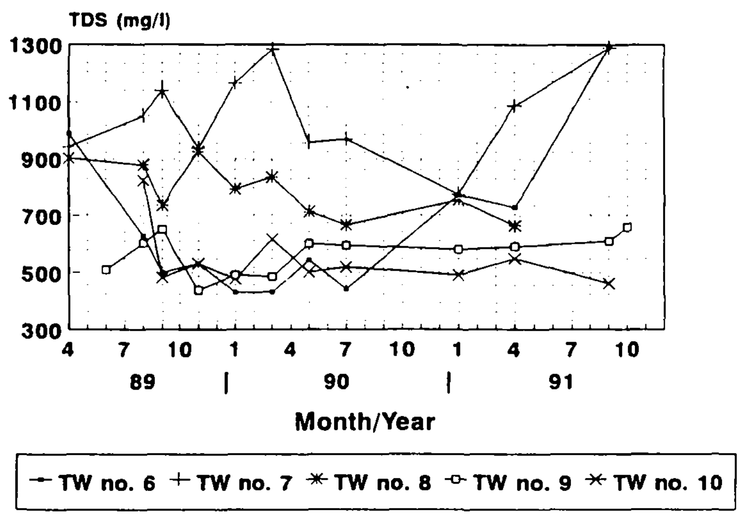

Fig. 19.2

SAMI-HARIJ REGIONAL WATER SUPPLY SCHEME
TDS Content Tube Well Water

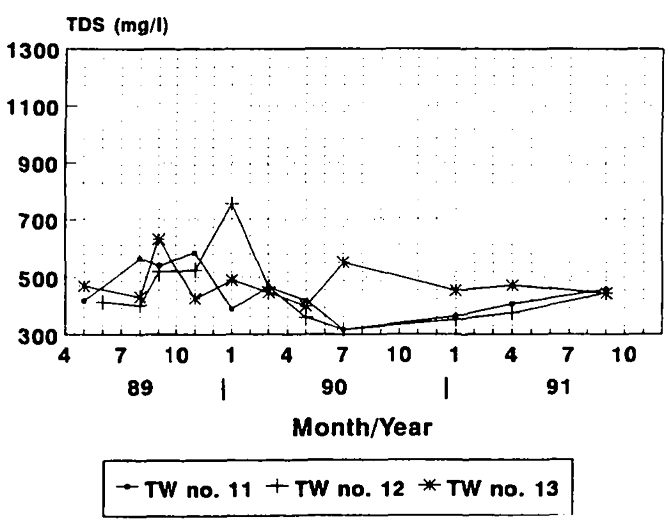

Fig. 19.3

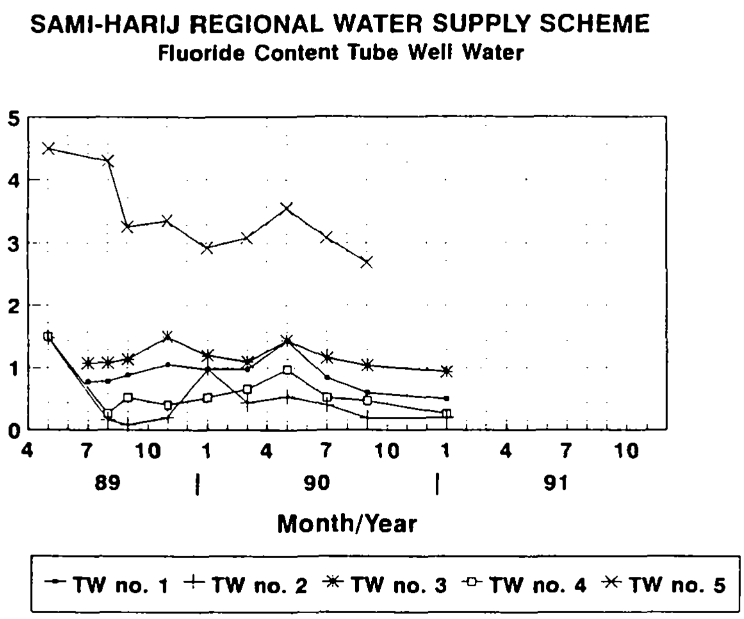

Fig. 20.1

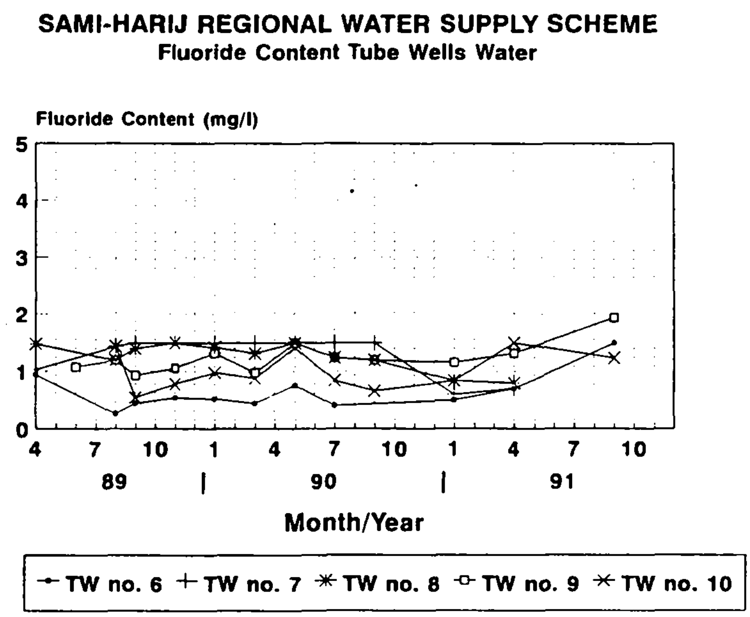

Fig. 20.2

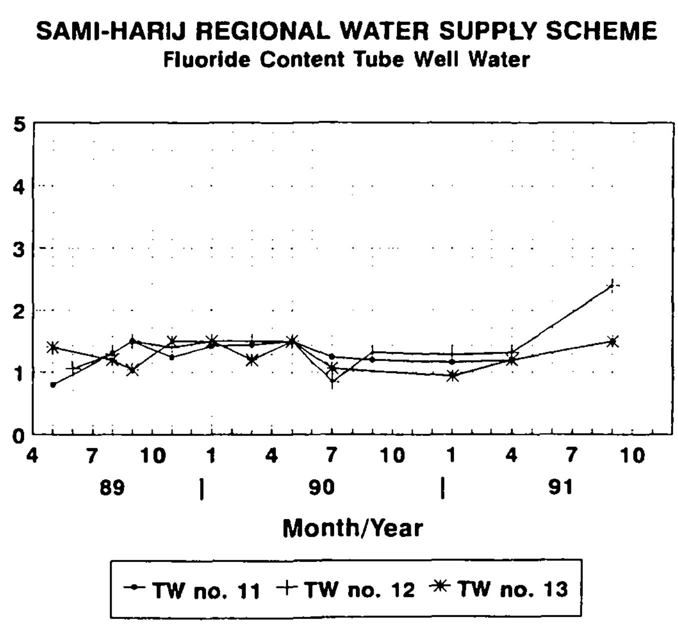

Fig. 20.3

PIPER DIAGRAM

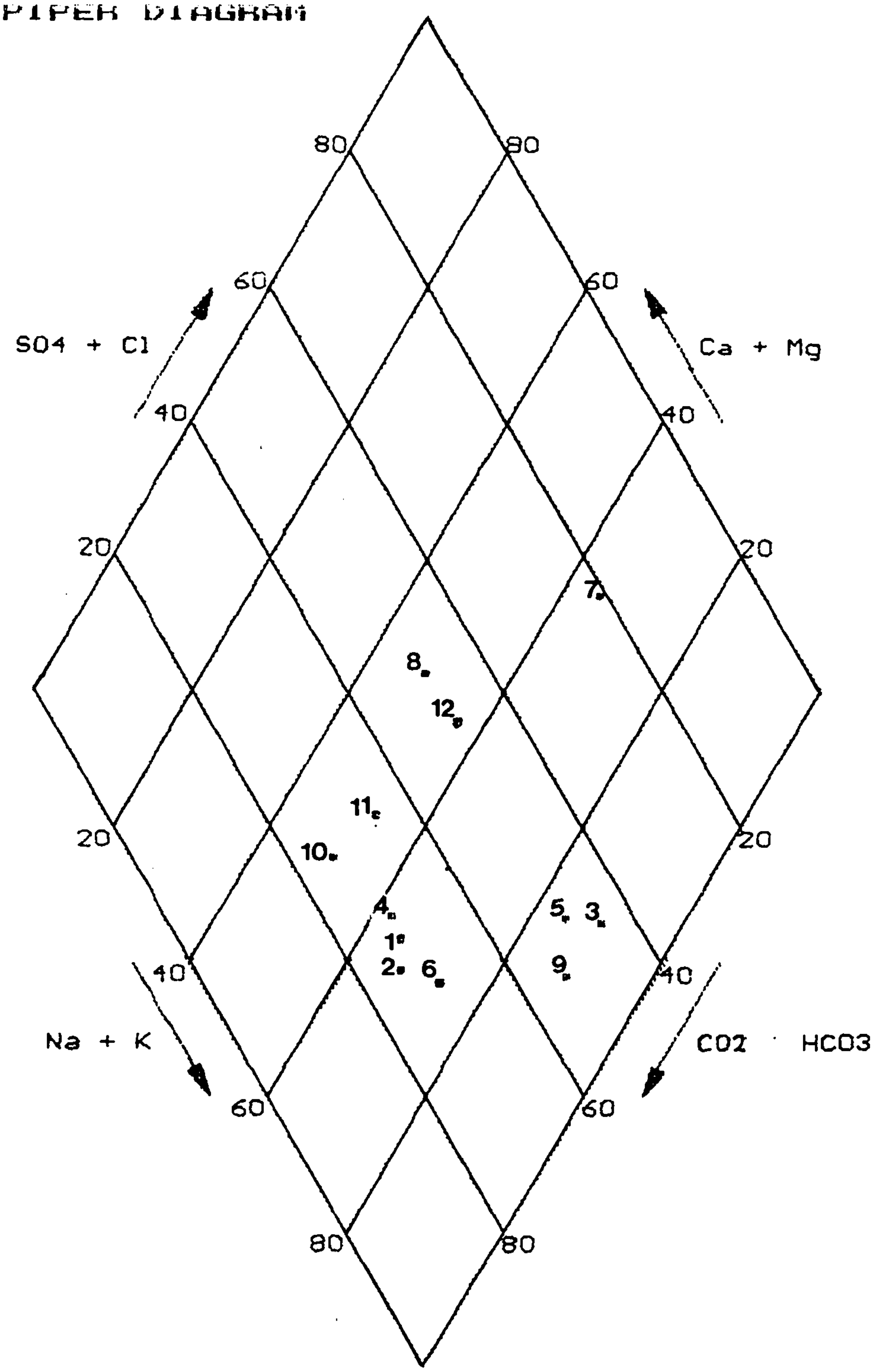

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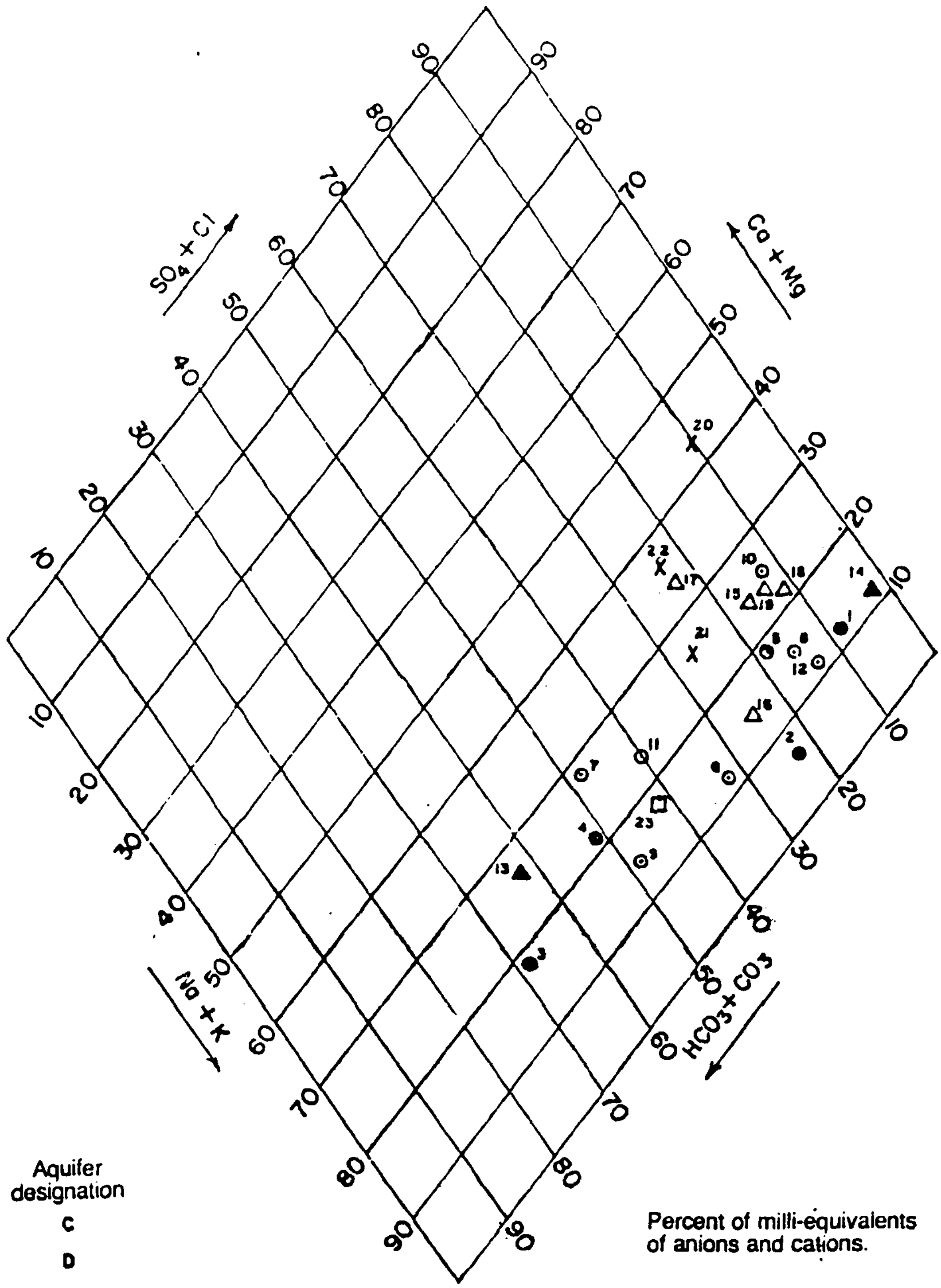
FIG. NO. 21

RESULTS OF CHEMICAL ANALYSIS OF SAMPLES FROM KAMLIVADA



Aquifer designation

- ● C
- ⊙ D
- ▲ E
- △ F
- X G
- □ H

CHEMICAL CLASSIFICATION OF GROUNDWATER SAMPLES

(Hill-Piper Diagram)

