PART OR WHOLE OF THE TEXT & THE
PLATES MAY BE REPRODUCED IN ANY WITH-
OUT THE PRIOR PERMISSION OF THE ONE
... ECWB.

DP/UN/IND-71-614/4

INDIA

RESTRICTED

GROUND-WATER SURVEYS IN RAJASTHAN AND GUJARAT

Technical report

UNITED NATIONS

Not to be Issued

(Library Copy)

DP/UN/IND-71-614/4

UNITED NATIONS DEVELOPMENT PROGRAMME

GROUND-WATER SURVEYS IN RAJASTHAN AND GUJARAT

INDIA

Technical Report

Prepared for the Government of India
by the United Nations,
executing agency for the
United Nations Development Programme

UNITED NATIONS
New York, 1976

NOTES

Abbreviations used:

agl	-	above ground level
AMH	-	available moisture holding
AMHC	-	available moisture holding capacity
AM%	-	available moisture percentage
atm	-	atmosphere(s)
B/C	-	benefit-to-cost ratio
bgl	-	below ground level
CAZRI	-	Central Arid Zone Research Institute
CEC	-	cation exchange capacity
cm	-	centimetre(s)
cusec	-	cubic foot per second
E	-	evaporation
EC	-	electrical conductivity
EDTA	-	ethylene diamine tetra-acetic
ESP	-	exchangeable sodium percentage
ESR	-	exchange sodium ratio
h	-	hour(s)
ha	-	hectare(s)
kg	-	kilogramme(s)
K	-	consumptive use factor
LSS	-	lower sub-soil
m^2/d	-	square metres per day (unit of transmissivity)
m^3/h	-	cubic metres per hour
$m^3/h/m$	-	cubic metres per hour per metre drawdown (unit of specific capacity)
mb	-	millibar
MCM	-	million cubic metres
meq	-	milli-equivalents
mm	-	millimetre
mmho/cm^2	-	micromhos per square centimetre
MSL	-	mean sea level
OH	-	observation well
O and M	-	operations and maintenance
P.E.	-	precipitation effectiveness
PH	-	piezometric hole
ppm	-	parts per million
psi	-	pounds per square inch
RSC	-	residual sodium carbonate
SAR	-	sodium adsorption ratio
SH	-	slim hole
TDS	-	total dissolved solids
topo	-	topographic
tr	-	trace
TW	-	tubewell
USGPD	-	United States gallons per day
U.S.S.L.	-	United States Salinity Laboratory
WHO	-	World Health Organization
WL	-	water level (water table)
yr	-	year(s)

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

DP/UN/IND-71-614/4

CONTENTS

		Page
INTRODUCTION		1
	A. Location and geography	1
	B. Project objectives and background	1
	C. Organization of the project	2
	D. Acknowledgements	2
	E. Summary and conclusions	2
I.	OPERATIONS AND METHODS	5
	A. Field and laboratory operations	5
	B. Methods of investigation	6
II.	GROUND-WATER RESOURCES IN THE RAJASTHAN PROJECT AREA	12
	A. Location and geography	12
	B. Climate	12
	C. Geology	27
	D. Ground-water basins	27
	E. Chemical characteristics of ground water	42
	F. Ground-water resources	52
	G. Pedology, land and water use	65
	H. Economic evaluation	85
III.	GROUND-WATER RESOURCES IN THE GUJARAT PROJECT AREA	109
	A. Location and geography	109
	B. Climate	109
	C. Runoff	117
	D. Geology and hydrogeology	123
	E. Chemical characteristics of ground water	129
	F. Ground-water resources	130
	G. Pedology, land and water use	147
	REFERENCES	161

Tables

1.	Number and type of wells drilled by the project in the Rajasthan project area	5
2.	Mean monthly climatological data	14
3.	Annual rainfall data, records and extrapolations 1901-1973	17
4.	Mean monthly rainfall distribution 1901-1973	17
5.	Variability of annual rainfall	18
6.	Probability of exceedence of annual rainfall	19
7.	Frequency of daily rainfall during the monsoon season, 1907-1972	20
8.	Variability of seasonal rainfall	23
9.	Drought frequencies	23
10.	Mean monthly and annual evaporation	25
11.	Criteria of climatic classification based on precipitation effectiveness	26
12.	Climatic zones of the project area	26
13.	General geologic sequence and aquifer properties	28
14.	Grain size of aeolian deposits in the Sikar basin	29
15.	Hydraulic characteristics of the aquifer in the Sikar basin as obtained from pumping tests	32

Tables (continued)

		Page
16.	Hydraulic characteristics of aquifers in Bikaner basin as obtained from pumping tests	37
17.	Interpretation of pumping tests at Badauli and Padukalan, Luni basin	44
18.	Geochemical classification of ground-water samples, Rajasthan area	47
19.	Recharge to the various aquifers in the Rajasthan area	53
20.	Ground-water resources in the Sikar basin	54
21.	Ground-water resources in Bikaner and Luni basins	55
22.	Estimated annual water surplus, Rajasthan area	56
23.	Annual water surplus frequences at Jhunjhunu 1907-1972	59
24.	Estimated water surplus for 11 stations during the period 1971-1973	60
25.	Present ground-water draft in the Rajasthan area	61
26.	Ground-water development schemes with high-capacity and medium-capacity tubewells in Rajasthan area	63
27.	Characteristics of tubewells for ground-water development in the Rajasthan area	64
28.	Criteria for classifying soils into irrigability classes	74
29.	Specifications for land irrigability classes	75
30.	Irrigability class of Sikar basin soils	76
31.	Irrigability class of Bikaner basin soils	77
32.	Irrigability class of Luni basin soils	78
33.	Suggested ground-water quality rating with reference to soils of project area	79
34.	Suitabili ty of tubewell water for irrigation on two soils types of the project area, according to sodium content classification	79
35.	Estimated depth of moisture extraction by mature crops on deep, well-drained soils	84
36.	Annual value of crops products in Nagaur district, total and per capita	87
37.	Effects of fertilizer on yields of Mexican wheat and hybrid millet	89
38.	Benefits and costs of improved practices for irrigated crops	91
39.	Benefits and costs of improved technology in dry farming	92
40.	Comparative costs of selected agricultural operations with motorized power compared to manual labour and bullock power	94
41.	Costs and incomes per hectare of selected fodder and food crops with irrigation in Rajasthan	95
42.	Determination of fertilizer use during fifth year of irrigation development	97
43.	Projections of fertilizer use per hectare of irrigated crops during the fifth and tenth years of development	98
44.	Fifth-year costs and incomes per hectare with and without irrigation	99
45.	Tenth-year costs and incomes per hectare with and without irrigation	100
46.	Crop yields in Sikar and Nagaur district, 1969-1972 and projections for irrigated and rain-fed crops in fifth and tenth years of development	101
47.	Cost of a tubewell and irrigation facility	103
48.	Costs of a sprinkler system in a tubewell area	105
49.	Summary of annual costs and benefits of irrigation with a tube-well and sprinkler system	106
50.	Possible total effects of irrigation development in the Rajasthan area	108
51.	Air temperature, Gujarat area	110
52.	Mean annual rainfall, records and extrapolation 1901-1973, Gujarat area	112
53.	Mean monthly rainfall distribution, 1901-73, Gujarat area	114
54.	Stream-gauge stations established by project	117
55.	Mean annual runoff data, Gujarat	118
56.	Monsoon runoff and estimated recession runoff in the Sabarmati and Banas rivers	124

Tables (continued)

		Page
57.	Runoff coefficients, Gujarat	125
58.	Geologic formations in the Gujarat area	125
59.	Geologic formations in the subsurface of the Gujarat plain and their aquiferous properties	126
60.	Recharge, draft and available ground-water resources, aquifer A, Gujarat area	134
61.	Summary of annual water surplus, Gujarat	135
62.	Annual water surplus from soil moisture balance computations, Gujarat	136
63.	Ground-water draft data, Gujarat area	137
64.	Summary of additional potential for development, Gujarat	138
65.	Irrigability classes of saline and alkaline soils	156
66.	Irrigability classes of calcareous sandy loams	156
67.	Irrigability classes of non-calcic soils	157
68.	Irrigability classes of calcareous sandy soils	157

Figures

			Page
1.	Monthly long term average pan evaporation and potential evaporation at Jodhpur, in mm		8
2.	Location map of project areas in Rajasthan and Gujarat		13
3.	Normal annual precipitation (1901-1973), Rajasthan project area		16
4.	Departures and cumulative departures from normal annual precipitation (1901-1973) at Jhunjhunu, Sikar and Didwana		21
5.	Departures and cumulative departures from normal annual precipitation (1901-1973) at Bikaner, Nawa, Nagaur and Merta City		22
6.	Geology and structure, Rajasthan project area		in pocket
7.	Geological cross section along A-A' (of figure 6), Rajasthan area	facing	28
8.	Geological cross section along B-B' (of figure 6), Rajasthan area	facing	28
9.	Geological cross section along C-C' (of figure 6), Rajasthan area	facing	28
10.	Geophysical and lithologic log, Setolao testwell	facing	28
11.	Grading analyses of selected formation samples from project boreholes in Sikar basin		30
12.	Saturated thickness of unconfined aquifers, Rajasthan project area		in pocket
13.	Water level depths with observation wells and boreholes, Rajasthan project area		in pocket
14.	Time-drawdown curves for observation wells from pumping test in Setolao well		31
15.	Tritium concentration distribution in pumping well at Setolao, Sikar Basin		34
16.	Filtration velocity distribution in a test well at Anandpura, Rajasthan project area		35
17.	Water table elevation contour map, Rajasthan project area		in pocket
18.	Time-drawdown curve for observation well from pumping test in Gadwala II test well, Bikaner Basin		38
19.	Time-drawdown curve for observation well from pumping test in Mudh well, Bikaner Basin		39
20.	Geophysical and lithologic log, Bandnau test well, Bikaner basin	facing	40
21.	Grading analyses of selected formation samples from Mudh, Bandnau and Raneri wells, Bikaner basin		41
22.	Geophysical and lithologic log, Badauli slim hole, Luni basin	facing	42
23.	Grading analyses of selected formation samples from wells in Luni basin		43
24.	Time-drawdown curve for observation well from pumping test in Padukalan test well, Luni Basin		45

Figures (continued)

		Page
25.	Time-drawdown curve for observation well from pumping test in Padukalan test well, Luni Basin	46
26.	Chemical classification of ground-water samples from Sikar Basin (Hill-Piper diagram)	48
27.	Chemical classification of ground water samples from Bikaner Basin (Hill-Piper diagram)	49
28.	Chemical classification of groundwater samples from Luni Basin (Hill-Piper diagram)	50
29.	Total dissolved solids distribution in unconfined aquifers, Rajasthan project area	in pocket
30.	Fluoride distribution in unconfined aquifers, Rajasthan project area	in pocket
31.	Water-level fluctuations in selected observation wells, Rajasthan project area	58
32.	Ground water resources, Rajasthan project area	in pocket
33.	Generalized distribution of soil groups, Rajasthan project area	66
34.	Relationship between clay percentage (x) and cation exchange capacity (y) in Sikar Basin soils	70
35.	Relationship between sodium adsorption ratio (x) and exchangeable sodium percentage (y) in Sikar Basin soils	72
36.	Relationship between sodium adsorption ratio (m. moles) 1/2 (x) and $NA_{ex}/Ca_{ex}+Mg_{ex}$ (y) in Sikar Basin soils	73
37.	Rainfall-elevation relationship for hilly regions of Gujarat project area	111
38.	Normal annual rainfall in Gujarat area (1901-1973)	in pocket
39.	Departures and cumulative departures from normal annual precipitation, 1901-1973, at Ahmadabad, Idar, Palanpur and Radhanpur	116
40.	Hydrograph of Banas River at Abu Road, for 1973	120
41.	Hydrograph of Saraswati River at Patan, for 1973	121
42.	Hydrograph of Sabarmati River at Ahmadabad, for 1973	122
43.	Geology and structure, Gujarat project area	in pocket
44.	Isopachs of post-Miocene formations and aquifer limits, Gujarat project area	in pocket
45.	Water-level depths, Gujarat project area	in pocket
46.	Time drawdown/recovery curve - Karora II (aquifer A)	128
47.	Geological cross section along A-A' (of figure 43)	facing 128
48.	Geological cross section along B-B' (of figure 43)	facing 128
49.	Geological cross section along C-C' (of figure 43)	facing 128
50.	Geological cross section along D-D' (of figure 43)	facing 128
51.	Observation well hydrographs, Gujarat area	facing 128
52.	Observation well hydrographs, Gujarat area	facing 128
53.	Observation well hydrographs, Gujarat area	facing 128
54.	Water-level contours, Gujarat project area	in pocket
55.	Time-drawdown/ recovery curve, Vasana I (aquifer B)	in pocket
56.	Time-drawdown/recovery curve, Mahi (aquifer B)	facing 128
57.	Time-drawdown/recovery curve, Saola (aquifer B)	facing 128
58.	Geophysical and lithologic log, Rasana I	facing 128
59.	Time-drawdown recovery curve, Dhinoj aquifer	facing 130
60.	Total solids distribution, phreatic aquifer A, Gujarat project area	facing 130
61.	Water quality and water level trend in aquifer B, Gujarat project area	in pocket
62.	Chemical classification of groundwater samples (Hill-Piper diagram), aquifer A, Gujarat area	in pocket
63.	Chemical classification of groundwater samples (Hill-Piper diagram), deeper aquifers, Gujarat area	131
64.	Chemical classification of groundwater samples (Hill-Piper diagram), aquifer B, Gujarat area	132
65.	Groundwater resources (aquifer A), Gujarat project area	133
66.	Schematic section showing dual-aquifer system concept	in pocket
67.	Gujarat mathematical model grid network	139
		141

Figures (continued)

		Page
68.	Simplified flow chart of the Gujarat mathematical model	142
69.	Gujarat mathematical model - stream flow of source deck	143
70.	Gujarat mathematical model - phreatic aquifer - 14 year regional drawdowns (1957-1971) - calibration run	145
71.	Artesian aquifer - 14 year regional drawdowns (1957-1971) - calibration run	146
72.	Phreatic aquifer - 5 year regional drawdowns operational run	148
73.	Artesian aquifer - 5 year regional drawdowns operational run	149
74.	Generalized soil map, Gujarat project area	150
75.	Relationship between clay content and cation exchange capacity (CEC) of soils in Gujarat project area	154
76.	Relationship between sodium adsorption ratio (SAR) of saturation extract and exchangeable sodium percentage (ESP) of soils in Gujarat project area	158

Annexes

1.	Data from representative existing tubewells, Rajasthan area	163
2.	Interpretation of pumping tests in Sikar Basin by Boulton method	166
3.	Results of boreholes drilled by Project in Rajasthan	168
4.	World Health Organization international standard for drinking water	174
5.	Chemical analyses of water from existing tubewells, samples collected in May 1973	175
6.	Ratios of various constituents of water from existing tubewells, samples collected May 1973	176
7.	Chemical analyses of water from project boreholes, Rajasthan area	178
8.	Chemical analyses of water samples from dug wells, Rajasthan area, samples collected May 1973	180
9.	Present ground-water draft in Sikar basin	185
10.	Present ground-water draft in Bikaner and Luni basins	188
11.	Summary of ground-water resources in the Rajasthan Project area, by district	190
12.	Physical properties of Soils in Project Area, Rajasthan	191
13.	Chemical Analyses of Soils in Project Area in Rajasthan	195
14.	Description of soil profiles in Rajasthan area	199
15.	Index to locations, Rajasthan area	205
16.	Details of tests wells drilled by Project in Gujarat Area, 1971-1974	210
17.	Details of piezometric holes drilled by project in Gujarat area, 1971-1974	214
18.	Details of exploratory boreholes previously drilled by Central Ground Water Board in and around Project area, Gujarat	217
19.	Chemical analyses of water from dug wells, aquifer A, Gujarat area	221
20.	Chemical analyses of water from tubewells and slim holes drilled by project, aquifer A, Gujarat area	225
21.	Chemical analyses of water from tubewells of aquifer B, Gujarat area	226
22.	Chemical analyses of water from tubewells, confined aquifers C, D, E, F, G and H, Gujarat area	227
23.	Physical characteristics of soils in Gujarat area	228
24.	Chemical characteristics of Soils in Gujarat Area	232
25.	Index to locations, Gujarat area	235
26.	Project personnel	237
27.	Fellowships	238
28.	Major items of equipment provided by UNDP	239
29.	Other UNDP projects and allied agencies with which contact was maintained	240

PREFACE

The technical report for the project "Ground-water surveys in Rajasthan and Gujarat" is based on the work of a team of international and national experts, Silas C. Brown, Project Manager for the United Nations, and D. Pandey, Project Director for the Government of India.

ABSTRACT

From April 1971 to October 1974 the United Nations and the Government of India, assisted by the United Nations Development Programme, investigated and evaluated the ground-water potentials and ground-water quality in areas of Rajasthan and Gujarat in north-western India. Phreatic and confined aquifers were delineated in the Sikar, Bikaner and Luni basins of Rajasthan and in the Gujarat Plain.

The chemical characteristics, existing and potential resources, pedologic applications and economic implications of the ground water were determined.

INTRODUCTION

The first request of the Government of India to the United Nations Development Programme for assistance in a ground-water project was submitted in 1965. This request, prepared with assistance of a United Nations Technical Adviser, was approved and resulted in a project entitled "Groundwater surveys in Rajasthan and Uttar Pradesh" (IND-67-549). The project was initiated in 1967.

The original project programme was revised in 1968, when investigations in Uttar Pradesh were substituted by studies on the Borunda limestone aquifer in the Jodhpur District of Rajasthan.

In January 1970, the Government of India requested the United Nations Development Programme to provide further assistance in developing ground-water resources in five additional districts in Rajasthan and Gujarat. This additional project (IND-71-614), entitled "Groundwater surveys in Rajasthan and Gujarat" started in April 1971 as a continuation of the first project terminated at that time.

After its completion in October 1974, this project was followed by a third project (IND-74-009) entitled "Groundwater studies in the Ghaggar River Basin".

The continuity of these projects resulted in important advantages, such as time saved in organization of the projects, counterpart personnel and part of United Nations personnel retained from one project to the following one, and effective utilization of United Nations equipment.

A. Location and geography

Both the Rajasthan and the Gujarat project areas are located in the north-western part of India. The State of Rajasthan extends between latitudes 23° and 30° north. The State of Gujarat adjoins Rajasthan in the south, and extends between latitudes 20°40' and 24°40' north and longitudes 68°10' and 74°40' east.

The Rajasthan project area is located in the semi-arid to arid western part of the State of Rajasthan, west of the Aravalli Range. It extends over about 42,000 km^2 and forms a part of the Thar Desert. The Rajasthan area is characterized by large flat to rolling terrain covered by aeolian sand, the absence of a surface drainage network with the exception of the Luni River catchment in the south of the area.

The Gujarat project area is located south of the Rajasthan area, north of the town of Ahmadabad. It forms a part of the Gujarat plains, belonging to the catchment of the Gulf of Cambay. The areal extent of the Gujarat project area is about 11,500 km^2. The Gujarat area is in general less arid than the Rajasthan area. Climate is classified as sub-humid to sub-arid. The area is drained by a number of intermittent streams, of which the Banas and Sabarmati rivers are the most important. Morphologically, most of the area is to be classified as aeolian-alluvial and alluvial plains.