DEEPER AQUIFERS

GUJARAT PROJECT AREA

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FIG. NO. 22

CHEMICAL CLASSIFICATION OF GROUNDWATER SAMPLES DEEPER AQUIFERS PROJECT AREA

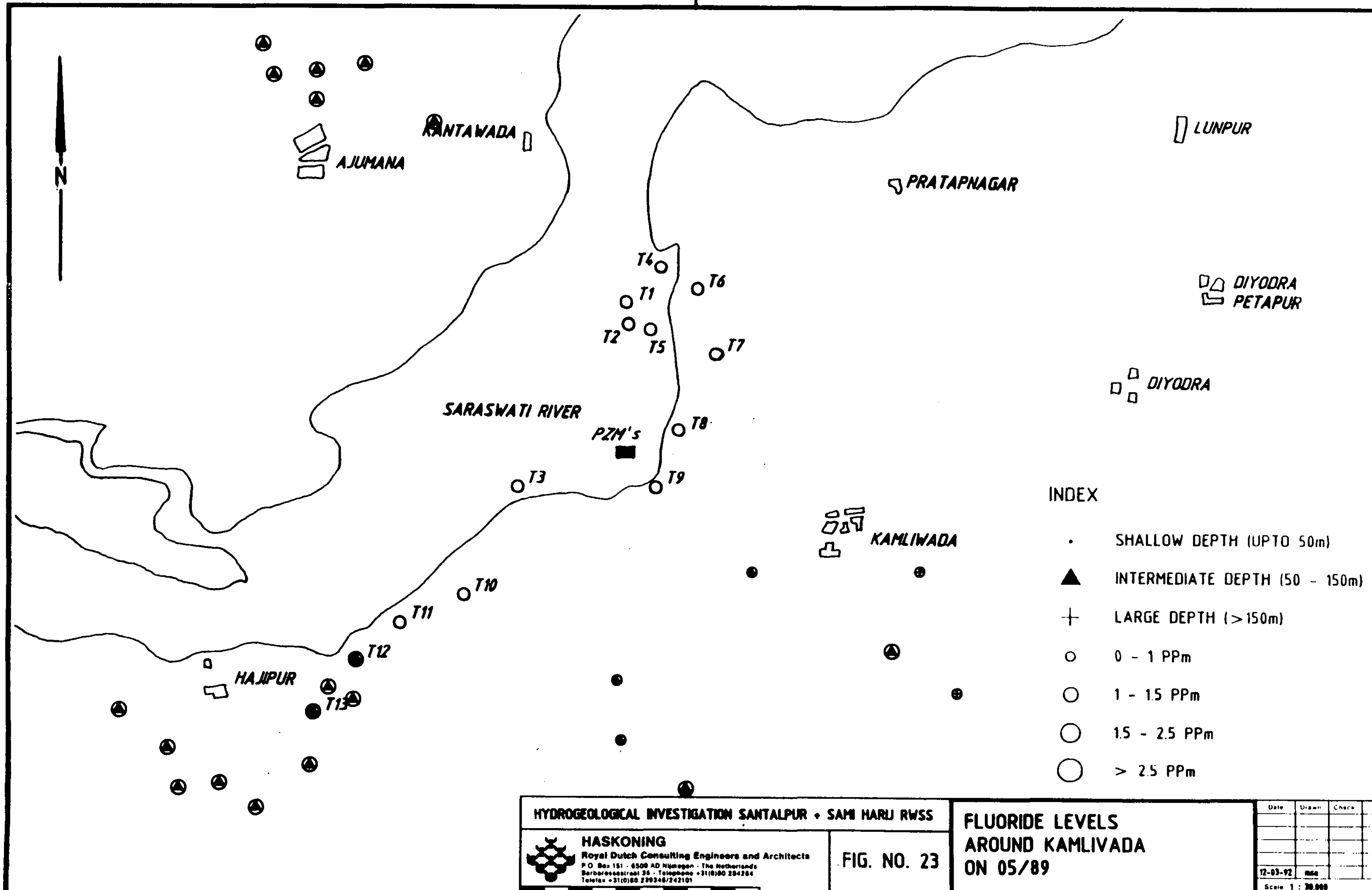

FIG. NO. 23
FLUORIDE LEVELS AROUND KAMLIVADA ON 05/89

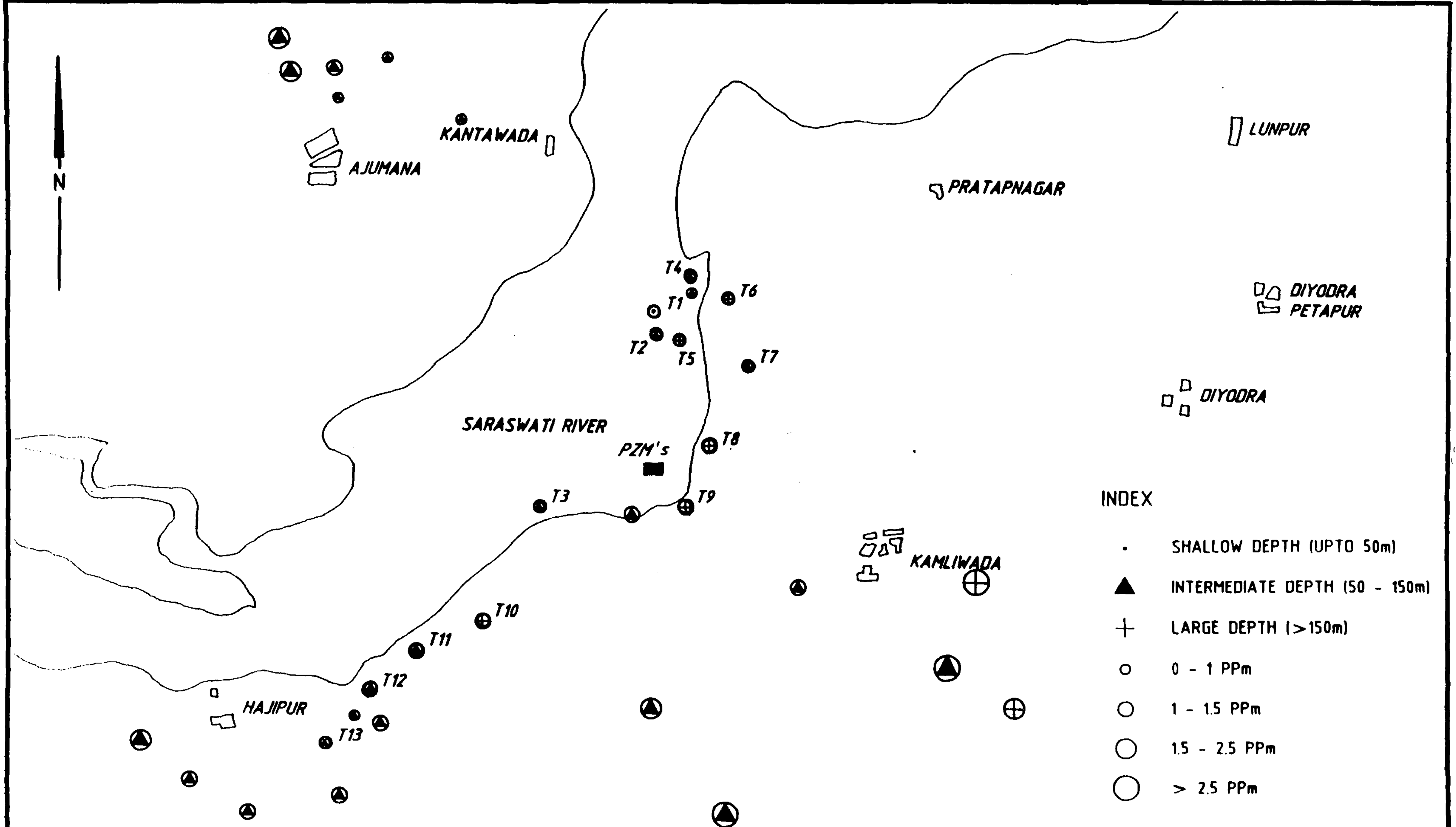

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FIG. NO. 24

FLUORIDE LEVELS
AROUND KAMLIVADA
ON 04/91

Date	Drawn	Check
12-03-92	mne	
Scale 1 : 30.000		

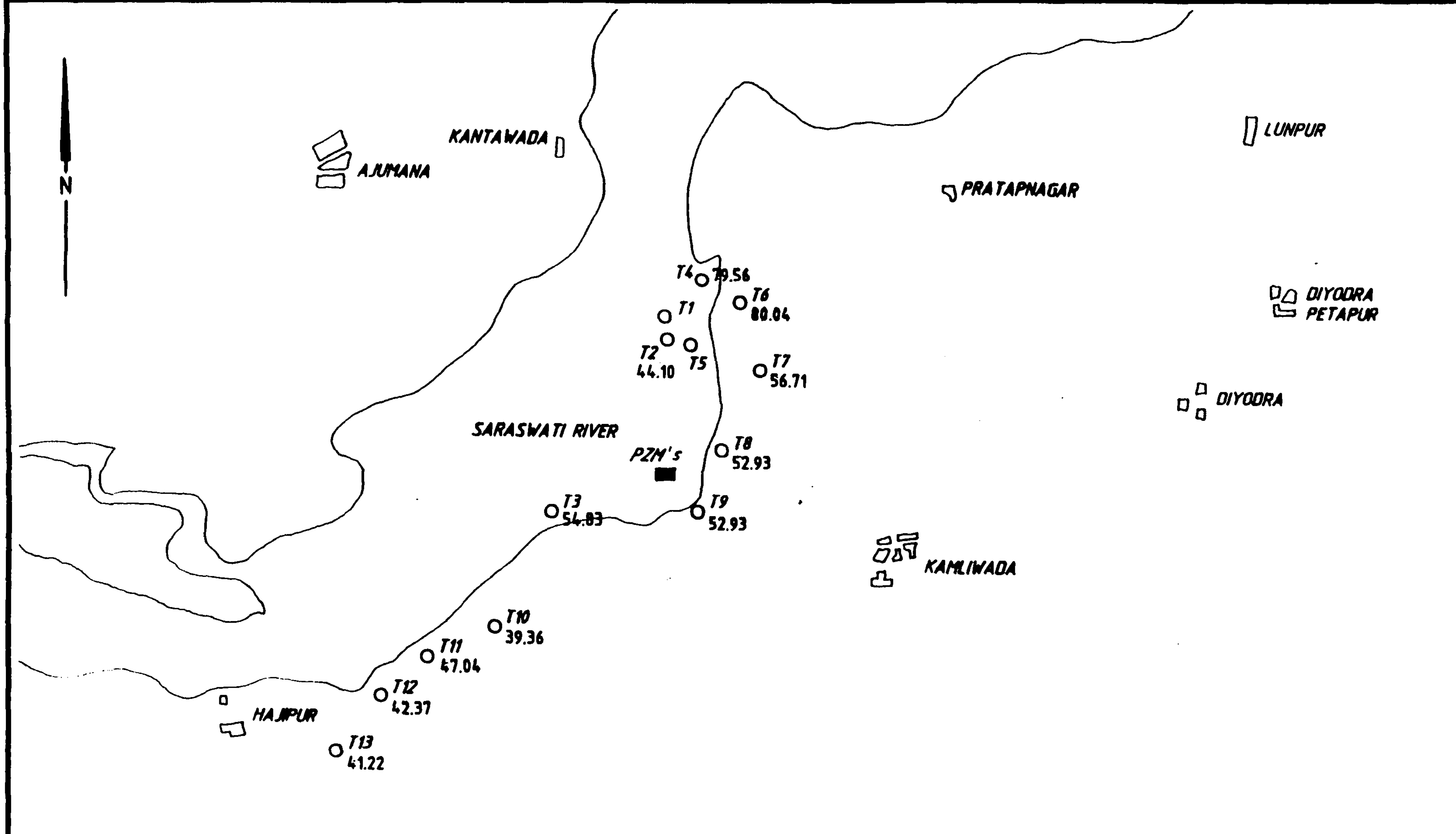

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FIG. NO. 25

STATIC WATER LEVELS
KAMLIVADA
m ABOVE msl AT 04/91

Bestell-Nr. 5154

5. CONCLUSIONS

- History of the Groundwater

Pair-wise comparison of the H-2/O-18 values of Shihori and Kamlivada indicate clearly that both well fields have a common source area. However, processes in the underground result in chemically different types of deeper (older) groundwater in Shihori and Kamlivada. Regarding the relative short lateral distance and the common source, the cause of these differences must be found very locally around the well fields and upstream from the well fields. The area around and northeast of Patan has a high level of groundwater development for irrigation whereas the area north and northeast of Shihori is less developed to this extent. During irrigation, large amounts of water are used and water with high evaporation characteristics (more negative O-18 and H-2 levels) infiltrates in the underground. Since water levels around Patan are extremely low, percolating groundwater has to travel a longer distance during which water with recent water characteristics (more negative C-13 and larger C-14) is added, reaching finally the deeper groundwater.

Taking into account the results from the chemical analysis, the latter phenomena is only occuring in Kamlivada and not in Shihori. In Kamlivada we have to do with a leaky aquifer with a stronger vertical flow component than in Shihori. The different water levels in the aquifer must be caused by the excessive irrigation from the deeper aquifers in the region around Patan.

The absolute age of the water is difficult to determine, since it requires several assumptions to be made. An estimation however, is that the shallow groundwater (up to 30 m) is not older than 30 years whereas the deeper groundwater (up to 250 m) can be several thousands of years old. Based on the distance between the location of the well fields and the source area (Aravalli mountains) and the regional hydraulic gradient the age of the water is estimated to be around 500 to 1000 years. This means that the deeper aquifers are not really replenished and contain relatively old water.

- Water Levels

The whole area is facing rapidly declining groundwater levels due to mining of deeper groundwater for irrigation purposes. It is clear that continuous mining of deep groundwater will exhaust the intermediate aquifers, especially those with relative good quality water. Both well fields of Shihori and Kamlivada have a small production compared to the production from the many irrigation tube wells around the well fields. Therefore, the rapidly declining groundwater levels are due to the enormous amount of irrigation tube wells which are productive in the region.

The well fields are not immediately affected by declining water levels since well diameters allow for adjusted pumpsetting. However, on the long term, energy consumption will increase and the quality of the water will deteriorate. There is no way to stop the general decline in water unless pumping for irrigation can be limited. It is therefore required to insist permanently on the necessary restriction for pumping for irrigation.

- Quality of the groundwater

  In general the quality of groundwater in the region of the well fields is reasonable except for the locally elevated fluoride levels. However, in both well fields the quality of the groundwater is deteriorating, probably caused by the declining groundwater levels. The Shihori well field has a better quality groundwater than the Kamlivada well field although the latter has not yet been taken into production. The area east and south-east of Kamlivada is known for its deteriorated and rather saline groundwater. The development of the waterquality in tube wells around the well field indicate that a deterioration of the waterquality in the tube wells of the well field can be expected, when taken into production.

- Fluoride in Groundwater

  It appears that even after extensive investigations, the origin of the fluoride and the cause of the fluctuations can not be well established.

  Several mechanisms and processes have been proposed which could influence the fluoride levels in samples from tube wells and piezometers. However, the role of the different processes and their relevance is not yet clear. Further investigations might reveal these, but go beyond the aim of these investigations for the Santalpur and Sami Harij RWSS.

  In the Shihori well field, the highest fluoride levels are found above the less permeable layers whereas in the Kamlivada well field the high fluoride levels are found directly below these layers. The latter may be induced by the higher vertical flow component in the Kamlivada well field due to lower hydraulic pressure and deep groundwater levels.

  Initially high fluoride levels found in recently constructed piezometers in Shihori as well as Kamlivada decrease in time when the piezometer is left in rest. The disturbance of the underground, by the introduction of mud (clay minerals) invading the aquifers and the exposing of the tapped aquifer to the open air apparently has a considerable influence on the fluoride levels.

  Monitoring of tube wells and construction and monitoring of piezometers on a regular basis appears to be very useful in obtaining hydrogeological and geochemical information. This information has already proven to give a better and broader insight in subsurface processes and can be used in long term planning of suitability and availability of groundwater resources.

6. RECOMMENDATIONS

- Monitoring existing tube wells

The monitoring of waterlevels and waterquality on a regular base should be continued. This monitoring should be carried out on the existing watersupply tube wells, irrigation or watersupply tube wells in the region surrounding the well field and on piezometers.

Annex VI gives a detailed monitoring programme for the Santalpur and Sami Harij Regional Water Supply Schemes.

- New Wells Shihori

Regarding the results from the samples from the piezometers it is not advised to construct and exploit the new well field as has been proposed by GWSSB. Two or three new wells could be constructed along the riverbank. The wells should be constructed with a depth of 204 meters and a diameter permitting to lower the pump down to the bottom. The wells should be screened from 95 to 204 m bgl with exception of the layer from 135 to 170 m bgl. The space around the casing should be sealed from 135 to 170 m with clay. A clay plug of 5 m has to be provided around the casing above the first screen in order to provide contact with the upper aquifers.

In order to increase the capacity on the long term, the following actions are recommended:

- A detailed desk and field survey of existing high TDS and low fluoride wells between Radhanpur and Varahi and along branches should be carried out in order to explore possibilities for injecting water into the network to reduce the level of fluoride and to increase the production capacity.
- Exploration of the feasibility to supply water from the resources of the Deodar RWSS at approximately 30 km.
- An overall study on the possibility to use the Sipu reservoir at approximately 50 km for the supply of surface water to the scheme.

- Future Kamlivada Well field

In view of the quality of the water of the irrigation tube wells in the region and the possible development of the waterquality in the tube wells of the well field, possibilities of alternative waterresources should be investigated. An inventory of tube wells near to the well field or mains should be carried out and tube wells with acceptable quality water should be monitored. If results appear to be positive, the possibility of connection of these tube wells to the scheme is to be considered.

On the long term, other possibilities of water supply should be investigated and evaluated. The possibility of water extraction of larger depth is worthwhile to investigate.

Since it is expected that groundwater will further deteriorate, the possibility of using surface water should be considered as well.

In general it is recommended to insist permanently on further restriction of groundwater abstraction for irrigation.

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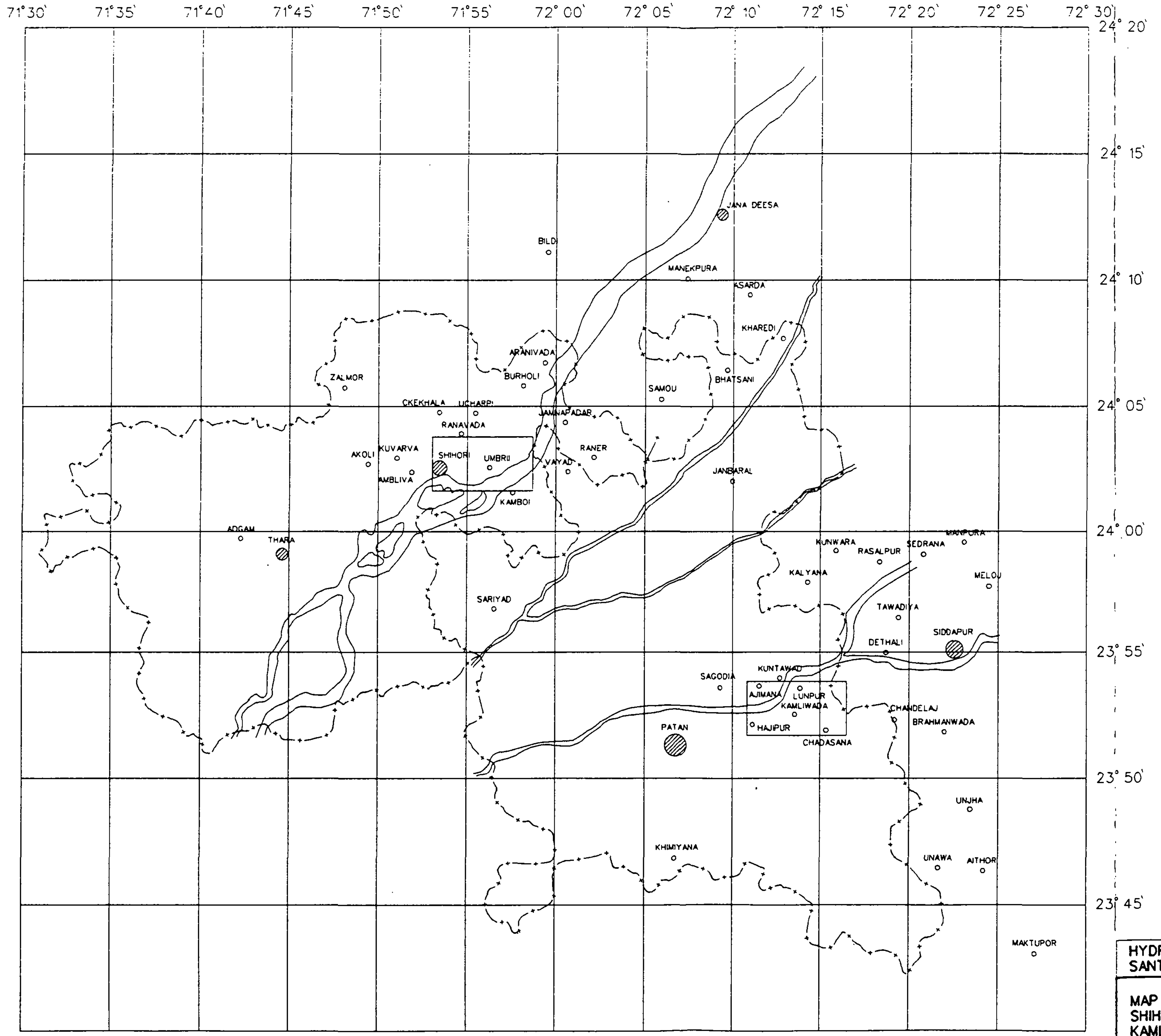
Annex I