B. Project objectives and background

The major objectives of the projects were to investigate and evaluate ground-water potentials and ground-water quality in the project areas, to make appraisals of the technical and economical feasibility of ground-water development, and to form a strong counterpart team, that would be qualified to carry out ground-water resources exploration and evaluation in the future.

The State of Rajasthan covers an area of 342,000 km^2 and has a population of over 25 million (1971). The project area covers approximately 42,000 km^2, and has a population of 2.88 million, of which 2.13 million live in rural areas. Thus, most of the population depends on agriculture. Periodic crop failures due to droughts that are frequent in this arid to semi-arid area and shortage of drinking water results in extreme hardship to the population and leads to their emigration. In the absence of surface-water sources, ground water is the only source from which additional water for irrigation and human and livestock consumption can be made available.

The Gujarat project area covers about 11,500 km^2. Population (1971) is 2.6 million. The climate is less arid than in the Rajasthan area, and there is some surface runoff that satisfies part of the water demand. Ground-water resources are in some parts of the area already overexploited, as shown by a continuous decline of water levels, while in other parts of the area ground-water salinity does not favour exploitation for irrigation. The main objective of the investigations was therefore the definition of ground-water management practices that would assure the most advantageous utilization of the available potential. For this purpose, the conventional field studies and water balance computations were complemented by a mathematical model study.

The ground-water resources investigations showed especially in the Rajasthan area, a certain potential for additional development. The possibility to use ground water of the expected salinity for irrigation had to be studied by a thorough evaluation of available soil resources and of current agricultural practices. These studies showed the need for improvement in the efficiency of irrigation and in farming practices.

The ultimate criterion is the economic feasibility of irrigation with ground water, and therefore an economic analysis of this question was included in the project operations.

C. Organization of the project

The Plan of Operation called for an allocation of $US 664,900 and a Government contribution equivalent to $US 50,300 towards local operating costs. Also provided was a contribution in kind by the Government of Rs 11,242,500 (approximately $US 1,500,000). The Plan of Operation provided also for 10 fellowships of 3 to 6 months duration. The Central Ground Water Board was appointed by the Government of India to act as the counterpart in the execution of the project.

Field work started in April 1971 and continued to May 1974 in Rajasthan and to June 1974 in Gujarat. Annexes 26-29 contain information of project personnel (26), fellowships (27) and major items of equipment provided by UNDP (28), on counterpart personnel provided by the Government of India (26), and on other United Nations Development Programmes and allied agencies (29) with which contact was maintained.

At the conclusion of the project, five field reports were prepared:

1. Ground-water survey of the Rajasthan Project Area, India (September 1974)
2. Ground-water survey of the Gujarat Project Area, India (September 1974)
3. Hydrometeorology and water balance of the Rajasthan and Gujarat Project Area, India (September 1974)
4. Pedology, land and water use of the Rajasthan and Gujarat Project Area, India (September 1974)
5. Mathematical model of the Gujarat Project Area, India (September 1974)

In addition a brief report entitled "Ground-water surveys in Rajasthan and Gujarat - Project findings and recommendations" was submitted to the Government of India in 1975. The present report is a condensation of the five above-mentioned technical field reports.

D. Acknowledgements

Grateful acknowledgement is made to the officials of various Government agencies and members of commercial concerns who devoted considerable time to providing the project staff with information through communication and verbal discussions. They include the following:

- The Director and staff of CAZRI Jodhpur and Pali who also provided laboratory facilities for soil analytical work;
- The Director and staff of State Depts. of Agriculture, Jaipur and Jodhpur;
- The Director and staff of the Dry Farming Section CAZRI, Jodhpur;
- Rajasthan State Ground Water Board at Jodhpur and Bikaner;
- Indian Agricultural Research Institute, New Delhi;
- State Public Health Department, Jodhpur and Jaipur;
- Rajasthan Canal Project, Bikaner;
- State Dept. of Agriculture, Jaipur;
- Ministry of Agriculture, Govt. of India, New Delhi;
- Sheep and Wool Commission, Jaipur;
- Forestry Department, Jaipur;
- Veterinary College, Bikaner;
- Haryana Agriculture University, Hissar;
- University of Jaipur, Rajasthan;
- State Dept. of Agriculture, Ahmedabad (Gujarat).

E. Summary and conclusions

1. Rajasthan project area

The Rajasthan project area extends over 42,000 km^2 west of the Aravalli Range. The climate is arid to semi-arid. Population was 2.88 million in 1971. The area is divided into three ground-water basins, the Sikar, Bikaner and Luni basins.

In the Sikar basin, there is a phreatic aquifer with a saturated thickness of 50 m. It consists of sand with lenses of silt and some clay. Transmissivity ranges between 100 and 330 m^2/day, the average being about 200 m^2/day. Specific yield

ranges from 6 to 15 per cent with an average of about 10 per cent. The specific capacity of test wells drilled by the project is 6 to 16 $m^3/h/m$, with an average of 11 $m^3/h/m$. Depth to water table is 30 to 45 m over most parts of the area. Ground-water salinity is less than 1,000 ppm total dissolved solids (TDS) in the eastern part of the area. Over two-thirds of the basin is between 3,000 and 5,000 ppm, and in one-sixth is more than 5,000 ppm. Mean annual replenishment is estimated at 390 million cubic metres (MCM) in areas where ground-water salinity is less than 5,000 ppm TDS. Present ground-water draft is about 80 MCM. On the basis of water balance estimates, the potential for additional ground-water development in the Sikar basin is 310 MCM per year. Of these, 240 MCM are expected to be ground water with a salinity of less than 3,000 ppm total dissolved solids. The Sikar basin presents the best prospects for ground-water development in the Rajasthan project area. About 200 new wells with a mean discharge of 150 m^3/h could be drilled in the eastern part of the basin (2,800 km^2) to produce 65 MCM per year of water in addition to the present draft.

In the Bikaner basin, a phreatic and a confined aquifer are known. The phreatic aquifer exists in the Palana Sandstone and in overlying aeolian deposits. The confined aquifer is in rock units of the Nagaur Series. Specific capacities of wells in the phreatic aquifer are between 3 and 38 $m^3/h/m$. Transmissivity of the phreatic aquifer as evaluated from pumping tests ranges between 100 and 1,000 m^2 per day. Average specific yield is 7 per cent. Transmissivity in the confined aquifers is only 3 to 50 m^2 per day, and average specific capacity is estimated to be 1 per cent. Ground-water salinity is below 1,000 ppm TDS in the southern, south-western and north-eastern parts of the basin. In two areas, high-capacity tubewells could produce about 15 MCM per year of additional ground water. Depth of these wells would range from 120 to 170 metres, and they would exploit the Palana Sandstone aquifer.

In the Luni basin, a phreatic aquifer exists in alluvial deposits in the eastern part, and in the western part of a continuous sequence of alluvial and underlying Tertiary deposits. Saturated thickness varies between 15 and 50 metres in the eastern part and between 30 and 120 metres in the western part of the basin. Transmissivity of the aquifers is from 100 to 800 m^2 per day. Specific yield is 5 to 7 per cent. Specific capacities of wells are 30 to 80 $m^3/h/m$. Depth to water table is from 15 m near the Luni River to 70 m in the extreme northern part of the basin. In most of the area it is between 30 and 50 metres below surface. Ground-water salinity is less than 1,000 ppm TDS in the eastern part of the Luni basin, and acceptable (up to 3,000 ppm) over most parts of the basin with the exception of a few centres with high-salinity ground water. In two areas of the Luni basin, 9 MCM of good-quality water could be exploited from the Quaternary alluvium aquifers, by high-capacity wells. Mean annual ground-water replenishment in the Bikaner and Luni basins is estimated to be about 340 MCM, in areas where ground-water salinity is less than 5,000 ppm TDS. Present ground-water draft amounts to about 38 MCM.

Ground water from medium-capacity wells, with an average capacity of 100 m^3/h, could become available, in the Sikar basin, to provide 110 MCM/yr, and 60 MCM/yr in the other two basins, in addition to the above mentioned annual volumes to be obtained from high-capacity wells. The economic feasibility, however, of irrigation with water from such wells, is, under existing conditions, questionable and some of this water may be too saline for irrigation.

Soils are mostly sand and sandy loams. They are poor in fertility and water-retention capacity. These and other factors render them economically marginal or unsuitable for irrigated agriculture unless their physical conditions and fertility can be improved. Most of the ground water to be obtained from possible additional development can be used for irrigation on the existing soils. Where high sodium absorption ratio (SAR) and unfavourable residual sodium carbonate (RSC) values coincide, appropriate soil management practices may be required. In some cases, a high boron content in the water may require addition of organic matter to the soil to counteract toxic effects. In view of the expected soil-water combinations, crops to be grown under irrigation must be selected in accordance to their salinity and boron sensitivity.

Ground-water quality is considered acceptable for livestock watering, with the exception of water from shallow aquifers in the north-western part of the Luni basin, and water from deep confined aquifers. According to WHO standards of water for human consumption, most of the ground water in the Sikar basin (eastern part) and Bikaner basin (central part) is acceptable. Much ground water in other parts of the project area is too saline, but the inhabitants have built up a tolerance to higher-than-standard drinking water salinity.

An economic analysis based on 1973 costs and prices has shown that the gross annual value of products from an area irrigated with well water can be appreciably higher compared to the value of dry farming products. Nevertheless, the economic benefits of irrigation with tubewell water with present methods in the project area will exceed costs only if well capacity is about 150 m^3/h (high-capacity wells). For irrigation with high-capacity wells, the benefit-to-cost ratio would be about 1:1 with the traditional method of irrigation and 1.25:1.00 if sprinkler irrigation were used. The benefit-cost ratio for medium-capacity wells (100 m^3/h) would be 0.90:1.00 with traditional irrigation methods, and 1.11:1.00 with sprinkler irrigation. The extension of ground-water exploitation in the Rajasthan project area could result in the irrigation of 61,000 hectares of land, thus increasing the irrigated area from 0.8 per cent of

total farm land at the present time to about 3.0 per cent.

From the economic point of view it appears desirable, therefore, to concentrate efforts first on the more efficient use of already available water in order to extend irrigated areas. This could be achieved by lining of canals and better control of the volumes of water applied. The introduction of sprinklers would result in an increase of about 40 per cent of irrigated area, provided expected benefits would justify the expense. Supplementary monsoon irrigation is recommended as being probably the most profitable use of ground-water resources.

Since the total supply of ground water in the area is limited, and the increase in irrigated area that can be achieved even with full development will amount only to a small percentage of total available farm land, the economic impact of extension of irrigation in the Rajasthan project area will remain relatively modest. The improvement of dry farming is recommended as the principal means for improving the incomes of the vast majority of the farmers.

2. Gujarat project area

The Gujarat project area extends over 11,500 km^2. The climate is considered as semi-arid, but rainfall is much higher than in the Rajasthan project area. Population was 2.6 million in 1971. A phreatic aquifer and a confined aquifer system exist in the sub-surface of the Gujarat plain. Near the Aravalli foothills, these aquifers merge to form a single phreatic aquifer. In this area recharge of the confined aquifers takes place.

The phreatic aquifer (A) is of greatest extension in the project area. It consists of sand and gravel with lenses of sandy clay and clay. Its thickness ranges from 35 to 125 metres. Depth to water table is 5 to 25 metres. Transmissivity ranges from 30 m^2/d to 1,000 m^2/d. Specific capacities of wells are 1 $m^3/h/m$ to 31 $m^3/h/m$. Mean annual recharge computed on the basis of water-level fluctuations is 790 MCM. Present net ground-water draft from this aquifer is 597 MCM. The confined aquifer system consists of seven sub-aquifers with different thicknesses and characteristics. Of these, only the upper-most sub-aquifer (B) is at present significantly exploited. Mean annual recharge is estimated as 70 MCM. Present ground-water draft amounts to about 90 MCM per year.

Effects of excessive ground-water exploitation are noted in both the phreatic and the uppermost confined aquifers, in the central and south-eastern parts of the project area where ground water is fresh. In these areas, pumping will have to be reduced by about 25 per cent in order to prevent further decline of water levels. Most of the additional ground-water resources that can be made available are located in the south-western and western parts of the project area, where soil conditions are not favourable. These resources amount to about 120 MCM of water with a salinity of up to 5,000 ppm TDS, including 38 MCM with less than 2,000 ppm TDS. Only about 7 MCM of water of this quality are available in the north-eastern part. Conditions for further development from deep aquifers are not favourable.

The aquifer system of the Gujarat project area was studied by a mathematical model. The results of the calibration and operational runs of this model have reinforced conclusions obtained from field investigations and led to the quantification of alternatives of future ground-water resources management in this area. It was found that additional wells can be drilled in the foothill zone where natural recharge is high. It is assumed that an additional annual volume of about 50 MCM can be pumped, without significant influence on water levels in most parts of the aquifer within the five-year period investigated by model simulations. Artificial recharge of the aquifers with excess river water in the foothill recharge zone would have a beneficial effect on the continued exploitation of the aquifers. In simulation runs made on the mathematical model to investigate the effects of artificial recharge, an annual recharge rate of 30 MCM was assumed.

It is recommended that observations be continued of water-level fluctuations in order to establish the influence that reduction of pumpage in the over-exploited areas will have on the water levels in aquifers A and B. A detailed investigation of possibilities of artificial recharge in the area between the Banas and Saraswati rivers should be undertaken as early as possible. This should be a full feasibility study in accordance with United Nations and World Bank standards. More detailed hydrological analyses should be prepared for all main rivers and their tributaries. Monthly runoff probabilities should be determined for each main stream for 80, 50 and 20 per cent probabilities of non-exceedence. Existing storage and diversion dams must be studied to determine the effect of artificial recharge releases on their present operational regimens. Future diversion works must likewise be studied in this respect.

Model input parameters such as transmissivity storativity and pumpage should be continually updated and the model should be recalibrated to the new values. Additional operational runs should be made to test various alternatives of pumping and recharge. Hypothetical new well fields should be introduced in various areas for simulation of different rates of pumping. Likewise, several artificial recharge patterns should be tried to determine locations that would most benefit the well fields.

I. OPERATIONS AND METHODS

A. Field and laboratory operations

1. Geology

Geologic maps were prepared for both project areas on the basis of existing maps and information. Supplementary field mapping was carried out in certain selected areas. Aerial photographs were used for tracing the contacts between alluvium and hard rock. The geologic maps incorporated in this report were compiled at 1:500,000 scale for the Rajasthan project area and at 1:250,000 scale for the Gujarat project area.

2. Drilling

A drilling programme was prepared, and carried out. It included drilling of aquifer test wells, stratigraphic boreholes and observation wells. The number and type of wells drilled in the Rajasthan project area is presented in table 1.

Total depth drilled in the Rajasthan project area amounts to 5,043 m for test wells and 5,118 m for slim holes.

In the Gujarat area, 19 test wells and 36 observation wells were completed by the project. Total depth drilled was 16,929 m; of which 5,636 m was for test wells and 11,293 m for stratigraphic and observations wells.

3. Well logging

Electrical and gamma-ray logs were run in two wells in Rajasthan and an electric log in one well in Gujarat.

4. Well inventories

Well inventories were made in both project areas; 1,026 wells were inventoried in Rajasthan, and 443 in Gujarat.

5. Observation-well networks

An observation-well network was established in both project areas for periodical observations of the water level. This network consists of 540 wells in Rajasthan and 430 wells in Gujarat. In addition, 16 wells in Gujarat were equipped with automatic water-level recorders. Provisions were made for the continuation of observations after completion of the project.

6. Analysis of ground-water samples

Ground-water quality was tested through the analysis of 5,797 water samples from Rajasthan and Gujarat wells. Water samples were collected from dug wells of the observation well network, from producing tubewells and from project exploration boreholes and test wells drilled. The following tabulation shows the distribution and analyzed water samples:

Area	Dug wells	Tubewells	Zone tests	Total
Rajasthan	3,728	131	137	3,996
Gujarat	1,473	328		1,801
Total samples analyzed				5,797

7. Pumping tests

Pumping tests were performed on 12 wells in

Table 1. Number and type of wells drilled by the project in the Rajasthan project area

Project area (Districts)	Test wells constructed	Stratigraphic boreholes drilled	Observation wells constructed	Total
Bikaner	8	2	3	13
Churu	1	9	1	11
Jhunjhunu	2	-	3	5
Nagaur	5	23	10	38
Sikar	5	2	7	14
Total	21	36	24	81

the Rajasthan project area (6 in the Sikar basin, 4 in the Bikaner basin, 2 in the Luni basin). In the Gujarat area, 14 well tests were carried out.

8. Well tests with radio-isotope tracers

Hydraulic characteristics of the aquifer were determined in one well in Rajasthan through the injection of radio-isotope tracers in an observation well and subsequent pumping. Filtration velocity tests with radio-isotope tracers were carried out in 4 boreholes in the Rajasthan project area.

9. Determination of ground-water withdrawals

Ground-water withdrawals were computed on the basis of the well inventories, and estimates of water consumption for human, livestock and irrigation needs.

10. Mathematical ground-water model

A mathematical aquifer model was prepared for the Gujarat area, and utilized to determine optimum rates and distribution of ground-water withdrawals.

11. Collection of meteorological data

Meteorological data such as rainfall, temperature humidity, wind velocity and evaporation were collected from existing stations located in and near the project areas. Four additional rainfall stations were installed by the project in the Rajasthan area (Sikar basin).

12. Surface runoff observations

Runoff data were collected from twelve river gauge stations on different rivers in the Gujarat area. Six river gauge stations were installed and operated by the project during 1972-1973 (listed in table 54), in addition to three dam stations set up by the Irrigation Department of the Rajasthan and Gujarat governments.

13. Pedological and land use studies

Data on the nature and characteristics of soils and on existing land use pattern and practice were collected, and completed by the sampling and analysis of additional soil profiles.

Fifty-five representative soil profiles were studied, 28 of these in the Rajasthan and 27 in the Gujarat project area. Profiles were studied to a depth of 130 cm by auger except where natural profiles were readily available. Sixty-nine soil samples were collected from the different soil horizons in the Rajasthan area and 75 in the Gujarat area. Representative descriptions were prepared for each soil group, and soil maps on a 1:500,000 scale were drawn for presentation in this report.

The hydraulic conductivity of the soils was measured in the laboratory by constant-heat method using disturbed soil samples. However, it is recommended that field experiments should be conducted using the tubewell water available on site to give more accurate values of hydraulic conductivity.

B. Methods of investigation

1. Collection and utilization of existing geologic and geophysical information

Full use was made of the results available from previous investigations. The Central Ground Water Board (CGWB) and the Geological Survey of India (GSI) undertook exploration drilling for ground water throughout Rajasthan and Gujarat at various times. The GSI also carried out geologic and geophysical surveys in the Nagaur and Bikaner districts, and drilled a few exploratory boreholes in the Kuchaman-Didwana area in Nagaur district.

Drilling operations by the CGWB, initially confined to exploration of aquifers in sedimentary terrain and definition of their supply potential, were switched to the drilling of production wells for village supplies during the drought periods of 1964-1966 and 1968-1969.

Geologic and geophysical data as well as logs of boreholes drilled for petroleum exploration in Gujarat were obtained from the Oil and Natural Gas Commission (ONGC).

2. Appraisal of rainfall observations

Rainfall is measured with a standard gauge, generally with a radius of 60 mm mounted about 30 centimetres about the ground. The water caught by the gauge is stored below the ground and is protected from evaporation losses by a funnel. The amount of rainfall is measured volumetrically. Most gauges are made of metal but they are successively being substituted by plastic ones with a receiving area of 200 square centimetres. There are no wind shields.

Several systematic errors are connected with rainfall measurements. All of these errors tend to decrease the measured amounts. Common causes for error are as follows:

Splashing	- causing raindrops to bounce out of the gauge;
Wetting	- the moist layer on the inside of the gauge escaping measurement;
Evaporation	- losses of water from the gauge between the time of the rainfall and measurement;
Wind deficit	- loss of raindrops due to the increased wind speed above the gauge.

The first three errors are probably small owing

to the design of the Indian gauge. By using plastic gauges the wetting losses will be further reduced.

The wind deficit is smaller than with a gauge mounted at the internationally agreed standard height of 1.2-1.5 metres above the ground. This deficit depends on the degree of wind exposure at the station and on the drop sizes - the bigger the drops the smaller the deficit. The rainfall stations seem to be reasonably well wind-protected and the wind deficit is estimated from experience in other countries where it generally amounts to 10-20 per cent, at 3-7 per cent in India, except at wind exposed sites where it could be appreciably greater. However, where rain gauges are mounted in the top of the roof of a building and without any windshield, the wind deficit must be very high-perhaps 15-20 per cent

There are also such "random" errors as reading error. It has been shown in other countries that these errors tend systematically to reduce the measured rain catch, with the reduction averaging about 8 per cent. Since many rain gauges are located at meteorological observatories this error is estimated at about 5 per cent on an average of India.

The reading errors together with the wind deficit are estimated to amount to 10 per cent on an average, that is all rainfall figures should be increased by 10 per cent. Owing to the uncertainty of this correction, it has not been applied to rainfall records in this report.

When using long-term records, errors could also be introduced owing to breaks in the homogeneity of the records. Such breaks could be introduced through changes in the vegetation, construction of new buildings, and other changes in the neighbourhood of the gauge, or a complete change of location or change of gauge or even through a change of observer. Homogeneity tests should therefore always be made before using long-term records.

Bikaner seems to give an example of a break somewhere around 1945, when the station probably was moved from the hospital to the meteorological observatory.

3. Evaporation

In the project area and adjacent areas, evaporation is measured at the meteorological observatories with Class A pans. These stations are part of a nationwide network. Generally, records are available for periods longer than 10 years. The pans are filled with water and the daily water loss is measured. They are covered with a wire mesh to protect the pans from birds and other animals, and they are painted white.

The use of the wire mesh screen reduces radiation which results in decreased evaporation. Work in India at Poona (WMO, 1966) shows that the correction factor for the conversion of "Wiremesh" readings to "Non-wire mesh" readings is 1.144. The Class A pan readings also have to be corrected for the heat exchange through the sides and the bottom of the pan as the Class A pan is a raised pan.

In warm arid climates the corrected pan evaporation is on the higher side owing to the advection of hot dry air. A combined correction factor for these two effects would be 0.6 for warm arid climates (WMO, 1966). What is obtained then is the evaporation from a large free water surface without heat storage - the so-called "free water evaporation". The combined factor to convert readings from a wire mesh Class A pan to "free water evaporation" would then be 1.144 times 0.6 in an arid climate, or 0.69.

An example of the conversion will be given for Jodhpur, where the long term mean annual evaporation from a wire mesh Class A pan is 2,640 mm. Correction (1.144) for the mesh gives 3,010 mm, and the correction to a "free water" evaporation (0.6) results in 1,822 mm. This "free water" evaporation is sometimes taken as the potential evaporation required for water-balance computations.

For the purpose of hydrometeorological water-balance computations, the Penman method for the determination of potential evaporation from land surfaces has been adopted in this project.

Long-term average monthly Penman and Thornthwaite values for Jodhpur are compared with uncorrected Class A pan data and Class A pan multiplied by the factor 0.7 (fig. 1).

It appears that the Thornthwaite values are too high in August and also probably too low during the cold season. The Penman values when derived from observed radiation data are considered more realistic for estimating the potential evaporation, particularly in a monsoon climate with a pronounced dry and wet season.

Figure 1 shows that the Penman estimate follows closely the observed pan evaporation multipled by the factor 0.7. This is particularly true during the monsoon season. It is argued that Penman underestimates the potential evaporation in arid climates in comparison to open pan evaporation (Krishnan and Kushwaha, 1970). However, even the corrected Class A pan observations can exceed the potential evaporation from a land surface in an arid climate.

The potential evaporation varies from day to day owing to such variants as solar radiation and humidity. In order to facilitate the computations, each day was assigned the mean monthly daily rate for the individual month. The error introduced is negligible compared to other approximations. (It results, however, in artificial steps from the last day of a month to the first day of the following month.)

Errors in the Penman estimates of potential

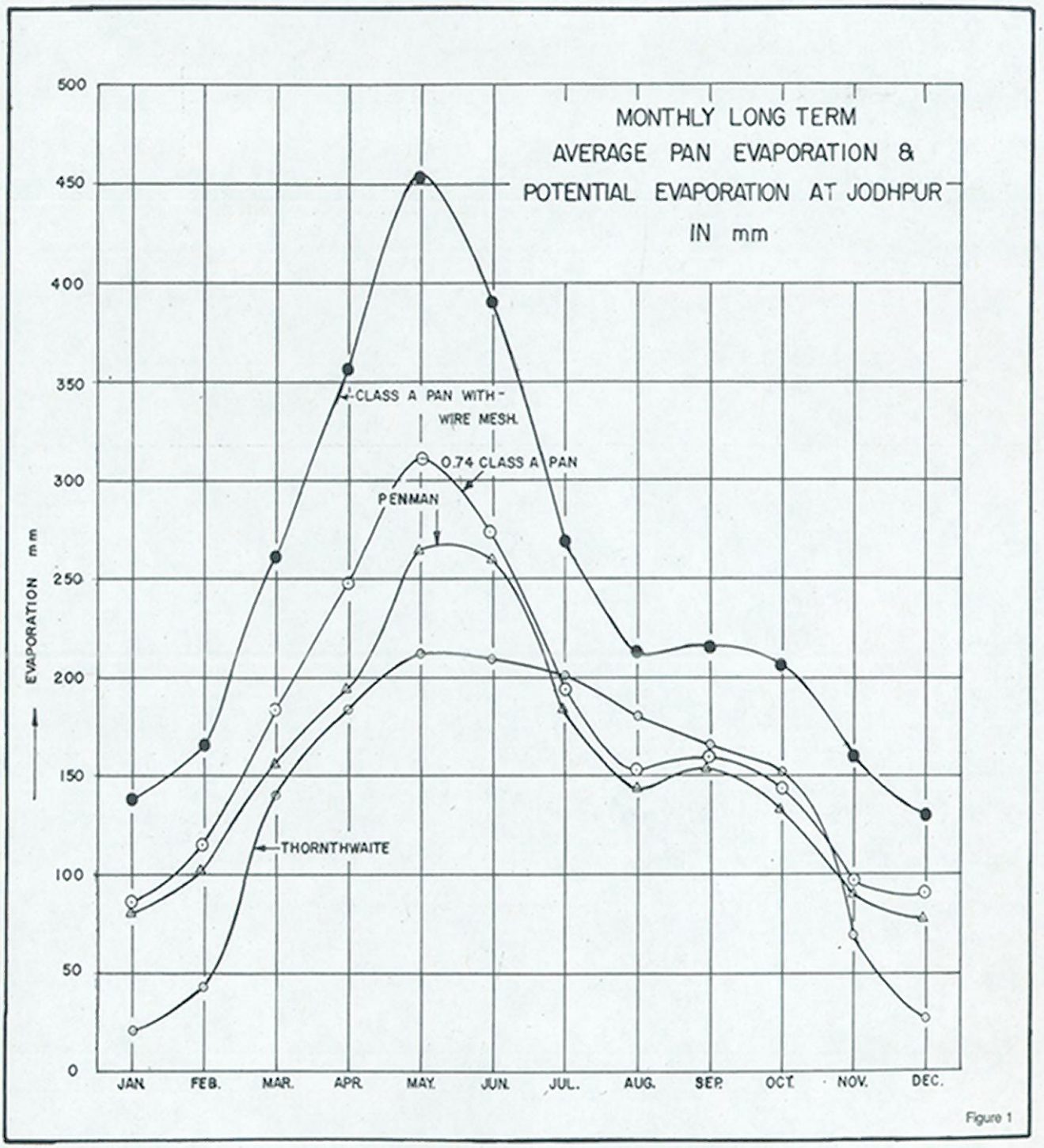

MONTHLY LONG TERM
AVERAGE PAN EVAPORATION &
POTENTIAL EVAPORATION AT JODHPUR
IN mm
EVAPORATION mm
500
450
400
350
300
250
200
150
100
50
0
CLASS A PAN WITH WIRE MESH.
0.74 CLASS A PAN
PENMAN
THORNTHWAITE
JAN.
FEB.
MAR.
APR.
MAY.
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.

Figure 1

evaporation are caused mainly by the errors in the measurements of the solar radiation. It is therefore important to calibrate the radiometers every year. Other uncertainties are introduced by errors in the measurements of air temperature and humidity, wind speed and cloudiness, but these have a smaller effect.

Another type of error may result from faulty location of the meteorological instruments. Anemometers in the project areas for instance, are generally placed on the top of the buildings and therefore tend to exaggerate the wind speed, but it is felt that this would only have a minor effect on the computations.

The cloudiness is estimated from the registered hours of sunshine, and it is assumed that the cloudiness is proportional during the night. In actual fact it can, however, deviate systematically to some extent, but the resulting error is probably small.

A substantial error could be introduced in the estimation of the albedo (reflexion coefficient) of the ground surface, the albedo of sand being about 45 per cent and for green grass and crops about 25 per cent (for water it is about 5 per cent).

An additional source of error are the empirical constants in the formula, which are given slightly different values by different research workers.

Taking all types of errors into consideration it is felt, based on error analysis made elsewhere, that the combined error is less than plus or minus 15 per cent, which is sufficiently accurate for estimating the ground-water recharge.

In table 10 the long-term mean pan evaporation is shown together with the potential evaporation according to Penman and Thornthwaite.

Since the Penman formula is used in this report it is felt appropriate to quote it in full here. Penman's formula as given by Penman (Wallen, 1966) is as follows:

$$PE = \frac{\frac{D}{gL}\left[R(1-r) - sT^4(a-b)\sqrt{e}(1-0.9m)\right] + c(0.5+dv)(e_s - e)}{\frac{D}{g} + 1}$$

The following notations have been used:

PE = potential evaporation (mm per day)

D = the derivative of saturation pressure as a function of air temperature (mb per degree)

e_s = saturation pressure at temperature T (mb)

T = air temperature (degrees Kelvin)

R = solar radiation (wattsec per square metre and day)

r = albedo

e = vapor pressure (mb)

m = cloudiness

v = wind speed at 2-metre level (m/s)

g = 0.66 mb/degree (psychrometer constant)

L = 25.10^6 wattsec per kilogramme (latent heat of water)

s = 0.00492 wattsec per square metre and degree and day (Stefan-Blitzman's constant)

Empirical constants as given by Penman are as follows:

a=0.56 b=0.08 c=0.26 d=0.53

4. Ground-water recharge computations

Ground-water recharge estimates were prepared for both the Rajasthan and Gujarat project areas by two independent methods - the analysis of water-level fluctuations and the soil moisture budget technique.

a. Recharge estimates from analysis of annual water table fluctuations

Data on water-level fluctuations during the three-year period 1971-1973, observed in about 600 observation wells in Rajasthan and more than 400 in Gujarat served as a basis for the computation of ground-water replenishment in the phreatic aquifers. Water levels were observed twice a year, prior to the monsoon in May-June (minimum levels) and after the monsoon in November (maximum levels). In Rajasthan, monthly measurements were performed in 60 observation wells from April 1973 to June 1974 and water levels were continuously recorded in three project observation wells (in the Sikar basin) to study the influence of the 1973 monsoon in greater detail. In the Gujarat area, daily water level observations were carried out in six dug wells in 1973 and during the first half of 1974.

For every quadrant of a topographic sheet, the average value of the water-table rise was computed separately for each of the three years and averaged for the three years. Where various aquifers exist on the area of one sheet (Rajasthan) calculations were made separately for each type of aquifer. Only areas with natural water-level fluctuations, undisturbed by recent withdrawals were taken into account.

The average value of water level rise for the three-year observation period was considered as representative for long-term average recharge conditions, because average rainfall for this period was close (about 10 per cent less in Gujarat) to the normal rainfall for the project area.

On the basis of estimated average specific yields of the aquifer, recharge (in millimetres) was computed.

b. Soil moisture budget technique

The general water balance equation was used to arrive at estimates for total runoff, consisting of surface runoff and ground-water replenishment; total runoff is in this report also called "water surplus" (R).

The natural water balance of an area, unaffected by human activities is expressed by the following formula:

$$P = E + (Qo-Qi) + (Go-Gi) + S + G + L$$

where:

P = rainfall (precipitation)
E = actual evaporation
Qi = inflow of river water (runoff)
Qo = outflow of river water (runoff)
Gi = inflow of ground water
Go = outflow of ground water
S = change in soil moisture storage
G = change in ground-water storage
L = change in lake storage

All the terms must be expressed in the same units, for example in millimetres of water depth over the entire area. Inflow and outflow of ground water across the project area boundaries are assumed as equal and are disregarded.

For the Rajasthan project area, inflow of surface water, lake storage and probably also river outflow can be disregarded too. The equation then reduces to:

$$P = E + S + G$$

where G equals "water surplus" (R)

In the Gujarat project area, however, river flow has to be taken into consideration, and the balance formula takes the following form:

$$P = E + S + G + (Qo - Qi)$$

The actual evaporation and the water surplus (R) have been computed on a daily basis according to a simplified version of the HBV-2 model, developed by Bergstrom and Forsman (1973). The water surplus (R) equals ground-water recharge G plus local runoff generated within the project area. But there might also be exchange of water between the river flow and the ground water in either direction and the total ground-water recharge G equals

$$G = R - (Qo - Qi)$$

According to the technique adopted, the actual evaporation (E) is computed from the potential evaporation (PE) in the following manner: The ratio E/PE is assumed to be a linear function of the actual soil moisture content. When the actual soil moisture is at the wilting point, E/PE equals zero (E = 0), and when it is at the field capacity E/PE equals one (E = PE). When the actual soil moisture is exactly in-between the wilting point and the field capacity, E/PE equals 1/2 and E = 0.5 PE.

A correct estimate of the soil moisture available between the field capacity and the wilting point for the different soils in the project area is, therefore, important.

The maximum available soil moisture is usually expressed in volume per cent of a soil sample. This percentage then has to be multiplied by the effective root depth to get the maximum available soil moisture expressed in millimetres of depth of water over an area.

The depth of the root zone can vary considerably over an area depending upon the type of vegetation and the depth of the soil mantle. In the project area it is assumed to be between 1.0 and 2.0 metres.

When converting potential evaporation into actual evaporation the stage of development of vegetation was disregarded. It is probable that a plant factor reducing the actual evaporation by a factor of 0.6 would be quite appropriate in the first month of the monsoon season. But in view of the small effect this would have on the computed water surplus it has been omitted.

The water-balance computations have been made on a daily basis. For each day the actual evaporation is subtracted from the actual available soil moisture and on each rainy day the rainfall is added to the soil moisture. The available soil moisture is assumed to be zero at the beginning of the wet season. It is assumed that any excess water after saturation of the field capacity percolates downward and becomes ground-water recharge or forms runoff and becomes river flow.

The infiltration capacity in the sandy soils of the project area is very high and is presumably seldom exceeded by the rainfall intensity - at least not on a daily basis.

It should be borne in mind that this water-balance technique implies many simplifications and gives only approximate results.

5. Chemical analysis of water samples and their graphic representation

The analytical methods employed for analysis are briefly outlined below:

(1) pH was determined with the help of an Electronic Corporation - pH meter using glass and calomel electrodes;

(2) Specific electric conductivity; resistance

was measured with a Phillips conductivity bridge; the values were converted to specific conductivity at 25°C;

(3) Total dissolved solids were determined by weighing, after evaporation of samples in silica dishes on a water bath;

(4) Carbonate was determined by titrating samples with standard sulphuric acid using phenolphthalein as indicator;

(5) Bicarbonate was determined by titrating with standard sulphuric acid using methyl orange as indicator;

(6) Sulphate was determined by back titration, with EDTA, of barium excess after adding of barium chloride solution

(7) Chloride was determined by argentometric method, using potassium chromate as indicator;

(8) Calcium was determined by titrating with EDTA, using Patton and Reeders Indicator, prepared in potassium sulphate;

(9) Magnesium/calcium and magnesium was determined by titrating with EDTA, using eriochrome black T as indicator; magnesium was found by subtracting calcium value;

(10) Sodium and potassium were determined photometrically using Systronics Flame Photometer MKI;

(11) Fluoride was determined by alizarin photometric method;

(12) Nitrate was determined by phenol-disulphonic acid method;

(13) Silicon was determined by molybdosilicate method;

(14) Iron was determined by thioglycolic acid method; and

(15) Boron was determined by curcumin method, after previous reduction of interfering nitrates.

Water quality data were graphically presented on Hill-Piper diagrams.

Saturation diagrams have been drawn with respect to calcium carbonate, calcium sulphate and calcium fluoride. Solubility of these compounds at 31°C mean temperature of the samples were considered. For Ca^{2+}, CO_3^{2-}, F^- the activities were taken into account obtained by means of the following relations:

$$a = m\gamma$$

$$-\log\gamma = Az\frac{2\sqrt{I}}{1+\sqrt{I}} - 0.2\,I$$

$$I = \Sigma 1/2\ m_i \times z_i^2$$

where

- a is the activity
- m is the molarity
- γ is the coefficient of activity
- z is the charge of ions
- I is the ionic strength
- A is a constant, whose value, according to Davies, is 0.5085

Since the calculation of the activities needs the value of the ionic strength which in turn depends on salinities, mean ionic strengths were calculated for group samples with similar salinities.

II. GROUND-WATER RESOURCES IN THE RAJASTHAN PROJECT AREA

A. Location and geography

The Rajasthan project area extends over 42,000 km^2 between latitudes 26°30' and 28°40' north and longitudes 72°40' and 75°30' east, in the north-western part of Rajasthan, including the districts of Bikaner, Nagaur, Sikar, Churu and Jhunjhunu. Most of the project area forms part of the Great Indian (Thar) Desert, and is covered by wind-blown sands. Its eastern limit is determined by the western foothills of the Aravalli mountain range.

The location map (fig. 2) shows the limits of the project area and a subdivision into three natural basins adopted for the purpose of the project. These are the Bikaner basin, comprising the western part of the project area, the Sikar basin, to which most of the eastern part of the area belongs, and the relatively small Luni basin in the southern part of the area.