MAP OF THE PROJECT AREA WITH RELEVANT FEATURES



HYDROGEOLOGICAL INVESTIGATIONS
SANTALPUR AND SAMIHARIJ RWSS

MAP OF THE REGION OF THE
SHIHORI AND THE
KAMLIWADA WELLFIELDS

DATUM	GET.	CORR.	
24-2-1992	HH		
10-2-1992	HH		
SCALE	1:350.000		A/

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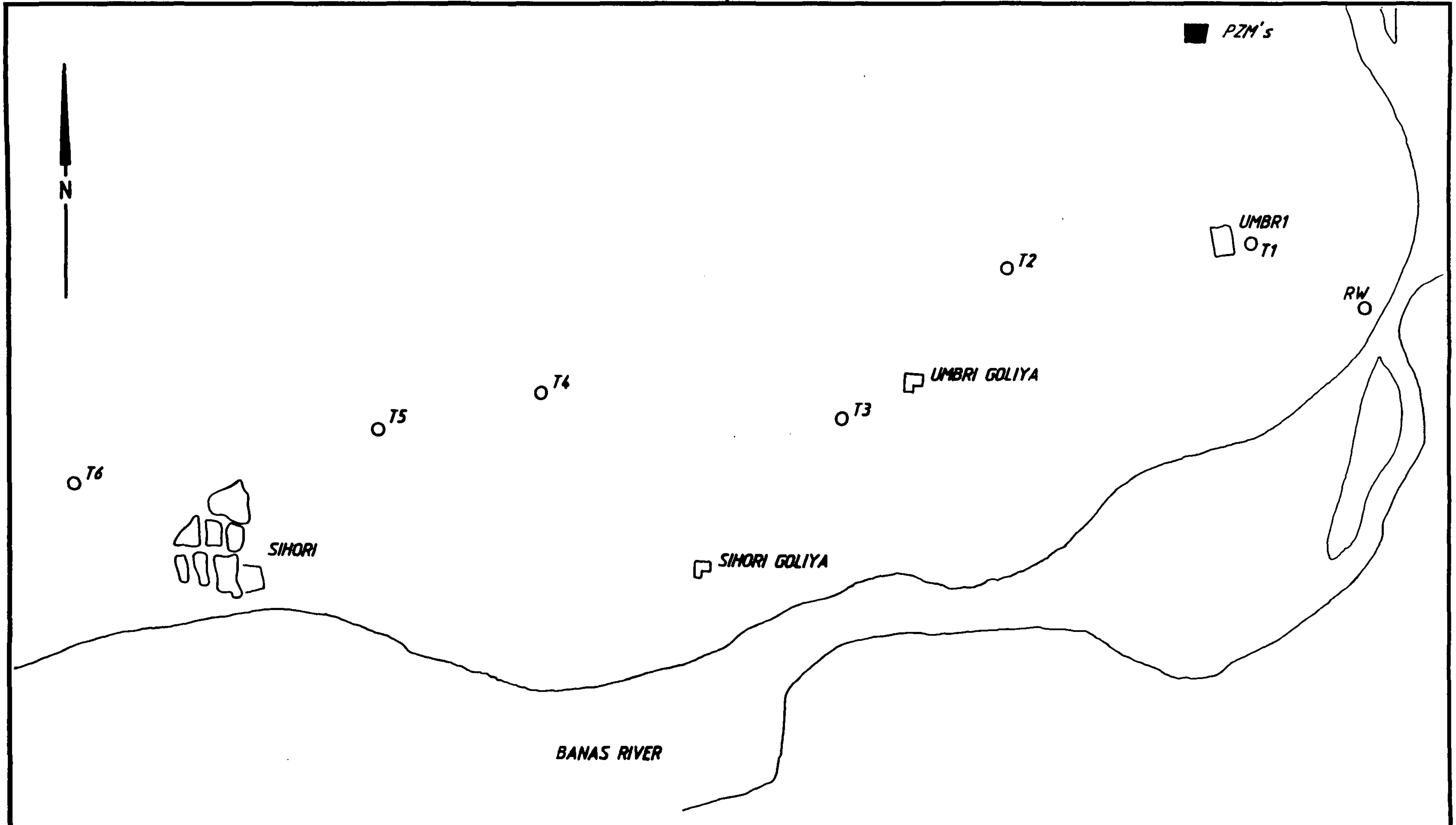

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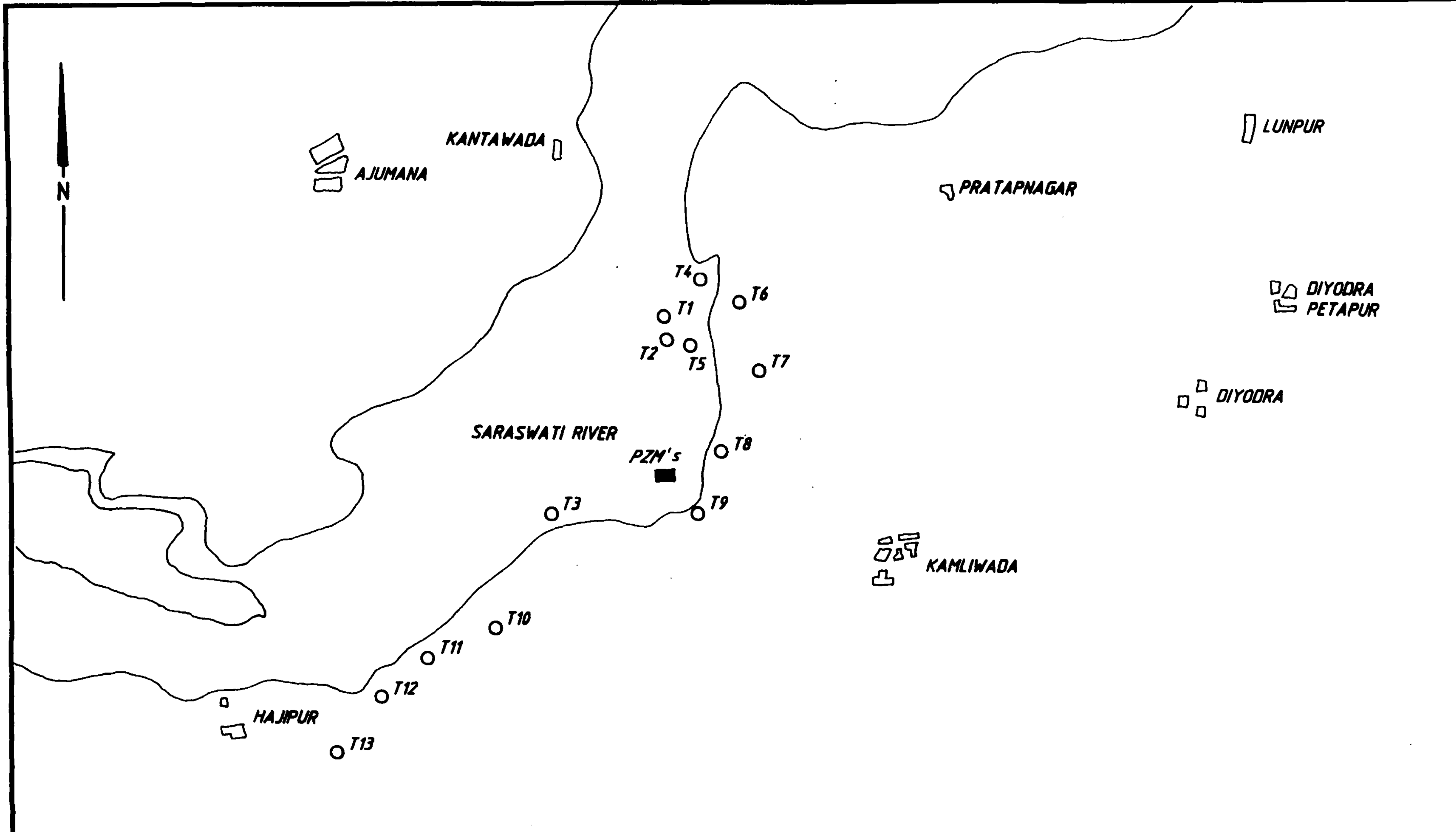
AREA OF
THE SHIHORI
WELL FIELD

Date	Drawn	Check
12-03-92	msa	

Scale 1 : 30.000



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AREA OF
THE KAMLIVADA
WELL FIELD

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Annex II

DISCUSSION ON THE ORIGIN OF FLUORIDE

Danger of high fluoride content of drinking water has only been recognised for 20 to 30 years. Since then numerous investigations and publications have been done on this subject. In general, it is known that fluoride is one of the rare components of groundwater which has a beneficial as well as a toxic effects, each of which have extreme important public health implications. Excessive fluoride consumption can lead to dental fluorosis and skeletal fluorosis and several other less serious complaints.

Fluorine does not occur in free form since it has a very high electro-negativity which means that it is very reactive. Its occurrence in nature is in solution in (sea)water and in rock as mineral (fluorite, fluorspar, cryolite and apatite). In soils it is mostly associated with clay minerals (mica's) or present in the weathering products of fluoride rich rock.

Fluoride concentration in groundwater depends on [4]:

- Presence of fluoride bearing minerals and gasses
- Weathering process
- Evaporation
- Calcium concentration

Approximately 150 fluorine bearing minerals are known according to Strunz [4]. Table II-1 lists groups of minerals which contain fluorine, the number of distinct minerals which contain fluorine and the most important examples of each group.

Table II-1 Fluorine bearing minerals

Mineral Group	Number	Major examples
Silicates	63	Amphiboles, Micas
Halides	34	Fluorite, Villiaunite
Phosphates	22	Apatite
Others	30	Aragonite

Also gasses (vulcanic) which are produced during the degassing of a magma, may contain fluorine as in HF, SiF_4 or H_2 Si F_6. In these vulcanic gasses, fluorine may reach a concentration of several thousands of ppm.

Fluoride can only occur in groundwater if fluorine bearing gasses and/or minerals are present. The concentration however, also depends on climatological and geochemical processes and conditions in the area under consideration.

The process of the formulation of fluoride rich waters has been extensively discussed [4] and may be schematized as in fig. II-1 [4].

If fluoride bearing minerals are present, the addition of CO_2 may lower the pH enhancing the weathering of these minerals. Evaporation may also increase the fluoride content if the solution remains in equilibrium with calcite and alkalinity is greater than hardness.

If fluorite is present, its solubility increases during hydrothermal processes with increasing temperature.

Also the dissolution of HF gas may increase the fluoride content. Dissolution of evaporative salts on the service may be an important source of fluoride.

For the Gujarat region several mechanisms have been suggested to explain the occurrence high concentrations of fluoride.

- The main cause, forming the baseline concentration of the present fluoride, is precipitation of the fluoride from the saline waters which during subsequent geological periods covered considerable parts of Gujarat State. Concentration of fluoride in sea water is around 1.3 ppm. Subsequent flooding of considerable areas and subsequent evaporation caused precipitation of fluoride. The general seasonal increase of the fluoride concentrations in the ground water during and after monsoon is caused by the leaching of the fluoride by infiltrating and percolating rainwater.

- As a second cause the ion exchange with hydroxide ions in clay minerals, abundantly present in the underground, has been mentioned. In some cases weathering of clays is mentioned which can be considered as a similar mechanism. Groundwater in this area is slightly alkaline (pH between 7.5 and 8.5) which might force an ion exchange of the fluoride and hydroxide ions which have comparable ion-radius and similar electronegativity.

- As a third cause the leaching of fluoride from igneous rock in the hilly region in the north-east and north of the State has been mentioned. Rainwater causes leaching of fluoride from the igneous rock (the rock type relatively containing the highest fluoride content) which then infiltrates the outcropping aquifers in the north-east of the State and moves with the general flow towards the south-west. However, this would imply a decreasing concentration of fluoride in south western direction which can not be observed.

- As a fourth cause direct leaching of fluoride from the sediments is mentioned. Alluvium consists for a considerable part of weathering products of the high areas in the north and east of Gujarat. These areas are known to consist of igneous and metamorphic formations. The fluoride content of these formations is relative high, resulting in a relative high fluoride content of the weathering products forming the alluvium.

  More to the south of Gujarat, in the Baroda district, high fluoride levels are caused by solution of fluorite from the fluoride rich rock (quartzite), underlying the area. In this area of Gujarat, also fluorite (CaF_2) mines are present. [21]

  In the western part of the Sabarkantha district in the east of Gujarat, also high level fluoride concentrations have been found. These are thought to associated with the presence of fluorite, apatite and fluor apatite in igneous and metamorphic rocks nearby. [19]

  Although not investigated, it may be clear that in the hardrock areas fluoride concentrations are more likely to be caused by direct leaching of fluoride from the weathered upper layer of the rock, which is accessible to circulating groundwater. In the alluvial areas, high fluoride concentrations more likely originate from marine sediments and from fluoride present in the weathered material. However, no thorough investigation has been made so far whether the fluoride occurs in the alluvium, whether it has been flushed in and to which depth it occurs.