Surface runoff is insignificant. It is noted mainly in and near the Aravalli hills, on terrain underlain by rocks of the crystalline basement complex. The salt lakes of Kuchaman and Didwana are closed inland drainage basins. Part of the runoff is intercepted and stored in numerous small tanks. Runoff is of short duration, and most of the water seeps into sand and alluvial deposits of the Sikar basin, at a short distance from the hills. The tributaries of the Luni River, in the extreme south of the project area, flow for a short period after heavy rainfall.

Flat areas of alluvial deposits are found mainly in the southern and north-western parts of the project area. Most of the region is covered by fine aeolian sand. In the eastern part of the project area there are ancient stationary dunes. Elsewhere, the aeolian material forms a thin veneer over other geologic formations, or appears in the form of mobile dunes.

The land surface is gently inclined towards the west and north-west. Elevations range from about 450 m near the Aravalli range in the east to about 175 m near the western limit of the area. In the eastern part of the area, isolated hills of Precambrian basement rocks rise to more than 200 m above the surrounding plains.

B. Climate

1. Meteorological and rainfall stations

There are four meteorological observatories in the project area and five outside of it but in the immediate vicinity. Meteorological data from 1931 to 1972 were obtained from the India Meteorological Department for these nine observatories. Mean monthly maximum and minimum temperatures, mean monthly relative humidity and mean monthly wind speed are given in table 2.

In addition to these meteorological observatories, there are 21 rainfall-measuring stations within or close to the project area and of these, 7 are located within the Sikar basin. Rainfall and evaporation are discussed below in some detail because of their importance as input data for hydrometeorological water-balance computations.

2. Rainfall records

Monthly and annual rainfall data from 1901 to 1973, or for shorter periods, as available, were obtained from India Meteorological Department and the Irrigation Department of the Government of Rajasthan.

Four additional rain gauge stations were set up during the project period in this area at Anandpura, Setolao, Talab-Ki-Dhani and Jhunjhunu. Data for these stations were available for one or two years only.

3. Mean annual rainfall

The distribution of mean annual rainfall over the Rajasthan project area is presented on the rainfall map (fig. 3). Long-term average annual precipitation will be referred to in this report as normal annual precipitation (or rainfall).

Average annual rainfall for the longest periods of records available was compiled for all stations. These averages were extrapolated to the common period 1901-1973 for those stations having a shorter record according to the following formula:

$$N_S = \frac{N_C}{\overline{R}_C} \times R_S$$

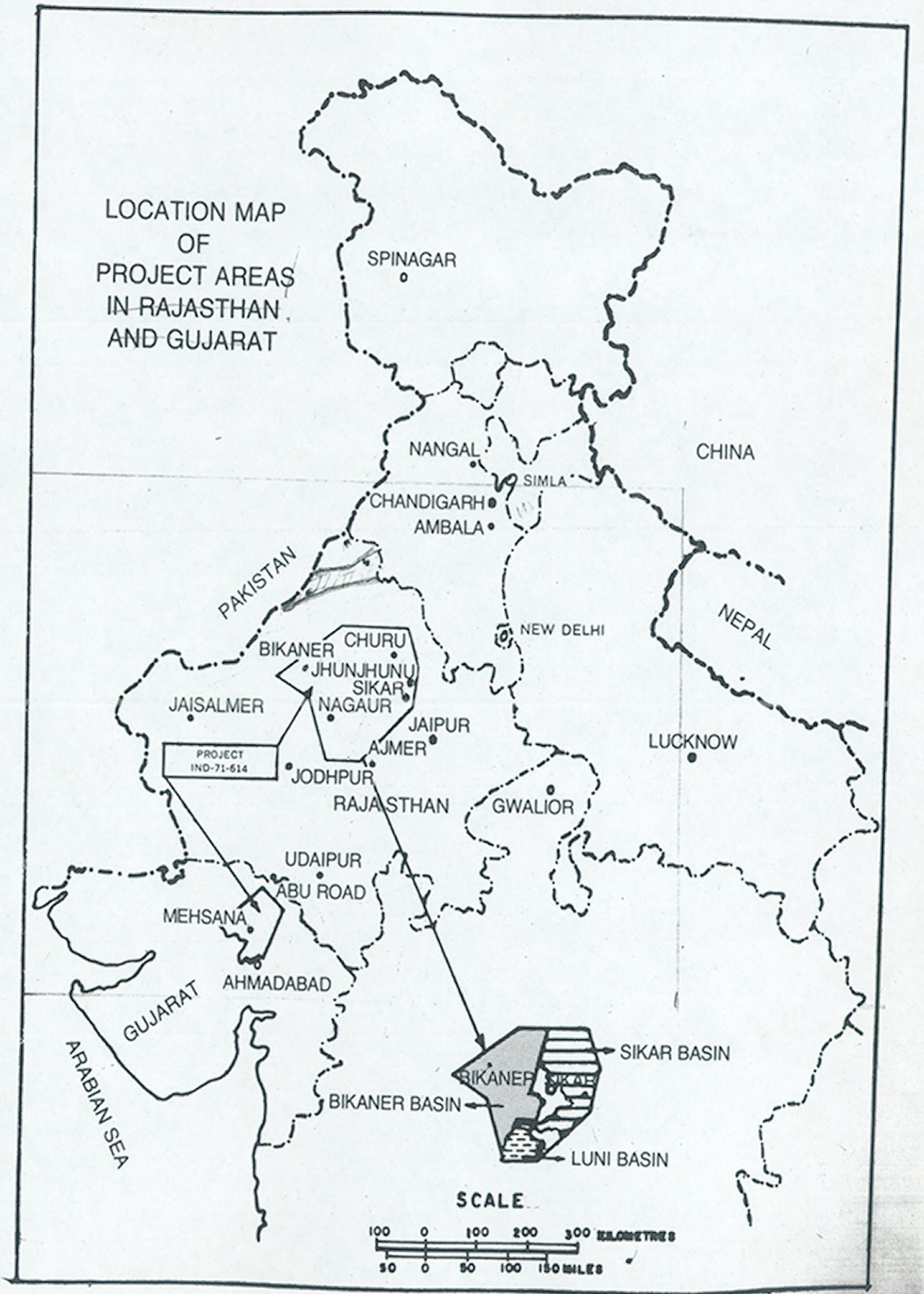

LOCATION MAP
OF
PROJECT AREAS
IN RAJASTHAN
AND GUJARAT
SPINAGAR
NANGAL
CHINA
SIMLA
CHANDIGARH
AMBALA
PAKISTAN
NEPAL
NEW DELHI
BIKANER
CHURU
JHUNJHUNU
SIKAR
JAISALMER
NAGAUR
JAIPUR
AJMER
LUCKNOW
PROJECT
IND-71-614
JODHPUR
RAJASTHAN
GWALIOR
UDAIPUR
ABU ROAD
MEHSANA
AHMADABAD
GUJARAT
ARABIAN SEA
SIKAR BASIN
BIKANER
BIKANER BASIN
LUNI BASIN
SCALE
100 0 100 200 300 KILOMETRES
50 0 50 100 150 MILES

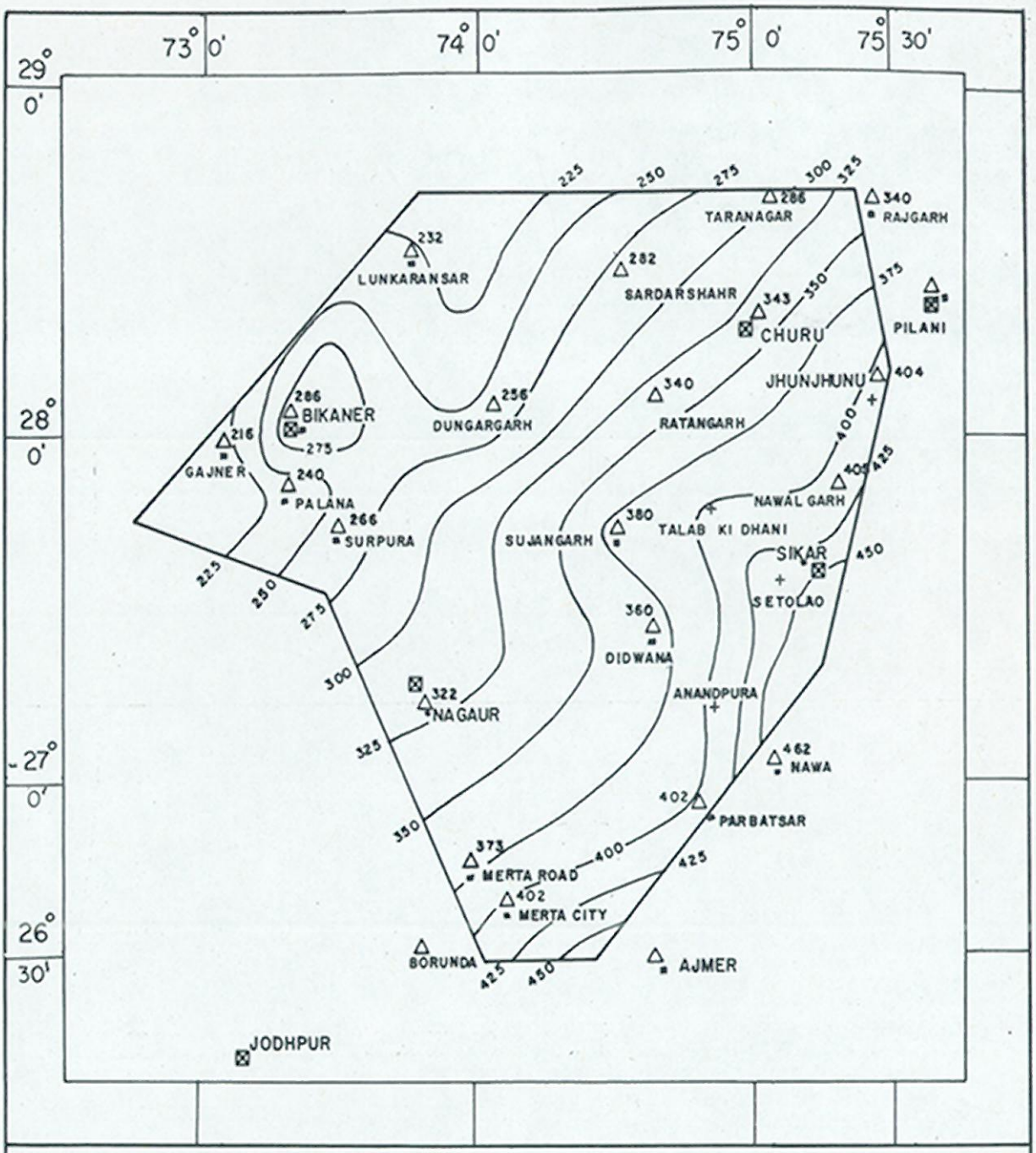
Figure 2

Table 2. Mean monthly climatological data

Station	Period	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
a. Mean monthly maximum temperature (°C)													
Bikaner	1931-72	22.5	26.1	32.0	37.6	41.8	41.6	38.8	36.3	36.7	35.5	30.3	24.7
Churu	1957-72	22.5	25.7	31.6	37.0	30.6	41.2	37.5	35.1	35.4	34.5	29.1	24.1
Erinpura Road	1955-72	26.2	28.8	33.8	37.9	40.3	38.4	33.7	31.5	33.0	34.8	31.6	28.0
Jodhpur	1931-72	24.9	28.0	33.6	38.4	41.6	40.1	46.0	33.5	34.9	36.0	31.5	26.8
Nagaur	1958-72	23.3	26.9	32.5	37.3	40.8	40.5	36.6	34.4	35.1	35.6	30.1	24.9
Phalodi	1931-72	23.0	26.6	32.4	37.7	41.5	40.8	34.2	34.9	35.8	35.5	30.5	24.8
Pilani	1958-72	22.4	25.7	31.5	36.7	40.1	41.2	36.7	34.7	35.0	34.5	29.4	24.2
Sikar	1951-72	22.7	26.0	31.4	36.4	39.5	39.3	35.4	35.2	33.9	33.6	29.2	24.4
Sriganganagar	1931-72	20.8	24.1	29.8	36.3	41.1	42.1	38.8	37.3	36.5	35.1	29.3	23.3
b. Mean monthly minimum temperature (°C)													
Bikaner	1931-72	4.4	8.0	14.5	20.9	26.8	29.2	28.0	26.7	25.1	18.6	10.3	5.6
Churu	1957 72	4.4	7.7	13.9	19.7	24.5	28.5	27.0	25.6	23.3	17.4	10.1	5.3
Erinpura Road	1955-72	8.7	11.9	18.1	23.0	26.1	27.1	25.6	24.7	23.8	21.0	14.5	10.3
Jodhpur	1931-72	9.4	11.9	17.8	22.5	27.1	28.4	26.8	25.3	24.1	19.7	14.2	10.7
Nagaur	1958 72	6.3	9.6	15.3	21.0	25.4	27.9	26.7	25.4	23.7	18.8	13.3	7.5
Phalodi	1931-72	6.5	9.9	15.8	21.7	26.3	27.7	26.9	25.7	24.3	19.6	13.0	7.8
Pilani	1958-72	4.5	7.7	13.4	19.0	23.5	28.1	26.2	25.0	22.8	17.2	10.6	5.4
Sikar	1951-72	5.5	7.9	13.8	18.8	23.6	27.6	25.7	24.4	22.4	16.6	10.0	5.9
Sriganganagar	1931-72	4.7	7.6	11.8	18.6	23.9	27.9	27.9	26.7	23.8	17.2	9.5	5.5
c. Mean monthly relative humidity % 0830 HRS. I.S.T.													
Bikaner	1931-72	63	55	45	31	32	50	66	71	68	49	48	58
Churu	1957-72	69	61	54	45	41	53	78	78	72	58	58	68
Erinpura Road	1955-72	73	61	55	49	52	67	78	82	77	61	66	74
Jodhpur	1931-72	50	44	35	31	42	60	74	81	73	48	40	48
Nagaur	1958-72	56	51	42	39	40	57	72	76	70	50	50	55
Phalodi	1931-72	60	54	50	43	51	66	75	80	75	56	51	56
Pilani	1958-72	61	55	45	36	36	50	70	79	73	54	53	57
Sikar	1951-72	67	60	51	44	48	60	75	82	73	59	59	66
Sriganganagar	1931-72	80	74	62	43	36	46	65	70	67	58	62	77

Table 2 (continued)

Station	Period	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					d. Mean monthly relating humidity % (17.30 hrs. I.S.T.)								
Bikaner	1931-72	33	30	25	17	16	27	46	52	43	26	30	35
Churu	1957-72	36	32	31	28	24	32	53	60	53	34	34	39
Erinpura Road	1955-72	44	35	37	34	32	44	62	69	61	45	45	49
Jodhpur	1931-72	26	20	16	14	15	30	52	60	47	24	23	27
Nagaur	1958-72	42	37	32	27	24	37	53	61	51	38	42	43
Phalodi	1931-72	34	35	31	26	25	34	50	58	48	33	35	37
Pilani	1958-72	31	26	20	18	18	30	53	63	51	33	30	32
Sikar	1951-72	41	38	35	29	33	40	56	63	56	40	42	45
Sriganganagar	1931-72	43	36	30	22	19	27	46	55	43	32	37	44
					e. Mean monthly wind speed kilometres per hour								
Bikaner	1931-72	4.4	5.1	6.4	7.4	10.1	13.6	12.5	11.0	9.3	5.3	3.6	3.7
Churu	1957-72	4.8	6.2	7.3	8.6	10.7	15.3	12.4	10.6	8.8	5.8	4.1	4.1
Erinpura Road	1955-72	3.1	4.3	5.9	6.5	8.7	10.7	8.9	7.3	6.0	4.7	3.1	2.7
Jodhpur	1931-72	8.4	8.5	9.6	10.1	14.1	18.1	16.4	12.8	10.3	6.5	6.2	7.3
Nagaur	1958-72	5.3	6.2	8.9	8.3	12.2	16.0	13.8	11.2	8.6	5.3	4.7	5.0
Phalodi	1931-72	9.1	9.0	12.4	13.7	19.7	25.2	22.7	18.7	15.8	11.1	10.5	8.3
Pilani	1958-72	6.7	8.2	9.4	10.3	12.8	18.3	14.2	11.6	10.3	7.5	6.2	6.2
Sikar	1951-72	6.1	5.6	6.9	6.9	8.5	11.7	8.3	6.7	6.0	5.2	4.0	3.9
Sriganganagar	1931-72	3.5	4.5	5.6	6.0	7.1	9.6	11.4	7.2	5.5	4.1	2.8	2.9



LEGEND

- ISOHYET IN m.m.
- RAIN GAUGE STATION (Pre Existing)
- METEOROLOGICAL OBSERVATORY
- U.N.D.P. RAIN GAUGE STATION (1 YEAR MEASUREMENT ONLY)
- PROJECT BOUNDARY

INDIA
GROUNDWATER SURVEYS IN RAJASTHAN & GUJARAT

NORMAL ANNUAL PRECIPITATION
(1901-1973)
RAJASTHAN PROJECT AREA

Scale
Miles 32 24 16 8 0 32 Miles
Kilometres 50 40 30 20 10 0 50 Kilometres

Figure 3

Table 3. Annual rainfall data, records and extrapolations 1901-1973
(Note: Extreme values refer to record period)

Station	Record period (No. of years)	Average for record period (mm)	Adopted average for 1901-73 (mm)	Extreme values				Maximum average	Minimum average
				max. (mm)	year	min. (mm)	year		
Bikaner	1901-73(73)	285.9	285.9	770.9	1917	45.8	1968	2.70	0.16
Churu	1906-73(68)	352.7	342.8	783.8	1917	77.2	1918	2.29	0.23
Didwana	1901-73(73)	360.1	360.1	1251.5	1917	47.8	1918	3.48	0.13
Dungargarh	1906-73(68)	263.0	255.8	769.0	1917	63.9	1969	2.97	0.25
Gajner	1906-48(42)	244.8	215.7	590.8	1936	48.8	1922	2.74	0.23
Jhunjhunu	1901-73(73)	403.8	403.8	777.8	1956	92.7	1901	1.93	0.23
Lunkaransar	1906-73(68)	238.1	231.6	844.6	1917	40.9	1918	3.65	0.18
Merta City	1901-73(73)	401.8	401.8	1286.8	1917	76.2	1918	3.20	0.19
Merta Road	1911-50(40)	387.8	372.8	993.6	1917	64.5	1918	2.67	0.17
Nagaur	1901-73(73)	321.8	321.8	815.6	1953	63.0	1918	2.53	0.20
Nawa	1910-73(73)	462.2	462.2	1174.2	1917	73.2	1905	2.54	0.16
Nawalgarh	1915-49(35)	421.8	405.4	882.7	1917	132.6	1918	2.18	0.33
Palana	1906-69(64)	250.9	240.5	986.3	1917	18.0	1968	4.10	0.07
Parabatsar	1901-73(72)	393.5	402.1	856.6	1971	69.1	1918	2.13	0.17
Rajgarh	1906-73(68)	349.7	339.8	880.6	1917	75.9	1918	2.59	0.22
Ratangarh	1906-73(68)	359.7	349.6	769.9	1917	35.6	1918	2.20	0.10
Sardarshahr	1906-73(68)	289.9	281.7	1085.9	1917	71.9	1938	3.85	0.26
Sikar	1901-73(73)	440.5	440.5	864.4	1942	179.3	1918	1.97	0.41
Sujangarh	1906-73(68)	373.1	369.4	1311.0	1917	70.4	1938	3.55	0.19
Surpura	1906-73(68)	273.5	266.0	822.7	1917	30.5	1911	3.09	0.11
Taranagar	1906-73(68)	294.8	286.5	900.2	1917	20.3	1918	3.14	0.07
Range	-	238-463	215-463	-	-	-	-	1.93-4.10	0.06-041
Average	-	341.4	335.0	-	-	-	-	2.83	0.19

Table 4. Mean monthly rainfall distribution 1901-1973
(in millimetres)

Station	Period of Record used (no.of yrs)	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Bikaner	1901-73(73)	4.8	7.3	6.3	4.9	12.2	27.0	80.4	89.3	41.7	6.3	1.7	4.0	285.9
Churu	1901-73(62)	10.0	6.4	5.9	3.9	11.3	39.6	109.8	111.4	46.6	5.6	1.5	4.9	356.9
Didwana	1901-73(72)	5.8	5.8	4.5	2.9	11.7	36.0	118.3	126.0	42.2	4.1	1.0	4.2	362.5
Dungargarh	1906-73(68)	5.6	6.5	3.1	3.4	7.6	28.6	79.0	81.1	36.7	4.3	1.5	2.6	263.0
Gajner	1906-48(42)	2.3	7.4	4.6	3.9	7.1	26.0	66.9	96.5	23.0	3.7	0.6	2.8	244.8
Jhunjhunu	1901-73(73)	8.5	8.7	6 6	5.5	14.2	41.1	126.0	115.4	60.4	10.1	2.0	5.3	403.8
Lunkaransar	1906-73(68)	3.7	6.6	4.1	2.8	8.5	23.2	71.5	72.0	33.5	5.5	0.7	6.2	238.1
Merta City	1901-73(73)	4.2	4.7	4.5	2.9	12.4	38.2	134.9	132.9	56.1	7.6	1.5	1.9	401.8
Merta Road	1911-50(40)	3.6	4.5	3.9	2.2	23.7	37.0	140.6	124.5	53.5	6.9	0.4	2.0	387.8
Nagaur	1901-73(67)	5.4	7.2	5.3	2.9	13.9	35.1	93.4	106.3	41.2	4.7	1.1	4.0	318.5
Nawa	1901-73(73)	9.2	5.9	5.9	3.5	13.5	46.5	149.6	148.8	63.7	9.1	1.7	5.0	462.2
Nawalgarh	1915-49(35)	8.7	8.3	7.4	4.3	11.7	42.5	137.5	132.1	57.4	7.4	0.2	4.3	421.8
Palana	1906-69(64)	2.6	4.3	4.0	4.4	7.7	22.0	71.7	90.5	33.0	7.0	0.6	2.2	450.9
Parabatsar	1901-73(72)	4.1	4.8	2.5	1.7	9.8	40.3	134.4	127.8	56.3	6.4	1.3	4.1	393.5
Rajgarh	1906-73(68)	11.6	8.3	6.3	2.7	11.9	35.1	105.5	98.3	53.6	9.5	2.5	4.6	349.7
Ratangarh	1906-73(68)	6.6	5.4	5.4	3.7	13.4	33.3	112.2	113.9	51.1	8.7	2.1	3.9	359.7
Sardarshahr	1906-73(68)	5.9	5.5	4.9	3.3	7.4	29.3	87.4	88.1	50.6	6.9	1.7	2.4	292.8
Sikar	1901-73(73)	8.2	7.3	7.5	3.1	17.4	39.4	139.8	146.2	53.7	7.8	4.2	5.9	440.5
Sujangarh	1906-73(68)	6.0	5.3	6.2	4.1	14.2	38.3	121.0	113.0	51.2	7.9	1.8	4.1	373.1
Surpura	1906-73(68)	3.0	5.5	3.5	2.5	12.8	28.9	75.5	101.5	32.1	5.1	0.9	2.5	273.5
Taranagar	1906-73(68)	7.2	6.6	5.3	4.1	7.9	26.2	90.9	90.8	45.4	6.4	1.3	2.7	294.8
Average		6.0	6.3	5.1	3.5	11.2	33.9	107.0	110.0	46.8	6.8	1.4	3.8	341.8
Percentage distribution		1.8	1.8	1.5	1.0	3.3	9.9	31.3	32.2	13.7	2.0	0.4	1.1	100

Table 5. Variability of annual rainfall

Mean rainfall, co-efficient of variation and standard error

Station	Period of record	Mean annual rainfall (mm)	Co-efficient of variation of rainfall (%)	Standard error of annual rainfall (mm)
Ratangarh	1906-73	359.7	39.9	17.4
Sardarshahar	1906-73	289.9	49.4	17.4
Churu	1906-73	352.7	38.3	16.4
Dungargarh	1906-73	263.0	47.6	15.2
Rajgarh	1906-73	349.7	43.2	18.3
Taranagar	1906-73	294.8	53.5	19.1
Sujangarh	1906-73	373.1	49.0	22.2
Jhunjhunu	1901-73	403.8	36.5	17.5
Sikar	1901-73	440.5	37.3	19.2
Nawa	1901-73	462.2	43.6	23.6
Parabatsar	1901-73	393.5	45.3	21.0
Didwana		360.1	48.7	20.5
Nawalgarh	1915-49	421.8	37.7	26.9
Nagaur	1901-73	321.8	49.8	18.8
Bikaner	1901-73	285.9	50.6	16.9
Surpura (Nokha)	1906-73	273.5	52.3	17.4
Merta City	1901-73	401.8	59.3	23.2
Lunkaransar	1906-73	238.1	49.4	14.3
Palana	1906-73	250.9	55.6	16.9
Gajner	1906-48	244.8	52.1	19.7
Merta Road	1911-50	387.8	44.8	27.5
Average	-	341.4	46.9	19.4

Table 6. Probability of exceedence of annual rainfall

Station	1 -2%	10%	25%	50%	75%	90%	98-99%	Probability of mean annual rainfall
	(in millimetres)							
Bikaner	771	483	347	261	182	121	46	45
Churu	734	504	405	326	274	195	77	42
Didwana	1252	567	431	329	254	179	48	43
Dungargarh	759	406	313	234	177	135	64	40
Gajner	591	426	315	235	146	185	49	47
Jhunjhunu	778	594	491	385	298	215	93	46
Lunkaransar	845	363	309	220	142	125	41	46
Merta City	1287	625	502	384	254	181	76	48
Merta Road	994	622	477	382	279	184	65	47
Nagaur	816	508	409	314	197	138	63	49
Nawa	1174	670	552	479	290	235	73	52
Nawalgarh	883	584	524	396	314	236	133	46
Palana	986	452	299	223	147	115	18	38
Parabatsar	857	625	482	376	272	169	69	45
Rajgarh	881	540	414	328	236	166	76	45
Ratangarh	770	543	447	356	262	162	36	49
Sardarshahr	1086	424	359	270	205	136	72	44
Sikar	864	661	565	419	307	225	165	47
Sujangarh	1311	598	469	347	245	179	70	46
Surpura	823	456	353	229	163	141	31	46
Taranagar	900	488	358	271	190	139	20	39
Range	591-1311	363-670	299-565	220-479	142-314	85-236	18-165	38-52

Note: 1 -2% Prob. denotes the highest observed annual rainfall, and

98-99% Prob. the lowest observed annual rainfall during the whole period of record.

N is the annual long-term average rainfall and R is the short-term average. Subscripts 'C' and 'S' refer to complete and short record stations, respectively. The short record data have been related to the nearest stations having a complete record of 73 years if both are lying in the same homogeneous meteorological region.

Average annual rainfall is 450 mm in the east, near the foothills of the Aravallis and decreases steadily to 225 mm towards the west. In table 3 maximum, minimum and average annual rainfall for the record period is shown. Lowest annual rainfall is less than 10 per cent of the long-term annual average, while the highest annual values are more than four times the long-term average.

4. Interpretation of rainfall records and occurrence of droughts

a. Statistical analysis

Table 4 shows mean monthly rainfall for all 21 stations. The monsoon rains contribute 87.1 per cent to the average annual rainfall, and the winter rains only 6.6 per cent. The share of pre-monsoon thunderstorms is 4.3 per cent and post-monsoon rains account for 2 per cent of the rainfall. The coefficient of rainfall variation and standard error of mean annual rainfall for all stations are shown in table 5. Average rainfall variability for the entire area is 47 per cent.

The adopted mean annual rainfall of 335 mm (table 3) gives, with a standard error of 19.5 mm, a 90 per cent probability that the mean areal annual rainfall is within 1.64 by 19.5 mm off the mean, or between 303 and 367 mm.

Departures from the long-term mean annual rainfall were calculated for all stations for each year of record. Eight stations were selected to present the entire area. Taking mean annual rainfall as unity, relevant departures and cumulative departures were calculated for these eight stations. In figures 4 and 5 these departure curves are shown. The salient features of these curves are as follows:

(1) The variability of annual rainfall seems to be independent and non-systematic in nature.

(2) The frequency of below-average annual rainfall is double that of above-average.

(3) Rainfall was close to the average between 1923 and 1930 and between 1960 and 1964; below average in the periods 1901-1906, 1911-1913, 1918-1922, 1935-1941, 1946-1949, 1951-1955, 1965-1969 and 1971-1972 and above average in the periods 1907-1910, 1915-1917, 1931-1934, 1942-1945 and 1956-1959.

To study the probabilities for the occurrence of various amounts of annual rainfall, probabilities based on a simple rank method were worked out from the formula:

$$\text{Probability (in per cent)} = \frac{M-0.3}{N+0.4} \times 100$$

where M is the rank of the annual rainfall in descending order and N is the number of years of record. For all 21 stations, probability percentages of 10, 25, 50, 75 and 90 were calculated. These are listed in table 6 along with 1-2 per cent and 98-99 per cent values. Probabilities of 1-2 per cent and 98-99 per cent correspond to the highest and lowest observed rainfall during the period of record. Probability of occurrence of mean annual rainfall varies from 38 to 52 per cent for individual stations.

b. Heavy rainfall

The frequency of daily rainfall in excess of 80 mm is almost double at Bikaner compared to Jhunjhunu, and even the frequency of daily rainfall over 40 mm is a little higher at Bikaner than at Jhunjhunu, although mean annual rainfall at Jhunjhunu is about twice as much as at Bikaner. This fact is important in relation to the water balance as shown in a later section (II-F.2).

Since Bikaner is representative of the western part of the project area and Jhunjhunu of the Sikar basin in the east, this means that the western arid part receives more heavy daily rainfall than the eastern part as shown in table 7.

Table 7. Frequency of daily rainfall during the monsoon season, 1907-1972

Daily rainfall in mm	Jhunjhunu No. of days	Bikaner No. of days
Over 120	1	1
Over 80	5	9
Over 40	35	42

c. Seasonal rainfall

Precipitation that falls during the south-west monsoon (June through September) period is known as seasonal rainfall. The seasonal rainfall totals for all stations and for all years of record were tabulated. Mean seasonal rainfall values were computed for all stations (table 8). The coefficient of variation in seasonal rains is about 48 per cent and the standard error is about 17.7 mm for the areal mean, which is 295.6 mm.

d. Droughts

Drought frequencies were computed for all 21 stations of the area (table 9). These frequencies are based on the agricultural definition of drought which takes into account the negative departures of seasonal rainfall from mean seasonal rainfall, as defined below:

DEPARTURES & CUMULATIVE DEPARTURES FROM NORMAL ANNUAL PRECIPITATION 1901-1973 AT JHUNJHUNU, SIKAR & DIDWANA

(BASED ON NORMALS FOR THE PERIOD 1901-1973)

Unit : Normal annual rainfall

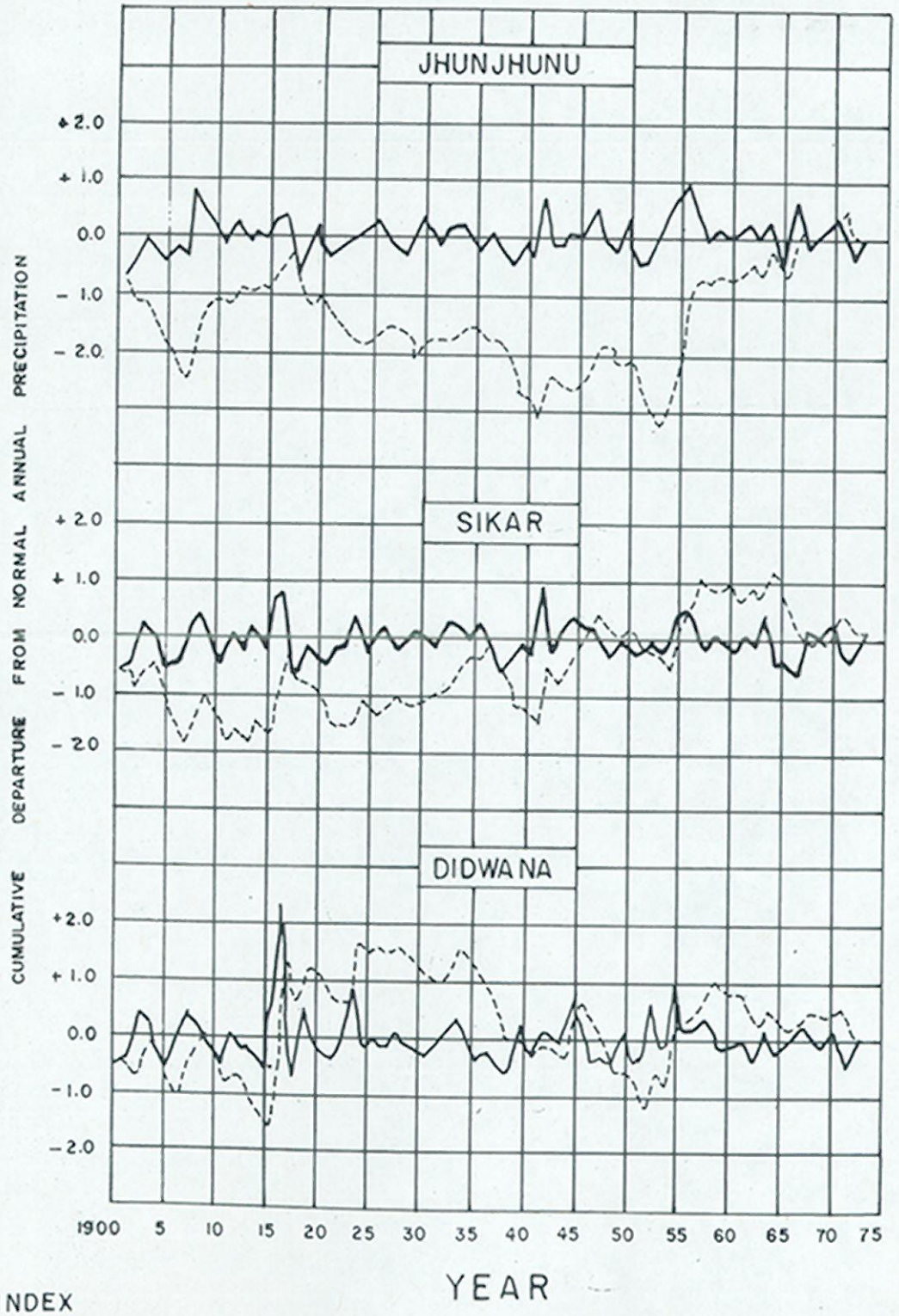


Figure 4

DEPARTURES & CUMULATIVE DEPARTURES FROM NORMAL ANNUAL PRECIPITATION 1901-1973 AT BIKANER, NAWA, NAGAUR & MERTA CITY

(BASED ON NORMALS FOR THE PERIOD 1901-1973)

UNIT: NORMAL ANNUAL RAINFALL

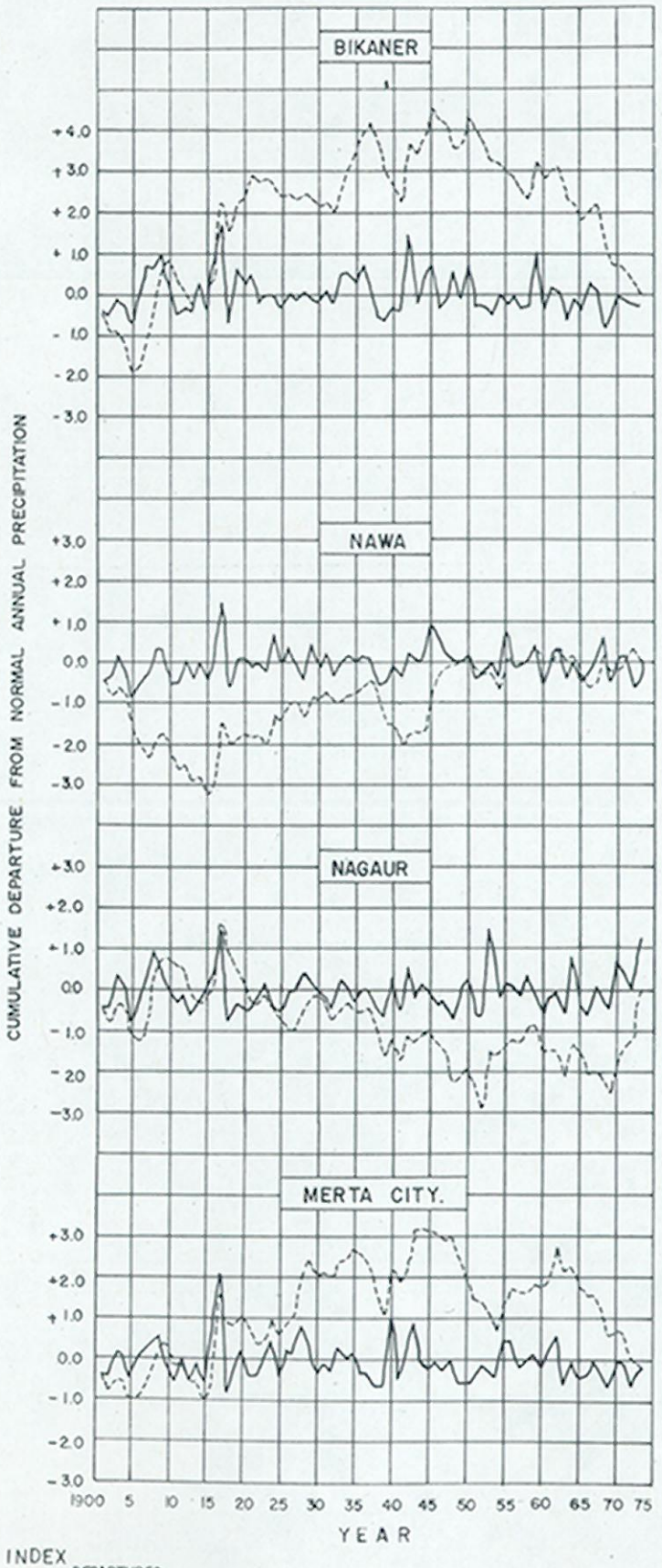


Figure 5

Table 8. Variability of seasonal rainfall

Station	Period of Record	Mean seasonal rainfall (mm)	Co-efficient of variation	Standard error of mean rainfall (mm)
Ratangarh	1906-73	309.73	40.9	15.4
Sardarshahar	1906-73	250.6	50.9	15.5
Churu	1906-73	308.4	42.5	15.8
Dungargarh	1906-73	226.5	48.9	13.4
Rajgarh	1906-73	293.6	46.9	16.7
Taranagar	1906-73	257.0	56.7	16.7
Sujangarh	1906-73	323.0	49.3	19.3
Jhunjhunu	1901-73	338.4	36.7	14.6
Sakar	1901-73	381.6	38.9	17.3
Nawa	1901-50	407.6	44.8	25.9
Parabatsar	1901-73	358.4	45.2	19.0
Didwana	1901-73	317.8	49.2	18.3
Nawalgarh	1914-50	349.3	39.2	22.6
Nagaur	1901-73	279.5	54.4	17.8
Bikaner	1901-73	241.1	53.8	15.2
Nokha (Surpura)	1906-73	237.3	55.4	15.9
Merta City	1901-73	362.2	48.8	20.7
Lunkaransar	1906-73	199.8	49.2	11.9
Palana	1906-73	213.0	57.4	15.3
Gajner	1906-47	213.1	57.9	19.1
Merta Road	1910-50	340.4	44.2	23.5
Average		295.6	48.2	17.7