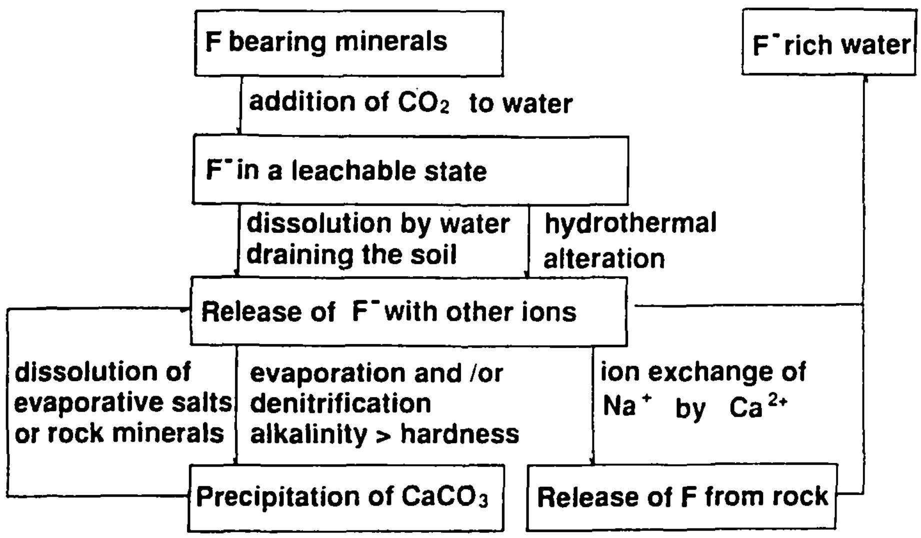


Fig II-1 Formation of fluoride-rich water [4]

Annex III

REGIONAL GEOLOGY AND HYDROGEOLOGY

BACKGROUND OF GEOLOGY AND GEOHYDROLOGY

Regional Geology

Of the total area of the State of Gujarat, 55.8 % consist of hardrock and 44.2 % is alluvial area. Due to flooding by seawater of considerable parts of Gujarat during subsequent geological periods, 17.7 % of the total area (mainly alluvium) is saline (fig. III-1). [16]

The flooding mainly has been caused by vertical movements of land mass causing transgressions and regressions which continued almost until recent periods. During the Miocene and Pliocene periods, medium scale tectonic movements along almost north-south and east-west oriented faults and deposition of thick tertiary formations took place in the slowly subsiding troughs along these lineaments. On top of these formations alluvium and mixed fluviatile and aeolian formations were deposited. These Quaternary sediments occupy the region in which the two well fields under discussion are located. In the south towards the coast, these formations have a thickness in the order of 700 m. To the north their thickness decreases to approximately 600 m in the area of the Kamlivada well field and 300 m in the area of the Shihori well field and diminishes to 50 m in the hilly region, Aravalli mountains, in the north of Gujarat.

These formations being mixed eolian and fluviatile and marine deposits are generally high in silt content. They are predominantly composed of clay, silt and sand with kankar (calcareous concretions) and show a great variation in character and composition. Towards the hilly region, the proportion of gravel pebbles and boulders increases. This high region in the north-east, forming the border with the State of Rajasthan mainly consists of igneous and metamorphic formations. Fig. III-2 gives a schematic cross section through the central basin. [16]

Regional Hydrogeology

In the project area, alluvium occurs upto a depth of approximately 500 m. In general they have a poor permeability and the transmissivity values vary between 50 and 600 m^2/day. In the upper aquifers, ground water occurs under phreatic conditions. In deeper horizons it occurs under semi-confined and confined conditions. The aquifers have their recharge zone in the piedmont terrain in the north-east. Aquifers coalesce into one phreatic aquifer in the recharge area, but are identified as separate aquifers in the central part of the alluvial basin and in the discharge zone towards the west and south-west, fig. III-3 [16]. The general direction of the ground water flow is north-east to south-west induced by the high terrain in the north-east, as indicated in fig. III-4 [16]. In close cooperation with UNDP, CGWB developed a schematised model of the underground of central Gujarat (basin filled with alluvium) and which since then has been widely used and is now officially adopted. Two major aquifer units have been identified in the Gujarat plain within the depth of 600 m below surface. The upper unit designated as aquifer A, is mostly phreatic, but becomes semi- confined to confined in some parts of the area under discussion.

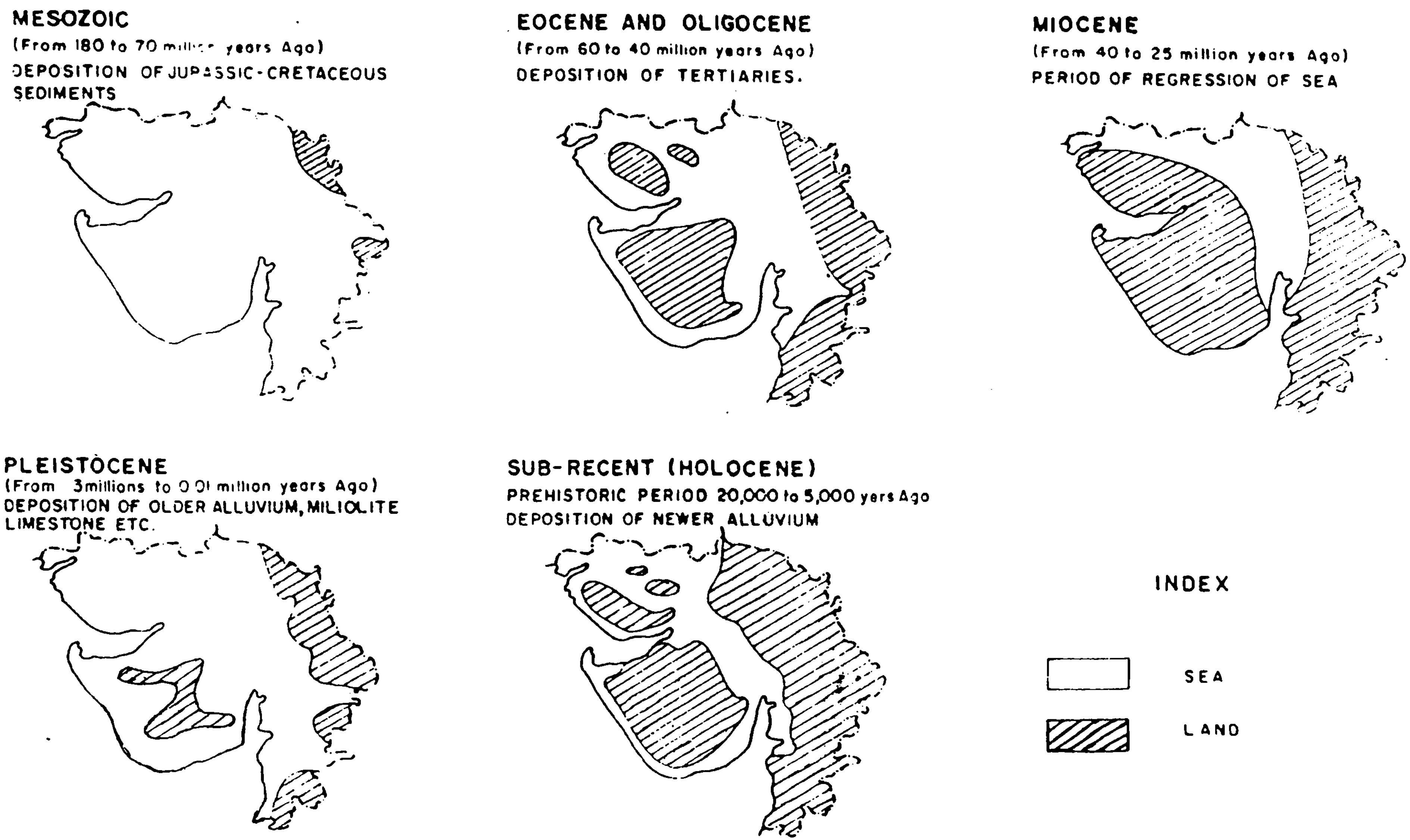
The lower unit comprises a few hundreds meters of alternating sandy and argillaceous beds, forming a confined aquifer system. It is sub-divided into aquifers B,C,D and E in post-Miocene deposits and aquifers F and G in the Miocene sediments. The post-Miocene aquifers are mainly coarse to fine sands, with occasionally gravel beds (aquifer B) whereas the Miocene aquifers are mainly fine- to medium grained sand and sandstone, interbedded with clay, claystone and siltstone.

Aquifer A is the most extensive aquifer in the project area and consists of fine to medium grained sand in the central part of the basin. It has a thickness of approximately 125 m in the central part where semi-confined and confined conditions occur. This unit can be sub-divided in three aquifers A1, A2 and A3 being respectively the phreatic aquifer, the first confined and the second confined aquifer with subsequent thicknesses of 10 to 35, 20 to 40 and 20 to 35 m. The first aquifer of the A unit is thought to be of eolian origin whereas the deeper aquifers of the A unit are from marine and fluviatile origin. The depth of the water table in general is 5-10 m but can increase to a depth of 20-25 m in the central area. Seasonal fluctuations in the water table are in the range of 0.5-3 m. Decline of water levels due to overpumping is about 1.5 m. Borehole measurements revealed that transmissivity varies between 30 and 1000 m^2/day. Aquifer A is the most extensive exploited aquifer.

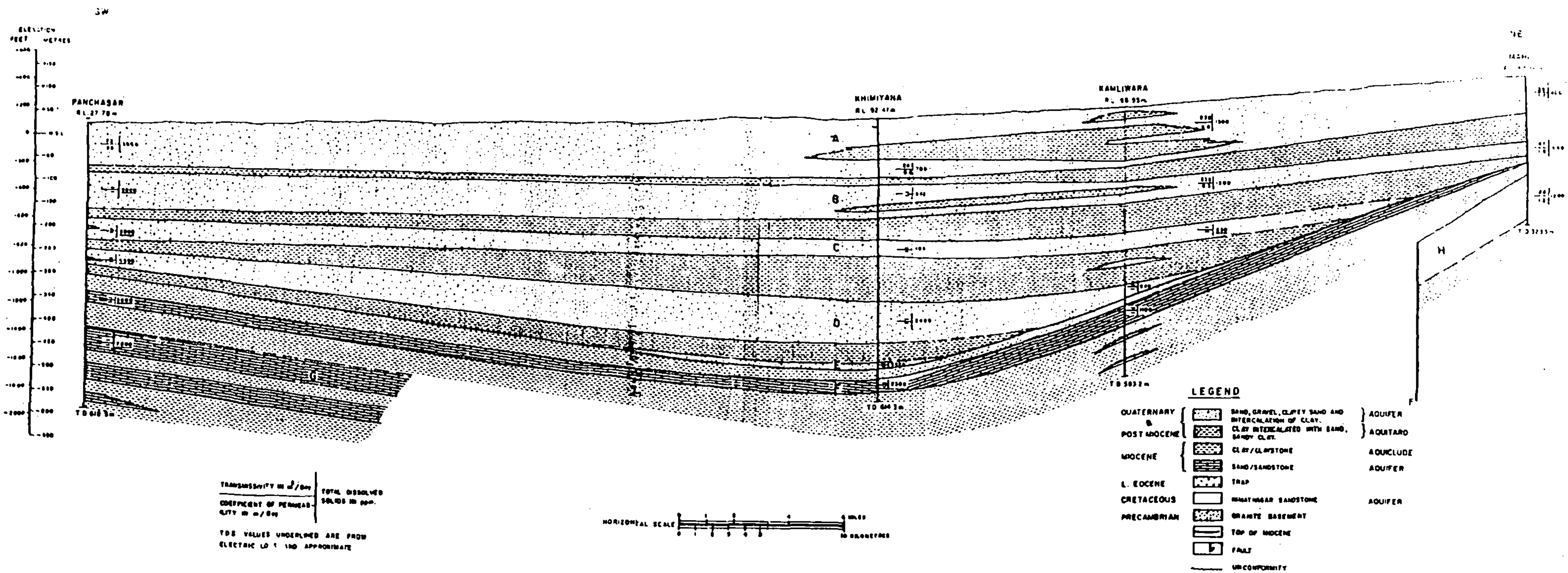
Aquifer B is the uppermost confined aquifer and consists of coarse grained sands and gravels locally interlaid with clay lenses. Its thickness ranges upto 80 m in the central part of the basin. Waterlevels exceed 20 m below ground level in the central part and seasonal fluctuations can be as much as 25 m. Transmissivity values are between 47 and 3400 m^2/day with most between 200 and 600 m^2/day. Aquifer B ranks second in rate of exploitation.

The quality of the water in both aquifers is generally good. The quality of the ground water deteriorates towards the west and with increasing depth. Salinity increases resulting in high TDS values and high chloride- and sulphate concentrations.

MAP OF GUJARAT SHOWING POSITIONS OF SEA AND LAND DURING VARIOUS GEOLOGICAL PERIODS



HYDROGEOLOGICAL INVESTIGATION SANTALPUR + SAMI HARIJ RWSS		FLOODING OF GUJARAT BY SEAWATER	Date: 13-03-92 / Drawn: mse / Check / Scale
HASKONING Royal Dutch Consulting Engineers and Architects P.O. Box 151 · 6500 AD Nijmegen · The Netherlands Barbarossastraat 35 · Telephone +31(0)80 284284 Telefax +31(0)80 238340/242101	FIG. NO. III-1		



HYDROGEOLOGICAL INVESTIGATION SANTALPUR + SAMI HARIJ RWSS		GEOLOGICAL CROSSSECTION KAMLIVADA AREA	Date	Drawn	Check
HASKONING Royal Dutch Consulting Engineers and Architects P.O. Box 151 - 6500 AD Nijmegen - The Netherlands Barbarossastraat 35 - Telephone +31(0)80 284284 Telefax +31(0)80 239346/242101	FIG. NO. III-2		13-03-92		
			Scale		

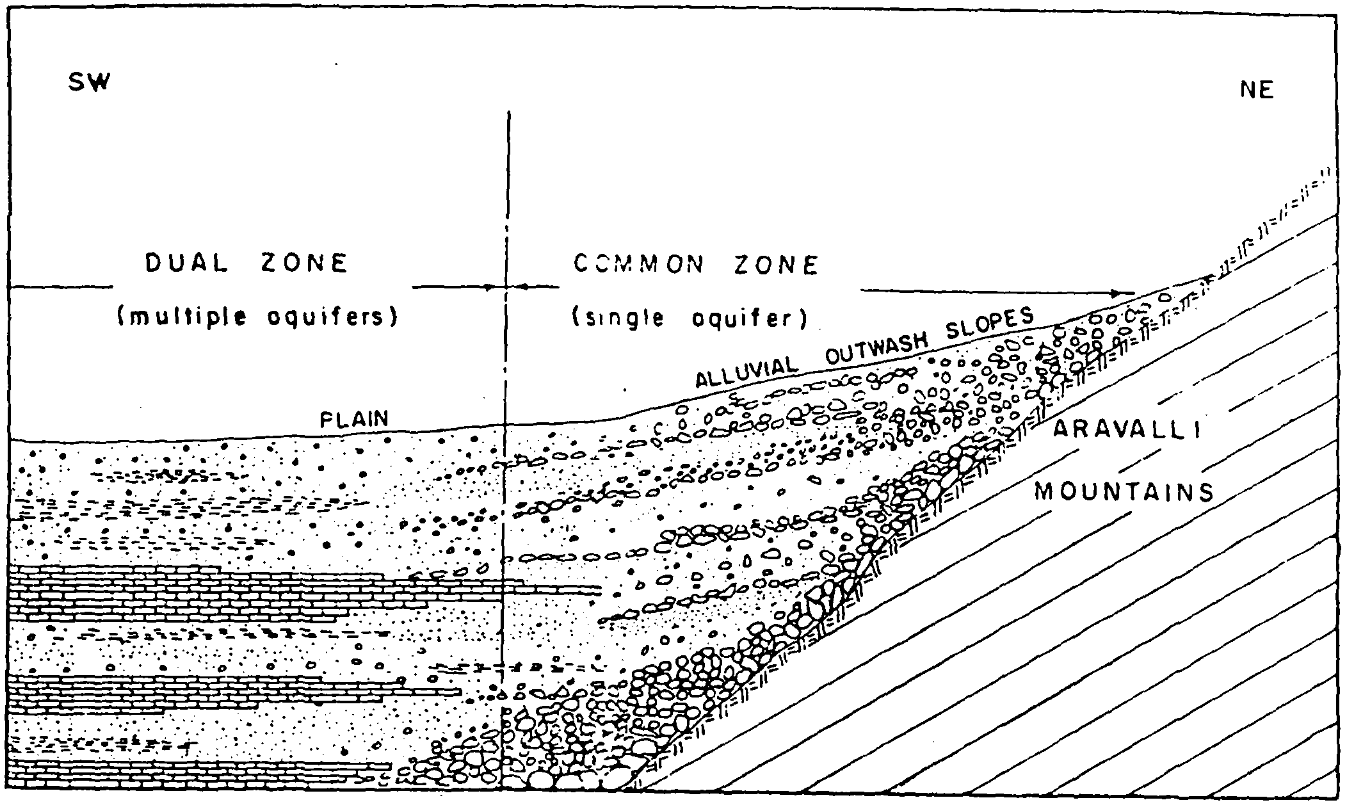


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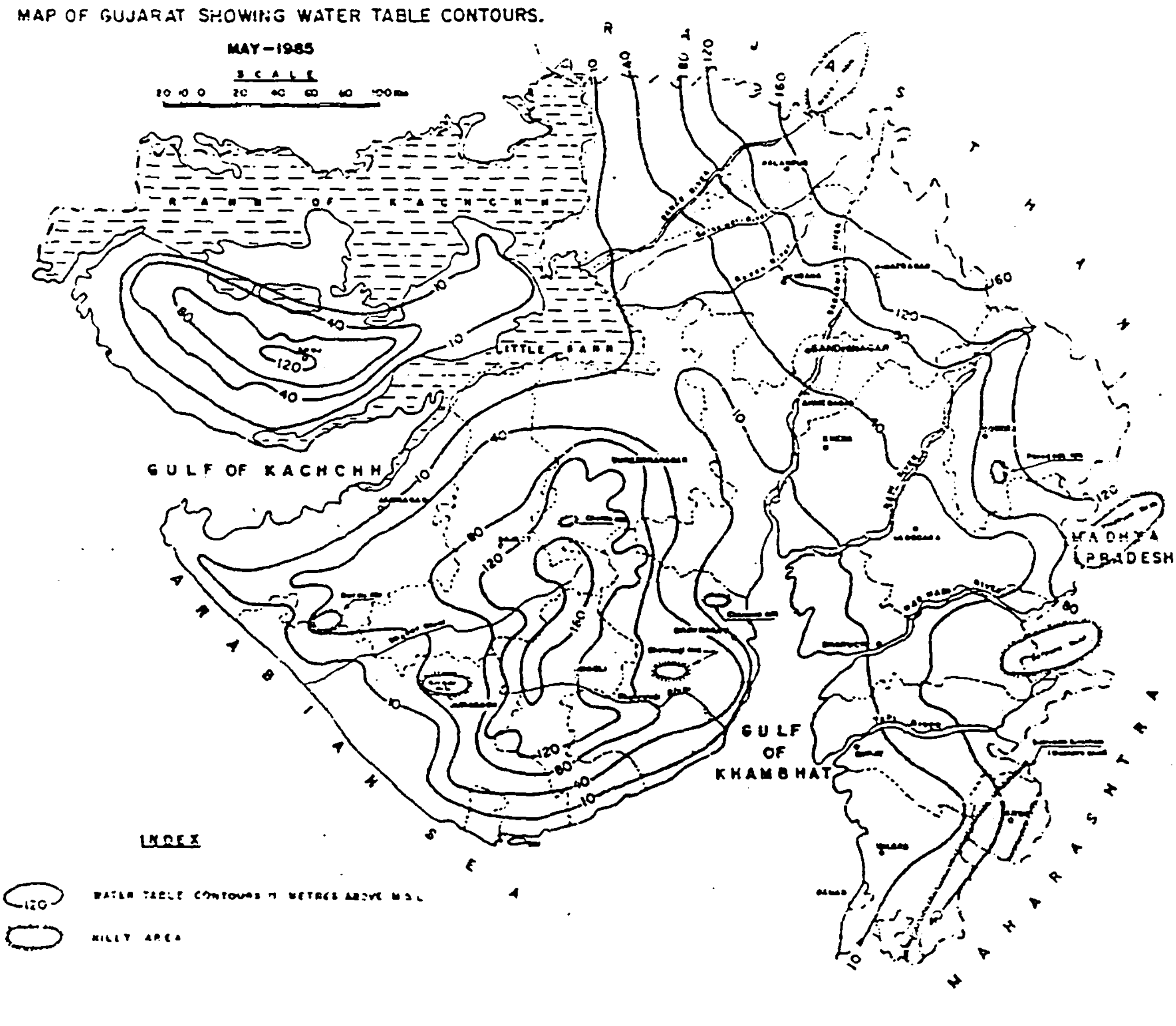
FIG. NO. III-3

SCHEMATIZED CROSSSECTION THROUGHT THE AGUIFER SYSTEMS IN NE. GUJARAT

Date	Drawn	Check
13-03-92	mm	

Scale



HYDROGEOLOGICAL INVESTIGATION SANTALPUR + SAMI HARIJ RWSS		WATER LEVELS CONTOURS GUJARAT MAY 1985
HASKONING Royal Dutch Consulting Engineers and Architects	FIG. NO. III-4	

Date	Drawn	Check

Annex IV

REPORT ON THE CONSTRUCTION OF PIEZOMETERS IN THE SHIHORI WELLFIELD

Note on Drilling of Piezometers [redacted] at village Shahori (Santalpur Regional Water Supply Scheme).

Due to continuous drop in water levels on a regional scale in Santalpur area and also contineous increase in Flouride values of water. Dutch Mission in consultation with GWSSB. suggested drilling of multiple piezometers in the area vide GU-24 AID MEMOIR Dt. 15th April 1991. for constant monitering of water levels and quality.

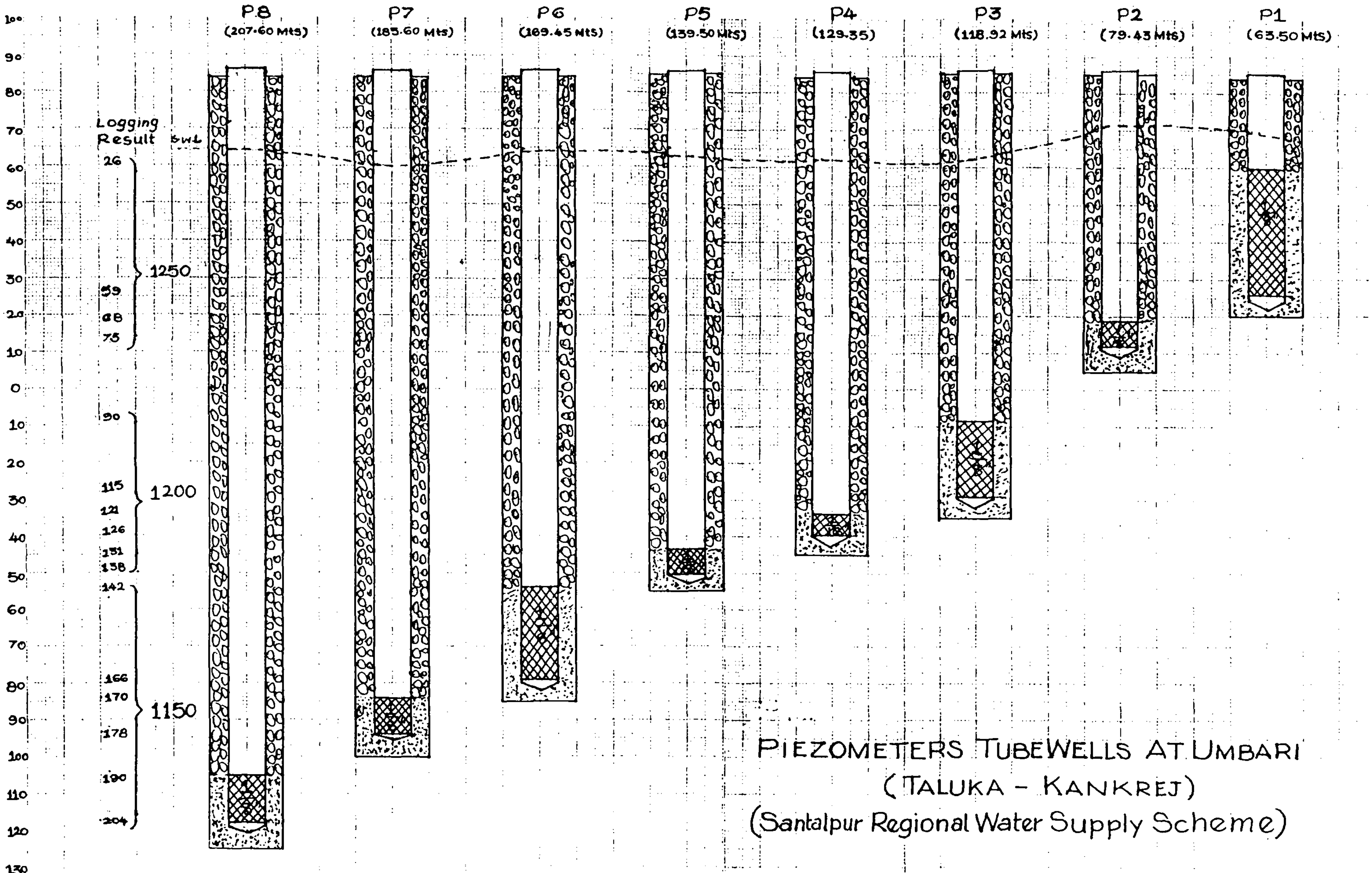
Accordingly 8 numbers of piezometers sites were selected (based on 8 number of aquifer/zones tapped in the master well) at 25 mtrs apart, near Master well. As per the recommandations. Only one zone is tapped in each piezometer so as to monitor water levels and quality of water of each zone and thus unwanted zones may be discarded.