Table 9. Drought frequencies
Relative frequency of occurrences in per cent of years

Station	Record period	Mild Drought	Normal Drought	Severe Drought	Rare Drought	
Sikar	1901-73	21.6	21.9	8.3	0.0	51.8
Jhunjhunu	1901-73	20.5	21.9	6.8	1.3	50.5
Parabatsar	1901-73	20.5	21.9	9.5	2.7	
Didwana	1901-73	30.1	19.1	5.4	2.7	
Bikaner	1901-73	21.9	23.2	8.2	4.1	57.4
Merta City	1901-73	23.3	21.9	10.9	1.4	
Nagaur	1901-73	16.4	21.9	13.7	4.1	56.1
Churu	1906-73	33.8	14.7	7.3	1.4	
Dungargarh	1906-73	22.1	25.0	7.3	1.4	57.2
Sardarshahar	1906-73	26.4	14.7	10.3	2.9	
Ratangarh	1906-73	20.6	16.2	7.3	4.4	
Rajgarh	1906-73	26.4	20.5	5.8	2.9	
Taranagar	1906-73	19.1	22.1	11.7	4.4	
Sujangarh	1906-73	23.5	19.1	11.7	2.9	
Lunkaransar	1906-73	10.3	26.5	10.3	2.9	
Surpura	1906-73	10.3	32.3	6.8	4.4	
Palana	1906-69	23.4	18.7	7.8	7.8	
Nawa	1901-50	18.0	22.0	10.0	2.0	
Gajner	1906-47	21.4	16.7	11.9	7.1	
Merta Road	1910-50	24.4	12.2	7.3	2.4	
Nawalgarh	1914-50	24.3	18.9	5.4	2.7	
Average		21.9	20.5	8.7	3.1	
Area covered by the Droughts (%)		-	53	76	96	

Departure from annual mean (%)	Type of drought
0.1 to 25.0	Mild drought
25.1 to 50.0	Normal drought
50.1 to 75.0	Severe drought
75.1 to 100.0	Most severe drought (rare droughts)

The following conclusions can be drawn from the classification of droughts and analysis of the frequency of their occurrences:

(1) Rainfall was below normal during 54 per cent of the years and 32 per cent of the years had normal drought conditions, i.e., almost every third year was a drought year;

(2) Severe and rare droughts occurred in 12 per cent of the years with an average recurrence interval of 8 to 9 years;

(3) Rare droughts of most severe intensity occurred on the average once in 32 years;

(4) Normal droughts occurred in 25 years out of a period of 73 years. In 10 of these years the drought affected less than half the total project area;

(5) Rare droughts invariably affect the whole area. Severe droughts cover generally 76 per cent of the area and normal droughts 53 per cent;

(6) Severe drought conditions prevailed for several consecutive years: 1901-1906 (except 1903), 1911-1913, 1918-1922 and 1938-1941;

(7) Normal drought conditions prevailed consecutively during the years: 1935-1937, 1946-1949, 1951-1955 (except 1953), 1965-1969 and 1971-1972.

e. Evaporation

Long-term average monthly values of potential evaporation from land surfaces, computed according to the Penman method for Jodhpur, Bikaner and Ahmedabad, are shown in table 10 together with Thornthwaite estimates of potential evapotranspiration and Class A pan evaporation. 1/ Comparison with observed Class A pan evaporation and computed Thornthwaite potential evaporation for a larger number of stations within and in the neighbourhood of the project area shows that Bikaner can be considered representative for the western arid part of the Rajasthan project area and Jodhpur for the eastern semi-arid part. The uncorrected 10 years mean daily pan evaporation for Bikaner is 7.3 mm and for Jodhpur 7.6 mm. The rather low values for Bikaner might be explained by the wind protected site.

Only long-term mean values were available, and since the variation of potential evaporation from one year to another is smaller than the variation of most other meteorological and hydrological parameters, the long-term mean monthly values were adopted for the individual years.

5. Climates classification and characteristics

The climate of the project area has been classified according to Thornthwaite's Climate Classification (Thornthwaite, 1948).

The precipitation effectiveness (P.E.) ratios were calculated for each month as mean values for the period 1961-1972 and the nine meteorological observatories located within the project area and immediately outside the area.

The P.E. ratio for a month is $115 \left(\frac{P}{T-10}\right)^{10/9}$ where P is the mean monthly rainfall total in inches and T the mean month air temperature in degrees Fahrenheit. The sum of the twelve monthly P.E. ratios is called the P.E. Index, which is shown in table 12 for the nine stations selected.

The classification criteria for the P.E. indexes are shown in table 11. It is quite clear that the most arid conditions prevail in the western part of the project area and that the aridity decreases eastward; 20 per cent of the area is semi-arid (in the east) and 80 per cent arid (table 12).

The aridity of the climate is evident also from the ratio between the potential evaporation and the rainfall which varies from $1,770/220 = 8.0$ in the west to $1,850/450 = 4.1$ in the east in the Sikar basin, that is the potential evaporation is between 8 and 4 times the annual rainfall.

Semi-arid conditions prevail over most of the Sikar basin. About 15 per cent of the western part of the Sikar basin near Churu are classified as arid. Here, the potential evaporation is about four times the annual rainfall.

The weather and climatic conditions are dependent upon the monsoon. Seasonal winds blow in a dominant direction and bring about contrasting weather conditions. This marked seasonal rhythm is the great dominating feature of the climate. The two monsoons are the north-east monsoon and the south-west monsoon. In the Rajasthan project area only the south-west monsoon occurs.

The climate of the project area is characterized by low mean annual rainfall, great seasonal and annual variability of rainfall, erratic heavy daily

1/ Kindly supplied by Dr. A. Krishnan of the Central Arid Zone Research Institute of Jodhpur.

Table 10. Mean monthly and annual evaporation
(in millimetres)

(a) Potential evaporation according to Penman

Station	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Annual
Jodhpur	83.7	101.3	156.3	192.3	264.7	260.3	184.0	145.2	156.1	134.3	87.7	76.5	1843.0
Bikaner	55.3	75.3	131.4	172.4	236.8	258.3	228.2	196.6	177.7	124.7	68.3	48.8	1772.4
Ahmadabad	89.6	104.7	164.4	197.7	284.8	190.8	131.0	116.7	133.7	139.6	99.3	73.9	1676.8

(b) Potential evapotranspiration according to Thornthwaite

Jodhpur	20.2	42.2	140.9	184.5	213.2	210.3	202.1	180.8	166.7	153.8	69.2	27.3	1611.2
Phalodi	12.9	31.7	123.6	182.6	214.4	211.0	207.1	189.8	171.9	154.5	66.6	18.9	1585.0
Bikaner	9.1	24.6	108.2	181.5	214.4	216.8	229.0	195.2	173.6	150.9	53.1	12.6	1569.0
Ahmadabad	47.0	62.3	148.0	182.0	208.7	200.6	185.1	170.0	156.3	149.5	92.0	49.7	1651.21
Pilani	12.7	27.3	97.8	174.1	208.5	213.2	203.8	181.0	160.6	140.8	49.5	16.2	1485.5
Sriganganagar	9.0	20.0	84.5	71.6	213.4	220.3	216.1	197.4	172.4	134.9	35.6	10.5	1385.7
Erinpura Road	15.8	42.7	118.5	180.4	224.3	201.4	188.2	165.5	155.6	144.7	61.9	23.7	1522.7

(c) Class A pan evaporation - wire mesh covered

Bikaner	84.5	124.2	208.7	288.0	378.2	386.3	300.1	240.1	226.1	206.0	125.9	85.1	2653.2
Jodhpur	138.8	167.6	262.6	356.7	456.4	392.6	271.5	212.1	216.6	208.1	160.5	130.3	2973.8
Ahmadabad	158.3	151.5	280.3	346.3	401.2	300.7	158.4	138.2	161.1	204.9	180.8	156.4	2638.3
Viramgam	237.1	220.6	340.5	443.9	510.4	426.9	270.9	246.3	238.7	268.1	236.1	211.1	3650.6

Table 11. Criteria of climatic classification based on precipitation effectiveness

Symbol	Humidity province	Characteristic vegetation	Annual P.E. index
A	Wet	Rain forest	Greater than 128
B	Humid	Forest	64 - 127
C	Sub-humid	Grassland	32 - 63
D	Semi-arid	Steppe	16 - 31
E	Arid	Desert	Less than 16

Table 12. Climatic zones of the project area

Station	Annual P.E. index	Type of climate	Vegetation
Jodhpur *	13.7	Arid	Desert
Phalodi *	8.5	Arid	Desert
Nagaur	13.9	Arid	Desert
Bikaner	8.2	Arid	Desert
Sikar	18.2	Semi-arid	Steppe
Churu	13.7	Arid	Desert
Pilani *	17.2	Semi-arid	Steppe
Sri Ganganagar *	10.9	Arid	Desert
Erinpura Road *	25.2	Semi-arid	Steppe

* Observatory outside Project area.

rainfalls, very high rate of potential evaporation and extreme temperatures. The average long-term annual rainfall varies in the Sikar basin between 450 and 350 mm proceeding from east to west. Annual rainfall is only about 220 mm in the western part of the Rajasthan project area.

The small amount of rainfall that occurs during the period November-February is caused by western disturbances originating in the Persian Gulf with a frequency of 3 or 4 a month. In the wake of these disturbances, cold-weather conditions occur and the temperature sometimes drops below freezing. January is the coldest month (see table 2). April-June is the hottest period, when the maximum daily air temperature sometimes exceeds 45 degrees Centigrade with 55 degrees Centigrade being the highest temperature observed. During the hot season dust storms and thunderstorms occur.

Normally, the south-west monsoon sets in between 28 June and 8 July and ceases between 1 and 15 September. During this rainy season about 87 per cent of the annual rainfall occurs. At the same time, the temperature decreases and the air humidity increases. July and August are the wettest months with each month receiving about 30 per cent of the annual rainfall. Highest wind speeds also are observed during the monsoon season.

The highest relative humidity is also observed in August - 80 per cent in the morning, 65 per cent in the evening. The annual and seasonal variability of rainfall is very great.

C. Geology

1. Stratigraphy and aquifer properties

Most of the project area is covered with Quaternary deposits which rest, in the western part, above sedimentary formations of Tertiary and older age, and in the eastern part, above Precambrian basement rocks. The known stratigraphic succession in the area comprises formations from Precambrian to Recent age. The formations and their main hydrogeologic characteristics are described in table 13.

A deep project borehole at Manasir (near Nagaur) penetrated the upper sandstone and the underlying limestone-evaporite sequence of the Nagaur Series and terminated in the Jodhpur Sandstone. Palynological studies of a core sample taken from the base of the limestone-evaporite sequence suggest a Lower Tertiary age. A project borehole, farther north at Lakhasar, encountered pure crystalline salt (halite) which may be correlated with the Kohat (Pakistan) salt of Lower Tertiary age.

2. Structure

The most significant structural feature is a major longitudinal fault that divides the area into two geologically distinct parts: the Precambrian basement platform on its eastern upthrow side, and Lower Tertiary terrain on its western downthrow side (see fig. 6). The throw of this fault exceeds 500 m in the extreme south and north of the project area.

There exist some smaller faults parallel to this major fault. Two cross faults are inferred from lateral dislocation of the major fault line (near Yael and Ladnum).

For the area west of the fault, structural contours have been drawn for the top of the limestone-evaporite sequence of Paleocene-Lower Eocene Nagaur Series. This sedimentary area is subdivided into three structural units: the Bikaner syncline in the north, the Nagaur uplift in the south, and a downfaulted graben structure filled by thick Quaternary alluvial deposits, in the south-east on the downthrow side of the major fault (Luni basin).

For the eastern, Precambrian part of the area, contour lines for the top of the buried or exposed Precambrian erosional surface are shown.

The geological cross-sections (figs. 7-9) demonstrate sub-surface conditions in the various parts of the project area.

D. Ground-water Basins

Three hydrogeologic units have been identified in the Rajasthan project area, on the basis of structural and lithologic criteria designated as the Sikar, Bikaner and Luni basins. Data from existing tubewells are given in annex 1.

1. Sikar basin

a. Description of basin

The Sikar basin is limited in the east by the impervious rocks of the Aravalli mountains, and in the south and west by structurally high subcrops of the impervious basement. Towards the north, there is no clear geologic boundary, and the transition into saline ground-water zones is taken as its limit. The basin extends over about 14,500 km^2.

b. Aquifers

The principal aquifer consists primarily of aeolian sand. The sand is composed of well rounded, very fine to fine grains, of yellowish colour, with lenses of silt and some clay beds as shown by the log of an observation hole drilled at Setolao (fig. 10). Locally, the sediments contain calcareous concretions and lenses known as kankar.

The total thickness of the unconsolidated aeolian sand overlying the hard-rock formations range up to 100 m. Thickness of the saturated zone of the aquiferous formation averages 55 m. The sand overlies Precambrian hardrock formation and in the north-western part of the basin the sand is found over the Jodhpur sandstone.

Table 13. General geologic sequence and aquifer properties

Era	Period	Series/system	Lithologic description	Aquifer properties
Quaternary	Recent to Sub-Recent	Dune sand, alluvium	Aeolian sand, river flood deposits and valley fill deposits	Major aquifer in project area
	Pleistocene	Pebble, cobble and boulder beds	Pebble to boulder conglomerate	Above water table
			Unconformity	
Tertiary	Lower Eocene	Palana series	Upper part: sandstone, white to pink, fine to coarse grained to gravelly, locally consolidated. Lower part: Varied, pink to reddish brown clay. Lignite widespread south of Bikaner. Nummulitic limestone at the top.	The sandstone is a good aquifer in parts of the Bikaner and Luni Basins.
	Lower Eocene to Paleocene	Nagaur series	Sandstone-claystone sequence: Sandstone, pink to reddish brown. Very fine to coarse, micaceous, generally compact, intercalated and interbedded with red claystone and shale.	Aquifer with low water yielding capacity
			Limestone-evaporite sequence: anhydrite and gypsum, halite in Lakhasar, mainly in the upper part. Limestone partly dolomitic or siliceous, associated with red clay and some sandstone, predominating in the lower part.	Small quantities of fresh water only in restricted areas
			Unconformity	
Paleozoic	Cambrian	Jodhpur Sandstone (Vindhyan)	Sandstone, purple to reddish brown, fine to very coarse, micaceous, very compact, associated with red claystone	Poor aquifer
			Unconformity	
Proterozoic	Upper Precambrian	Malani suite Delhi system	Acid volcanic rock and granite. Mainly quartzite and impure calcareous rock.	
		Raialo series	Marble (Makrana marbles) schist	Small localized quantities of water from fractured and weathered zone
			Unconformity	
Azoic	Archean	Aravalli system	Metamorphic schist, phyllite quartzite and marble. Gneiss and granite.	Small localized quantities of water from fractured and weathered zones

Grain-size analyses of formation samples taken from boreholes in various parts of the Sikar basin (table 14) demonstrate the homogeneity of the aeolian deposits, although some of the samples may be mixed as a result of caving in the borehole.

Table 14. Grain size of aeolian deposits in the Sikar basin

Location	Size of grains retained (mm) 90% Effective size	50% Mean size	40% size
Jhunjhunu	0.077	0.265	0.560
Mukandgarh	0.082	0.860	1.500
Fatehpur	0.092	2.400	2.750
Dadhia	0.065	0.124	0.151
Talab-Ki-Dhani	0.066	0.125	0.140
Anandpura	0.067	0.104	0.126

The unusual amount of coarser grains in the Fatehpur sample was identified as kankar nodules. The grading analyses of part of the samples are graphically presented in figure 11.

c. Depth to water table, direction of ground-water flow and saturated thickness of the aquifer

Depth to water table ranges from 50 m near the foothills in the south-east to 20 m near the northern boundary of the basin. Over most of the area, depth to water table is between 30 and 45 metres (see fig. 13).

The configuration of the water table can be roughly appraised on the basis of a ground-water contour map with figure 17. The general direction of ground-water flow is from the hill region in the east and the elevated basement subcrops in the south of the basin towards north and north-west.

The saturated thickness of the aquifer averages about 55 metres throughout the basin and reaches a maximum of over 80 metres near Sikar (see fig. 12). The maximum saturated thickness recorded in boreholes was found at Dadhia and Setolao (78 and 72 metres respectively, annex 3).

d. Hydraulic characteristics of the aquifer

Six pumping tests with one or more observation wells were carried out in the Sikar basin (fig. 13). Responses of the water level showed the delay phenomena and phreatic conditions to be as expected from a sandy aquifer. Boulton's equation corresponds to these conditions and was applied for the interpretation of the result (annex 2).

The initial trend of the time-drawdown graph according to Jacob's method gives a reasonable although higher transmissivity value, as compared to the one obtained by Boulton's method. This way of interpretation is useful in those cases where no observation wells are present, and the duration of the test is too short to permit the recording of the water level trend after the cessation of the delayed yield phenomenon (see fig. 14).

The hydraulic characteristics obtained from the pumping tests are shown in table 15. Transmissivities range from 111 to 327 m^2 per day, with an average of 230 m^2 per day. The lowest transmissivity was found in the Anandpura well, probably owing to the reduced thickness of the aquifer due to a high elevation of the basement. The second lowest transmissivity corresponds to the Talab-Ki-Dhani well, also located in an area of relatively high elevation of the impervious basement.

The highest transmissivity was found in the Fatehpur well, located in the central area of the basin. Coefficients of permeability range from 2.6 m/day in the Anandpura well to 6.8 m/day in the Fatehpur well.

Specific yield (or effective porosity) varies between 7.4 and 15 per cent with an average of about 10 per cent.

Specific capacities of wells tested range from 5.9 $m^3/h/m$ in the Mukandgarh well to 16.4 $m^3/h/m$ in the Fatehpur well, with an average of 11 $m^3/h/m$.

e. Determination of aquifer characteristics with radio-isotope tracers

Radio-isotope tracers were used in testing the Setolao well, with the objective to obtain figures for the hydraulic characteristics of the aquifer by an additional method.

Tritiated water (HTO) and chromium-51 -EDTA served as tracers to determine the specific yield (effective porosity) of the unconfined aquifer of the Sikar basin at this point. Field tests were conducted 2/ in February and March 1974. Field procedures followed those described by Halevy (1963).