So far drilling of all the 8 number of tubewells (piezometers) is completed and monitering work is take-up on hand.

The data recorded so far is as under:-

Sr. No.	Piezometer Number	Depth of Piezometer	Zones Tapped	Static Water Level	'F' contents	Date of Analysis
1.	2.	3.	4.	5.	6.	7.
	Pz1	Details awaited.	27.60 mt.	Details	awaited.	
2.	Pz2	80.0 mt.	68.5-76 mt.	-do-	-do-	-do-
3.	Pz3	119.0 mt.	95.0-115.0 mt.	26	1.72	24.6.91
4.	Pz4	129.0 mt.	120.0-[illegible] mt.	[illegible]	[illegible]	[illegible]
5.	Pz5	140.0 mt.	130.0-[illegible] mt.	[illegible]	2.00	16.6.91
6.	Pz6	170.0 mt.	140.0-166.0 mt.	[illegible]	1.50	26.[illegible].91
7.	Pz7	186.0 mt.	170.0-[illegible] mt.	[illegible]	1.70	22.5.91
8.	Pz8	220.0 mt.	190.0-[illegible] mt.	[illegible]	1.26	1.[illegible].91

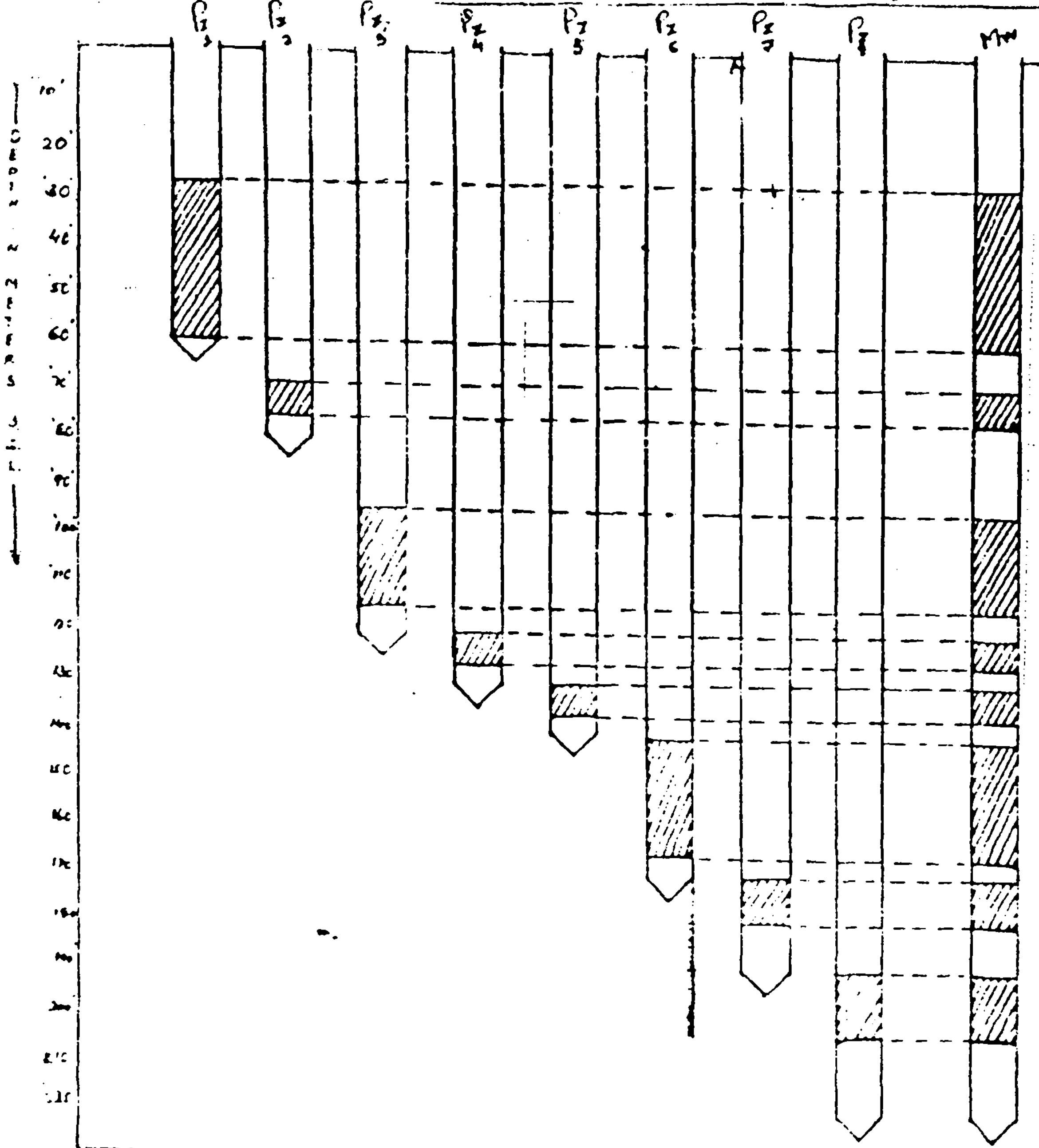
The details of cross section of Piezometer Test at Shihori (Santalpur Reg. Water Supply Scheme) is attached herewith for reference, record and study.



PIEZOMETERS TUBEWELLS AT UMBARI
(TALUKA - KANKREJ)
(Santalpur Regional Water Supply Scheme)

SCALE
VERTICLE : 1 : 10 (cm : Mts)

DETAILS OF PIEZOMETERS DRILLED AT SAMORI FOR SANTALPUR REG SCHEME SHEET 15.



DATE	SWL	FLOURIDE (PPM)
24.6.91	76'	1.72
4.6.91	76'	2.0
16.6.91	75'	1.80
26.5.91	73'	1.50
22.5.91	72'	1.50
1.4.91	69'	1.76

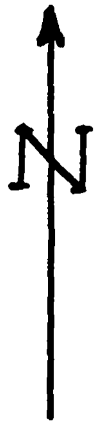
GWSSB
Gandhinagar

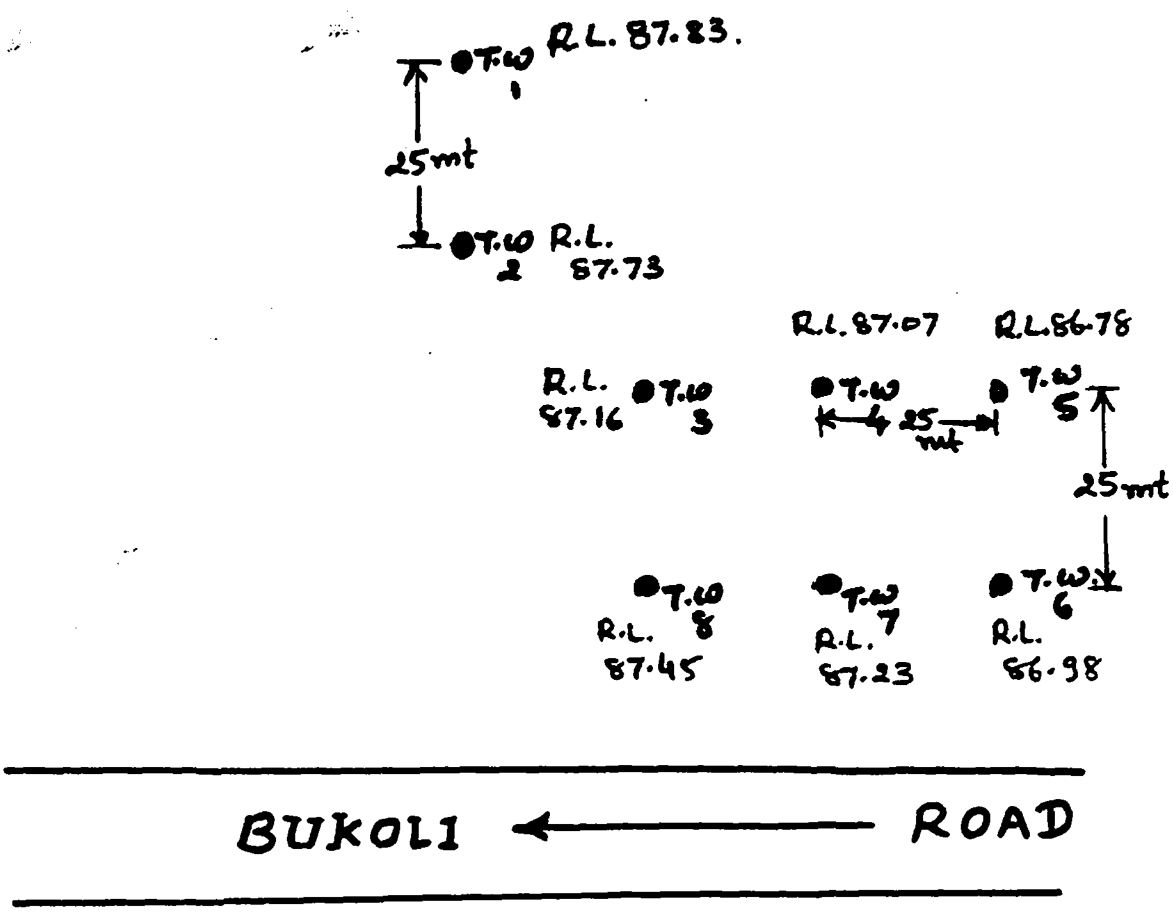
Santalpur Reg. W/s Scheme.
Piezometer Field (Nos of Tubewells eight)
Near vill. Umbari - Bukeli.

Piezometer TW 4" ɸ →	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8
1. Total depth drilled/cased	63.5 mt	81.00 mt	120.0 mt	129.5 mt	141.0 mt	171.0 mt	189.00 mt	218.00 mt
2. Date of completion.	3-6-91	20.6.91	24.6.91	4-6-91	16-6-91	26-5-91	22-5-91	1-4-91
3. Zones taped.	27.60 mts.	68.5 to 76.0 mts	95 to 115 mts.	120.0 to 126.0 mt	130 to 137.0 mts	141 to 166 mts	170.0 to 180.0 mt	190.0 mt to 204.0 mt
4. Discharge by compression	-	-	-	-	-	-	-	-
5. Water Level.	15.62	16.55	24.85, ~~75~~	24.90, ~~76~~	24.45 ~~75~~	23.86 ~~73~~	23.26 ~~72~~	22.50 ~~69~~
6. Top. R.L. of pipe.	87.83	87.73	87.16	87.07	86.78	86.98	87.23	87.45
7 Hight of pipe from G.L.	1.01 mt	0.92 mt	0.85	0.98 mt	0.91 mt	1.01 mt	0.89 mt	0.89 mt
8. R.S.W.L.	72.43	71.18	62.31	62.17	62.33	63.12	63.37	64.95
9. Chemical Analysis.								
(A) T.D.S.	608	650	368	348	324	410	530	470
(B) Fluoride	0.86	3.75	1.5	2.04	1.5	1.5	1.5	1.76

...ve Engine...
...Sub Division
...W. S. S. Board

LOCATION OF
PIEZOMETER TUBEWELLS
NEAR BUKOLI - UMBRI VILLAGE
SANTALPUR AUG. EXTENSION
REG. W/S SCHEME





Deputy Executive Engineer,
P. H. ... Division,
G. W. S. & ... Board.

Annex V

REPORT ON THE CONSTRUCTION OF PIEZOMETERS IN THE KAMLIVADA WELLFIELD

Installation of piezo meter nest at the source area Hajipur-Kamlivada of Sami-Harij Reg.w/s/s, Dist Mehsana.

x x

Generals - Sami-Harij Reg. w/s/s , Dist. Mehsana is covered by 112 villages of sarivesure of Sami and Harij Taluka of Mehsana district. To supply drinking water to all villages, tubewells have been drilled in Hajipur-kamlivada field in sidhpur taluka of Mehsana district, situated near & on bank of Sarswati river, 5 tubewells drilled by G.W.W.B.(Named T1 to T5) and 8 tubewells drilled by GC.W.S.& S.B. (named T6 to T13). Out of 5 tubewells drilled by C.G.W.B T1 is having shallow depth i.e.only 57 mts, and T5 is having excessive flouride content. i.e. 5 to 4PPM, hence both tubewells have been rejected and remaining 11 tubewells willbe utilised for drinking purposes to villages of Sami-Harij R.W.S.S.

Details of each tubewell is attached in separate statement purpose & utility of piezometer nest :-

It is found that at number of places ground water quality is found deteriorated and there is general trend of ground water decline. To know the cause of such phenomena, it is necessary to have knowledge of individual aquifers in respect of W.L. & quality of water. In view of above, it is instructed by superintending Geo hydrologist, to start with the construction of piezometor nest at the source area Hajipur-Kamlivada and feasibility report. [illegible]

From the analysis of water levels from piezometer the direction of the Fluid potential gradient and the d dependent ground water flow may be determined. The piezometer nest is a group of piezometers located at different depth/ zones for determination of Fluid potential distribution with in the major aquifers as well . the enveloping aquitards under existing & fully stressed conditions. The piezometer is nothing, except 100mtm [illegible] bore tapping only one aquifer.

Design & construction of piezometer Nest :-

1. First studie the lithological log & strat chart of the all tubewells of SC, and prepared geological cross section of all tubewells & deter-mined individual maximum aquifers having vast horizontal extension, of Te.

2 On the basis of indentification of such aquifers, Nine (9) piezometers are required to tap such aquifers.

Following is the details of each piezometer (P) to be constructed having 100 mm dia pipe:

No. of piezometer	Aquifer tapped in T9 in mts.	Length of aquifer	Ele.log.result aquifer of T9 in Mts.	suggested depth for piezometer in Mts.
1	2	3	4	5
P1	25-37	12	25-45	55
P2	49-61	12	47-62	70
P3	76-82	6	76-87	95
P4	92-104	12	90-111	120
P5	143-152	9	133-152	160
P6	158-170	12	158-171	180
P7	176-188	12	176-189	200
P8	198-210	12	192-211	220
P9	216-222	6	216-219	230

Benefits of piezometer nest:

1 Variation in S.W.L. during pumping

2 Quantitative effect of pumping on each aquifer.

3 Aquifer wise quality monitoring

4 Aquifer wise confirmation of fluoride as increase of decrease.

5 Permeability capability of each aquifer through seive analysis.

6 Seasonal fluctuations & yearly effect in the area.

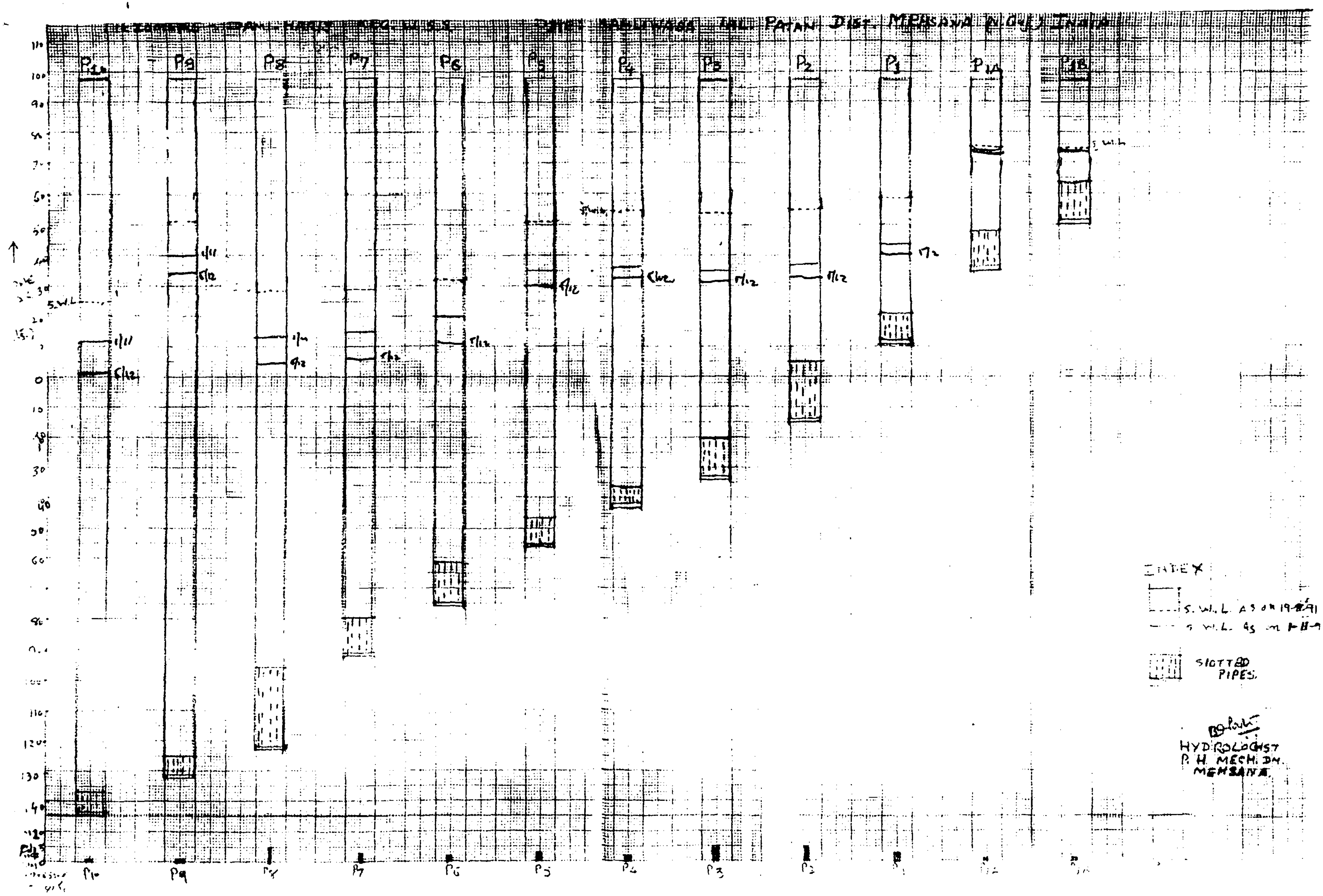
7 Better development of augmention in future.

8 Simulation of aquifer yielding & safe pumping rate in the area.

9 Effects of recharge after good precipitation.

~~Executive Engineer~~

Hydrologist
Public Health Mech. Dn.
Dn. MEHSANA.


PATAN DIST. MEHSANA (N.GUJ.) INDIA
P10
P9
P8
P7
P6
P5
P4
P3
P2
P1
P1A
P1B
S.W.L
INDEX
S. W. L. AS ON
S. W. L. AS ON
SLOTTED PIPES.
HYDROLOGIST
P. H. MECH. DN.
MEHSANA

Conclusion from Piezometers drilled near Kamlivada for Sami-Harij R.W.S.S. dist Mehsana.
Report of the hydrologist, P.H. Mechanical Division, Mehsana.

It is found that water quality is deteriorated due to excessive Fluoride in some aquifers and there is general trend of groundwater decline in the tube wells drilled in Kamlivada field for Sami-Harij Reg. W.S.S. dist. Mehsana. It covers 112 villages of Sami-Harij talukas aided by the Netherlands. Hence it was necessary to have knowledge of an individual aquifer characteristics in respect to static water level and quality of water. In view of above, piezometers work have been completed as per suggestion by the Netherlands expert.

On basis of data of source tube wells, first piezometer (P_{10}) was drilled near tube well No T9. (considered as masterwell) with maximum depth of 240 mts and then after, as per the Netherlands experts, other piezometers were drilled. Work of total 12 piezometers is now completed. After completion of work of piezometers, monitoring of S.W.L. & quality of water is already started from August 1991.

The details of monitoring data is attached herewith in separate statement.

Following are the details of piezometers showing the total depth (cased), tapped individual aquifer etc.

Syno.	Piezometer No.	Total cased depth in (mts)	Aquifer tapped in mts.
(1)	(2)	(3)	(4)
1.	P10	240.58	234.08-239.98
2.	P9	229.65	223.15-229.05
3.	P8	220.74	194.8-220.14
4.	P7	190.51	178.41-190.01
5.	P6	172.56	160-172.06
6.	P5	155.36	145.56-154.86
7.	P4	141.10	134.60-140.60
8.	P3	130.53	118.00-130.03
9.	P2	115.50	93-111
10.	P1	86.50	77.15-85.96
11.	P1A	62.50	50-62
12.	P1B	47.18	34.68-46.68

Conclusion:

Monitoring data regarding the S.W.L. & quality aspect, specially in fluoride, is situated & following conclusions are made from the piezometers.

1) Fluoride: It was found 1.5 ppm & less than that, which is considered maximum permissible limit in the piezometers having shallow depthbore i.e. 47 mts. & 63 mts. and in the deepest aquifer i.e. at 230 mts. & 240 mts. depth, while in piezometers of 87 mts. to 222 mts. depth fluoride was found more than 1.5 ppm, i.e. excessive limit during compressor test.

2) Static water level: (S.W.L.) From the study of S.W.L. data, following conclusion is made.

	period
(a) piezometer of 47 mts & 63 mts depth ... (shallow depth) S.W.L. around 23 mts	within 3 months
(b) piezometers of 87 mts to 155 mts depth... S.W.L. 43 mts to 60 mts	within 3 months
(c) piezometers of 172 mts to 240 mts depth... S.W.L. 66 mts to 82 mts	within 3 months

From above, it is noticed that there is decline in S.W.L. in the area. First S.W.L. was measured in August 1991 after compressor test of piezometers, i.e. during monsoon period. From monitoring of present S.W.L. data, it is observed that there is fall in S.W.L. in the area. The reason is expected due to completion of monsoon period & surrounding private tube wells have been started for irrigation purpose.

Annex VI

HYDROGEOLOGICAL MONITORING PROGRAMME

Hydrogeological Monitoring Programme

- Shihori

Monitoring of the tube wells of the well field can be continued as currently taking place: waterlevels every month and fluoride every three months. Every year one more complete chemical analysis should be carried out which might also be used to display the results in Piper diagrams. The latter requires the analysis of the following constituents: Na^+, Ca^{2+}, K^+, Mg^{2+}, NO_3^-, SO_4^{2-}, Cl^- and HCO_3^-. Additionally TDS and F^- should be analysed.

The same procedure should be carried out for the piezometers: waterlevels every month, fluoride analysis every three months and a complete chemical analysis once every year.

For the monitoring wells around the Shihori well field (in the villages Sudrosan, Anganwada, Jalmor, Ankoli, Adgam and Thara) it is necessary only to analyse fluoride every 3 months. The complete chemical analysis (elements for Piper diagram) should be carried out every year. In addition, also monitoring tube wells to the north and east should be selected and monitored according to the above. Ucharpi, Burholi and Raner should be added to the existing villages with monitoring tube wells. In this context, Adgam and Sudrasan can be excluded from the monitoring programme.

- Kamlivada

Monitoring of the tube wells of the well field must be continued. As soon as production starts, monitoring of waterlevels should be done on a fourth-night base. Monitoring of fluoride levels should be done on a monthly base. After a period of production of a year, monitoring can be continued as in Shihori: waterlevels every month, fluoride every three months and a complete chemical analysis (elements for Piper diagrams) once a year.

A selection of irrigation tube wells and water supply tube wells around the well field should be made in order to serve as observation tube well. Proposed tube wells for monitoring purposes are:

* Kamlivada	Village Panchayat Tube well
	ITW. no. 330
	" no. 436
	" no. 238
* Hajipur	ITW. no. 357
	" no. 175
	" no. 77
* Ajimana	ITW. no. 309
	" no. 174

It may be clear that these numbers are landsurvey numbers.

These wells should only be analysed on fluoride quality every three months and a complete chemical analysis (elements Piper diagrams) every year.

The piezometers in the well field should be monitored every fourthnight for waterlevels and fluoride for the first year and every three months for waterlevels and fluoride thereafter. Once a year a complete chemical analysis (elements for Piper diagram) should be made.

Thorough monitoring is very important and should be carried out simultaneously for all monitoring wells. This means that waterlevels of tube wells and piezometers should take place preferentially on the same day and at least in the same week. The samples for the general chemical analysis and for the fluoride analysis for all sampling points should also be taken within the timespan of a week.

Additionally it is proposed to collect data on the recharge conditions of the aquifers. Rainfall data should be obtained from nearby meteorological stations with at least one in the Aravalli mountains. The rainfall data should be available at scheme level.