Tracers consisting of 330 millicuries of chromium-51 -EDTA complex and 220 millicuries of tritiated water (HTO) were introduced into a well located at a distance of 72.5 m from the pumping well. Pumping at a constant discharge rate of 138.3 m^3/h started a few hours in advance of the injection of the tracers, and continued for 33 days.

Gamma radiation emitted by the chromium-51-EDTA tracer was periodically observed by a waterproof scintillation probe, immersed in a 600-litre-capacity measuring tank, through which about 4 per cent of the water pumped from the pumping well was flowing. For observing the activity originating from the tritium tracer, samples were taken at

2/ In co-operation with the Nuclear Research Laboratory of the Indian Agricultural Research Institute, Pusa, in New Delhi.

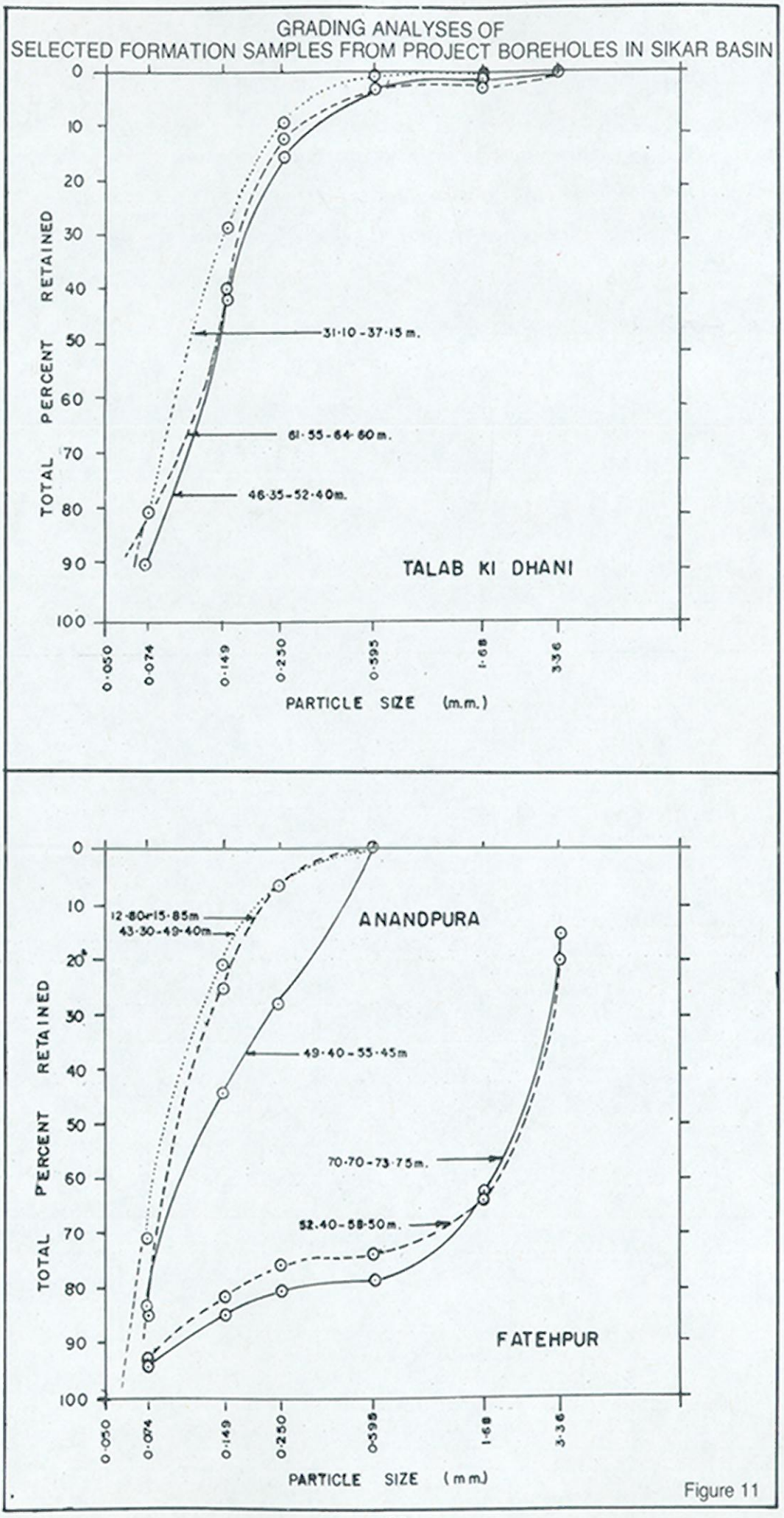

GRADING ANALYSES OF
SELECTED FORMATION SAMPLES FROM PROJECT BOREHOLES IN SIKAR BASIN
TOTAL PERCENT RETAINED
0
10
20
30
40
50
60
70
80
90
100
31·10 - 37·15 m.
61·55 - 64·60 m.
46·35 - 52·40m.
TALAB KI DHANI
0·050
0·074
0·149
0·250
0·595
1·68
3·36
PARTICLE SIZE (m.m.)
12·80 - 15·85m
43·30 - 49·40m
ANANDPURA
49·40 - 55·45m
70·70 - 73·75m.
52·40 - 58·50m.
FATEHPUR
PARTICLE SIZE (mm)

Figure 11

Table 15. Hydraulic characteristics of the aquifer in the Sikar Basin as obtained from pumping tests

Site	Pumping rate		*Specific capacity		Saturated thickness		Co-efficient of transmissivity		Field Co-efficient of permeability		Specific yield
	m^3/h	US/GPM	$m^3/h/m$	US/GPM/ft	m	ft	m^2/d	US/GPD/ft	m/d	US/GPD/ft^2	$x10^{-2}$
Anandpura	90.8	400	9.0	12.1	43	141	111	8,938	2.6	63	7.4
Dadbia	95.4	420	12.9	17.5	78	255.9	287	23,109	3.7	90	7.6
Fatehpur	90.8	400	16.4	22.0	48	157.5	327	26,330	6.8	167	15.0
Jhunjhunu	56.8	250	7.3	9.8	40	131.2	156	12,561	3.9	96	10.1
Mukandgarh	68.1	300	5.9	7.9	60	196.8	256	20,613	4.3	105	1.3
Setelao	138.3	609	15.8	21.2	72	236.2	288	23,190	4.0	98	6.1
Talab-Ki-Dhani	56.8	250	9.6	12.8	34	111.5	186	14,977	5.5	134	12.9
Average			10.98	14.76	54	175.7	230	18,531	4.4	105	10.3

* Specific capacity after one day of pumping.

TIME-DRAWDOWN CURVES FOR OBSERVATION WELLS FROM PUMPING TEST IN SETOLAO TEST WELL

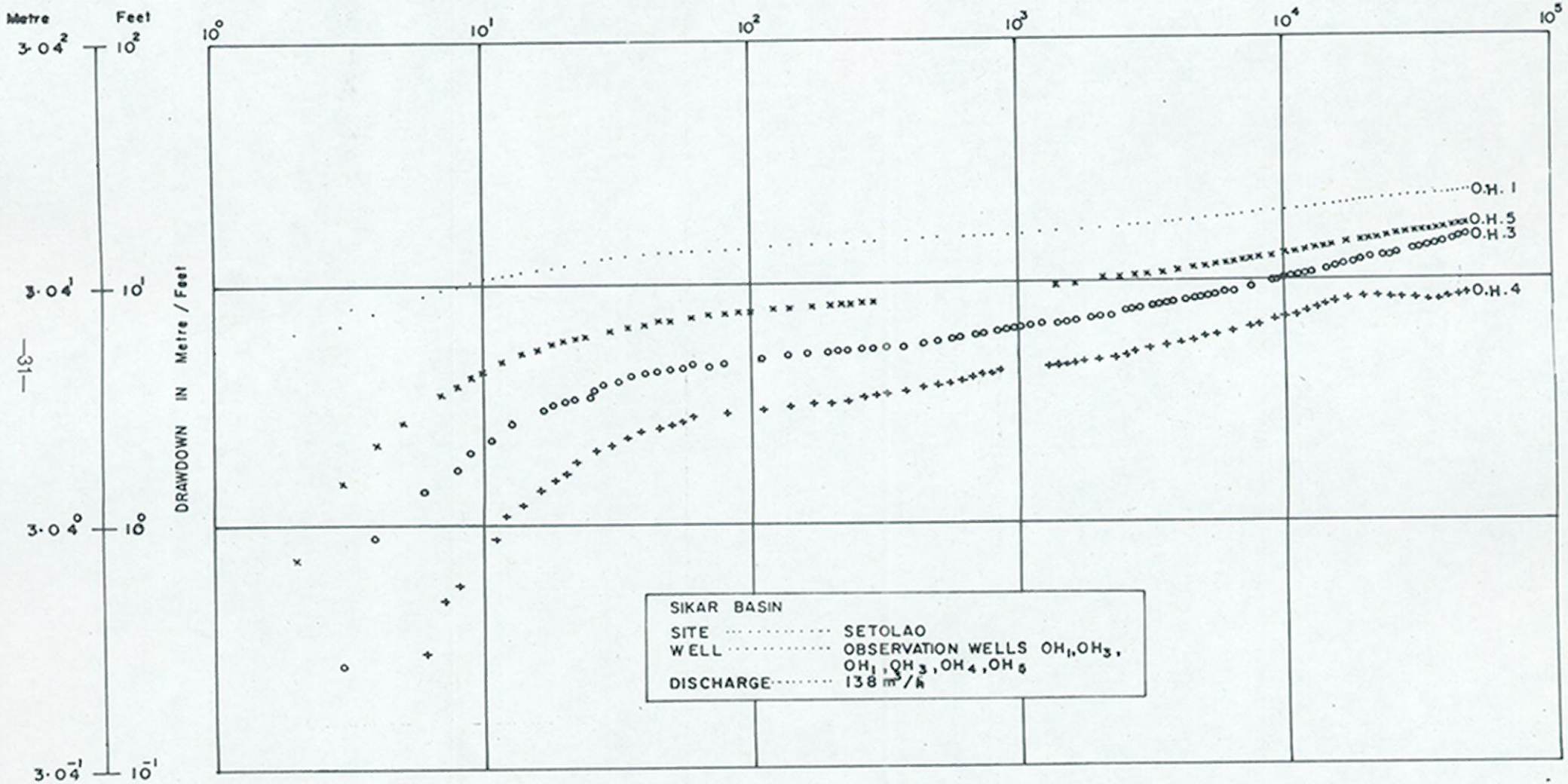


Figure 14

TRITIUM CONCENTRATION DISTRIBUTION IN PUMPING WELL
AT SETOLAO – SIKAR BASIN, RAJASTHAN

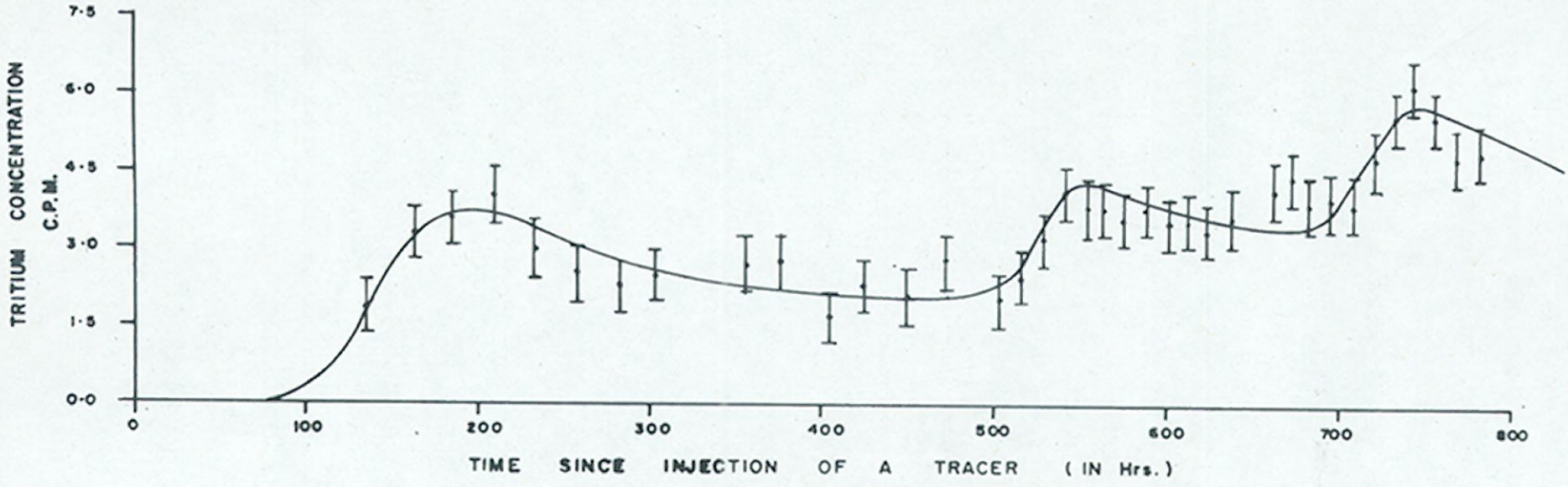
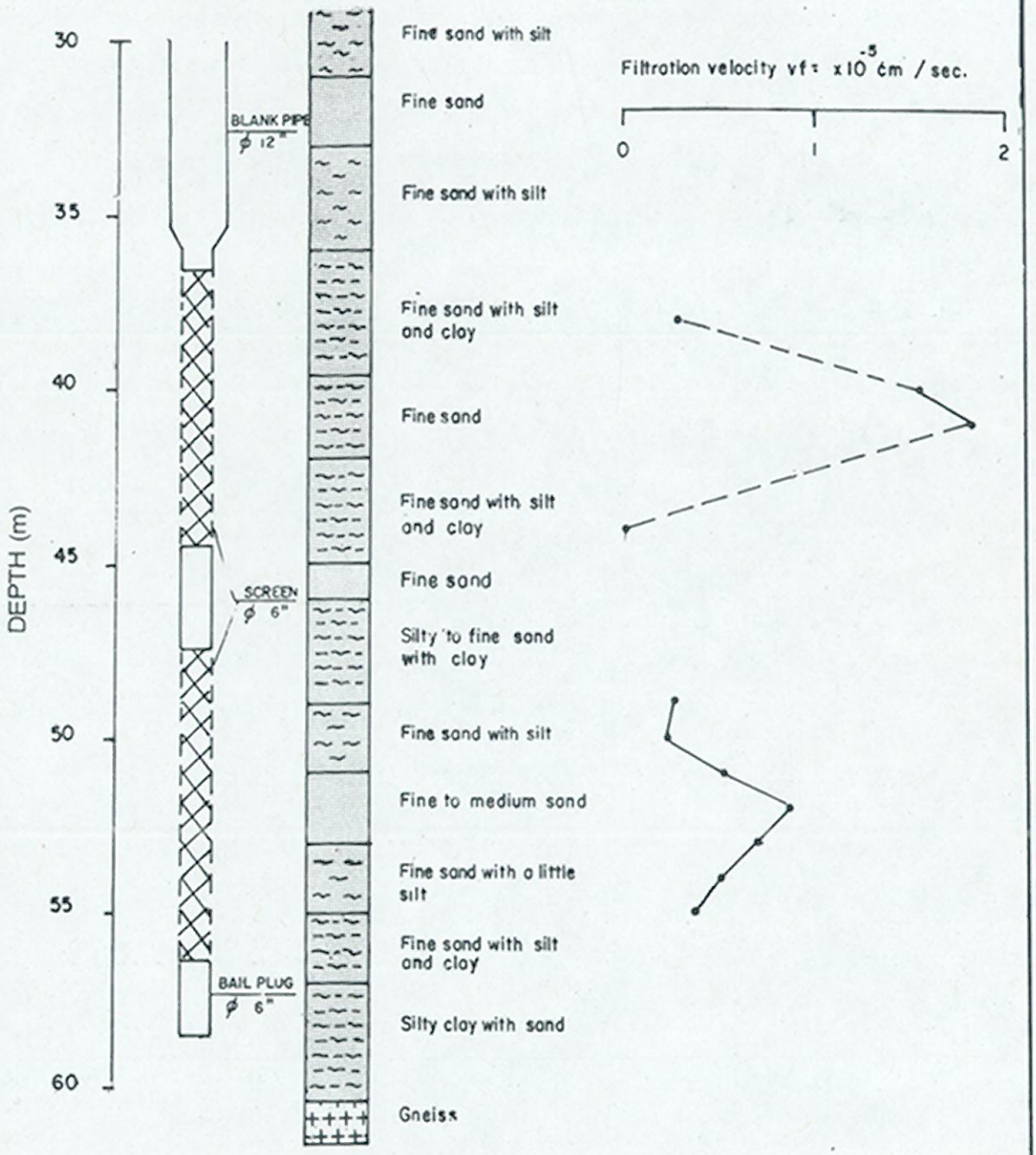


Figure 15



INDIA

GROUNDWATER SURVEYS IN RAJASTHAN & GUJARAT

FILTRATION VELOCITY DISTRIBUTION IN A TEST WELL AT ANANDPURA

RAJASTHAN PROJECT AREA

Vertical Scale 0 5 10 Metre

Figure 16

2. Bikaner basin

a. Description of basin

The Bikaner basin adjoins the Sikar basin in the west. It extends over 21,000 km^2, covering roughly half of the project area. The Palana Sandstone member of the Palana series of Lower Eocene age is the main aquifer in the Bikaner basin. Other aquiferous formations are sandstones and limestones of the Nagaur series, and the Jodhpur Sandstone. A major fault separates this basin from the Sikar basin in the east, and extends into the Merta Trough, which forms part of the Luni basin.

b. Palana Sandstone aquifer

The Palana Sandstone is fine to coarse grained, well sorted, white to gray with some pink tinge, poorly to moderately cemented, soft and friable. Locally it is more gravelly and poorly sorted and it is intercalated with thin clay beds, especially in their lower part, close to their contact with the thick lower clay member of the Palana series (see also fig. 20).

The Palana Sandstone overlies the Nagaur series of Lower Eocene to Paleocene age and is topped by Quaternary deposits. These, too, form part of the aquifer wherever they extend below the water table. The contact between the Palana Sandstone and the Quaternary deposits is not well defined.

The saturated section of the aquifer attains its greatest thickness in the northern part of the basin, north of Bikaner, where it exceeds 80 m (fig. 12). However, the general tendency of increase in thickness of the aquiferous section towards the north - in accordance with the regional structural pattern - is disturbed in the axial part of the Bikaner syncline by an increase in thickness of the lower clay member, and a corresponding reduction in thickness of the sandstone member, so that the saturated thickness of the aquifer is greatly reduced (only 15 m at Sital, see fig. 12). The average thickness of the aquifer over the rest of the basin is about 40 m.

Aquifer characteristics were obtained from pumping tests performed in 4 tubewells and interpretation of their results, using the Jacob formula (table 16). Figure 17 shows the position of the water table.

A representative semi-logarithmic time drawdown curve is presented in figure 18, to illustrate the behaviour of the water level during the test, which was of about 30 hours duration.

Because of equipment failures, only one pumping test was of a sufficient duration to indicate leaky aquifer or delayed yield conditions. The leakage may be due to slow drainage from beds with low permeability such as silt, very fine sand and clay.

The storage coefficient obtained from one of the tests (Mudh) is characteristic for confined conditions, but this seems to be a local phenomenon because geologic and hydrogeologic data indicate phreatic conditions. Specific capacities of wells range from 3.6 to 28.1 m^3/h/m. Transmissivities obtained from tests range between 99 m^2/day and 1,024 m^2/day; permeability varies between 1.65 m/day and 13.5 m/day.

Transmissivity over most of the basin is assumed to range between 100 and 200 m^2/day. In the axial zone of the syncline where the aquifer is thin, transmissivity remains much below 100 m^2/day. Relatively high transmissivities of about 100 m^2/day are to be expected in the eastern part of the basin, and at the western limit of the project area at Raneri. Average specific yield of the aquifer is estimated at 7 per cent.

c. Aquifers of the Nagaur series

The upper part of the Nagaur series is composed of the Nagaur Sandstone member. In the uplifted Nagaur area it is exposed, or eroded, and forms a discontinuous phreatic aquifer. Thickness of the saturated zone varies from a few metres to about 50 m. Elsewhere in the basin, this lithologic unit is found at depth ranging from 130 to 260 m, and constitutes a confined aquifer of 40 to 310 m thickness.

Transmissivities are low, ranging from 2.5 to 50 m^2/day. Permeabilities are correspondingly low. Specific capacities of wells range between 0.17 and 1.20 m3/h/m. The specific yield of the aquifer is estimated at 1.0 per cent. The time drawdown curve from a pumping test in the Mudh well is presented in figure 19.

Another aquiferous unit associated with the Nagaur series is the lower part of the limestone-evaporite sequence, mainly composed of limestone.

In some fault blocks in the Nagaur area, the evaporites have been removed by erosion and there the limestones supply a small amount of fresh water to dug wells. Fresh water may be produced from the limestones also in some fault zones, but the extent of such aquifers is limited. In most parts of the Bikaner basin, limestone is associated with evaporites, and even where hydraulic characteristics are favourable, the water is too saline for most purposes.

d. Jodhpur Sandstone aquifer

A narrow belt of Jodhpur Sandstone is present between the major fault and the basement block, in the south-eastern part of the Bikaner basin. The sandstone is compact, fine to coarse grained micaceous, purple to reddish brown. It constitutes a poor aquifer. A few dug wells produce a small amount of water of variable quality. In most of the Bikaner basin, the Jodhpur Sandstone lies below the evaporite sequence and the ground-water it contains is saline.

Table 16. Hydraulic characteristics of aquifers in Bikaner Basin as obtained from pumping tests

Location	Aquifer	Type of aquifer ***	Pumping rate		Specific cap.*		Saturated thickness		Co-efficient of transmissivity		Co-efficient of permeability		Storage co-efficient
			m^3/h	USGPM	$m^3/h/m$	USGPM/ft	m	ft	m2/d	USGPD/ft	m/d	USGPD/ft	
Bandnau	Palana Sdst.	P	28.40 63.40	125 301	37.6 21.7	50.00 29.1	76	249	1,024	82,500	13.5	331.30	-
Gadwala II	"	"	56.80	250	3.90	5.30	60	197	99	8,000	1.65	40.40	-
Jasrasar	"	"	20.4	90	3.62	4.87	12	39.40	122	9,825	10.10	247.85	-
Raneri	"	"	50.00	220	28.10	37.80	95	312	721	58,000	9.50	233.10	-
Pharrod	Nagaur Sdst.	"	2.60	11.30	0.17	0.23	33	108	2.5	205	0.078	1.90	-
Gadwala I	"	C	45.40	200	1.20	1.60	121	397	36	2,900	0.30	7.3	-
Mudh **	"	"	28.40	125	0.98	1.32	88	289	53	4,265	0.60	14.72	4.2×10^{-5}
Sital	"	"	13.20	58.20	0.26	0.35	64	210	9.0	730	0.14	3.43	-

* Specific capacity after 24 hours of pumping.

** Hydraulic characteristics of Mudh well were calculated from observation well data

*** C - Confined; P - Phreatic

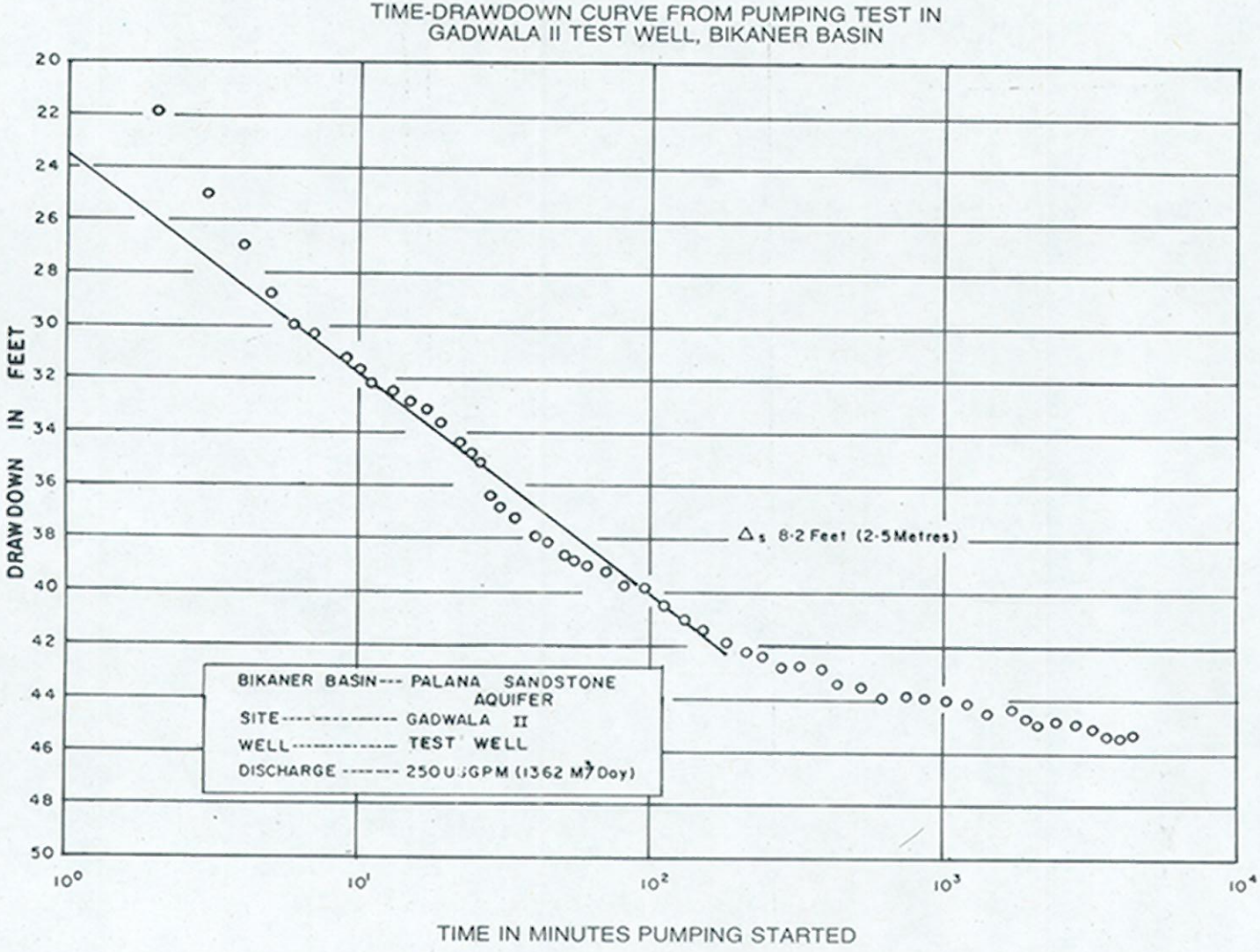

TIME-DRAWDOWN CURVE FROM PUMPING TEST IN
GADWALA II TEST WELL, BIKANER BASIN
DRAWDOWN IN FEET
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
10^0
10^1
10^2
10^3
10^4
Δ_s 8·2 Feet (2·5 Metres)
BIKANER BASIN--- PALANA SANDSTONE AQUIFER
SITE---------- GADWALA II
WELL---------- TEST WELL
DISCHARGE ------ 2500 GPM (1362 M³/Day)
TIME IN MINUTES PUMPING STARTED

Figure 18

TIME-DRAWDOWN CURVE FOR OBSERVATION WELL FROM PUMPING TEST
IN MUDH WELL, BIKANER BASIN

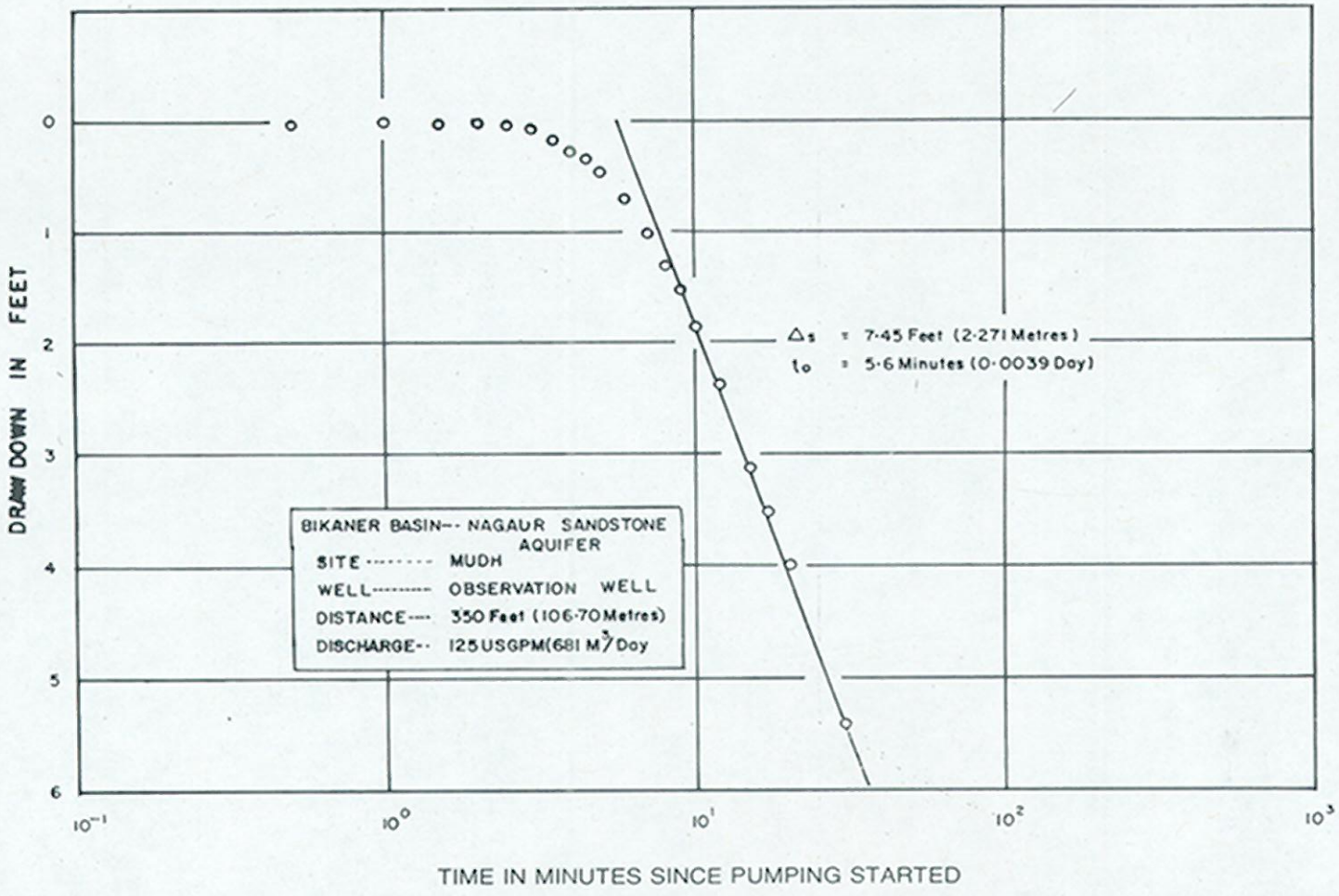


Figure 19

The log of the Bandnau well (fig. 20) gives an example of the succession of aquiferous and non-aquiferous formations in the north-eastern part of the Bikaner basin. The grading analyses of selected samples (fig. 21) present an impression of the grading of the sandstones.

3. Luni basin

a. Description of basin

The Luni basin is situated in the southern part of the project area and covers approximately 5,500 km^2. It is traversed, in an approximate north-south direction, by the major fault separating basement terrain on its east side from sedimentary terrain on its west, corresponding to a structural depression called the Merta Trough. East of the main fault, Quaternary alluvial sediments overlying the Precambrian impervious basement constitute the main aquifer. West of the fault, in the Merta Trough, a single, mainly phreatic aquifer exists in the Tertiary-Quaternary sequence.

The Quaternary alluvium consists of coarse to very coarse grained sand, with beds of sub-angular to subrounded pebbles and gravels (figs. 22 and 23). Locally, the sand is mixed with silt and variegated plastic clay. The intercalations of clay in the lower part of the saturated zone create confined conditions at Badauli and leaky confined conditions at Padukalan, both in the southern part of the basin (fig. 22).

b. Aquifers

The saturated thickness of the Quaternary aquifer in most of the eastern part of the basin ranges between 15 and 50 m. On the north-western border of the basin, the Palana Sandstone member is exposed and dips towards it centre. It has been partially eroded prior to the deposition of the Quaternary alluvium.

The sandstones here are generally coarse to very coarse grained, and contain also some finer material and gravel lenses. They are loosely consolidated, with the exception of a few tighter beds, formed by a greater proportion of admixed clay. The sandstones of the Nagaur series are generally more consolidated and richer in gravel beds than the overlying Palana Sandstones. Because of the absence of continuous clay layers, the alluvium, the Palana Sandstone and the Nagaur Sandstone form a single aquifer. The thickness of the Tertiary sandstones, exclusive of non-aquiferous clay beds, is 140 to 240 metres. The saturated thickness of the combined Tertiary-Quaternary aquifer complex is between 180 and 270 metres.

Another potentially aquiferous unit is the limestone member of the Nagaur series tested in three of the project boreholes. Maximum thickness of the limestones penetrated by these holes was 140 m. The unit consists of thin layers of hard limestone alternating with beds of reddish claystone. The uppermost clay bed covering the limestone is not continuous, and does not provide hydraulic separation from the overlying sandstones.

A few dug wells in the Luni basin produce some ground water from the rocks of the basement complex. They consist in this area of mainly granite, phyllite, quartzite, gneiss and marble. Ground-water movement and occurrence is controlled by fracture joints and solution cavities, like those found in the Makrana marble.

Specific capacities of wells range from 0.6 to 79 m^3, with most values remaining between 7 and 12 $m^3/h/m$ in areas of medium to good transmissivity.

Permeabilities in the Quaternary alluvium are fair to high, with an average of 5 m/day. The Tertiary sandstone has low permeabilities because of the presence of cementing material. Zone tests at Oladan and Lai yielded little water.

Effective porosity in the saturated part of the alluvium and in the Palana Sandstone is at least 7 per cent. Various lithologic logs show a relatively high proportion of clay in the zone of fluctuation of the water table, and an effective porosity of about 5 per cent should be attributed to this portion of the aquifer.

d. Depth of water table and flow regime

Depth to water table ranges from 15 m near the Luni River to about 70 m in the northern part of the basin, mainly depending on topographic conditions. Over the greater part of the basin, depth to water table is between 30 and 50 m.

In the eastern part of the basin, ground-water flow is directed westwards, from the Aravalli range towards the centre of the basin. In the western part, the ground-water flow is directed westwards, from the Aravalli range towards the centre of the basin. In the western part, the ground-water flow assumes a southern direction in the Luni River catchment, which is limited in the north by a surface-water divide west of Degana. North of this divide, ground-water flow is deflected to the north-west, towards the aquifers of the Bikaner basin. The surface-water divide coincides, therefore, with a ground-water divide.

The average specific yield of the basement aquifer is estimated at 0.5 per cent. Depth of the water table ranges from 5 to 70 metres, depending on surface elevations. It is believed that near the centre of the Luni basin, where intense tectonic activity created faults and fractures, buried valleys and deeply weathered zones may be found which could provide more favourable conditions for ground-water occurrences.

e. Hydraulic characteristics of the aquifer

The hydraulic characteristics of the Tertiary-

The log of the Bandnau well (fig. 20) gives an example of the succession of aquiferous and non-aquiferous formations in the north-eastern part of the Bikaner basin. The grading analyses of selected samples (fig. 21) present an impression of the grading of the sandstones.

3. Luni basin

a. Description of basin

The Luni basin is situated in the southern part of the project area and covers approximately 5,500 km^2. It is traversed, in an approximate north-south direction, by the major fault separating basement terrain on its east side from sedimentary terrain on its west, corresponding to a structural depression called the Merta Trough. East of the main fault, Quaternary alluvial sediments overlying the Precambrian impervious basement constitute the main aquifer. West of the fault, in the Merta Trough, a single, mainly phreatic aquifer exists in the Tertiary-Quaternary sequence.

The Quaternary alluvium consists of coarse to very coarse grained sand, with beds of sub-angular to subrounded pebbles and gravels (figs. 22 and 23). Locally, the sand is mixed with silt and variegated plastic clay. The intercalations of clay in the lower part of the saturated zone create confined conditions at Badauli and leaky confined conditions at Padukalan, both in the southern part of the basin (fig. 22).

b. Aquifers

The saturated thickness of the Quaternary aquifer in most of the eastern part of the basin ranges between 15 and 50 m. On the north-western border of the basin, the Palana Sandstone member is exposed and dips towards it centre. It has been partially eroded prior to the deposition of the Quaternary alluvium.

The sandstones here are generally coarse to very coarse grained, and contain also some finer material and gravel lenses. They are loosely consolidated, with the exception of a few tighter beds, formed by a greater proportion of admixed clay. The sandstones of the Nagaur series are generally more consolidated and richer in gravel beds than the overlying Palana Sandstones. Because of the absence of continuous clay layers, the alluvium, the Palana Sandstone and the Nagaur Sandstone form a single aquifer. The thickness of the Tertiary sandstones, exclusive of non-aquiferous clay beds, is 140 to 240 metres. The saturated thickness of the combined Tertiary-Quaternary aquifer complex is between 180 and 270 metres.

Another potentially aquiferous unit is the limestone member of the Nagaur series tested in three of the project boreholes. Maximum thickness of the limestones penetrated by these holes was 140 m. The unit consists of thin layers of hard limestone alternating with beds of reddish claystone. The uppermost clay bed covering the limestone is not continuous, and does not provide hydraulic separation from the overlying sandstones.

A few dug wells in the Luni basin produce some ground water from the rocks of the basement complex. They consist in this area of mainly granite, phyllite, quartzite, gneiss and marble. Ground-water movement and occurrence is controlled by fracture joints and solution cavities, like those found in the Makrana marble.

Specific capacities of wells range from 0.6 to 79 m^3, with most values remaining between 7 and 12 $m^3/h/m$ in areas of medium to good transmissivity.

Permeabilities in the Quaternary alluvium are fair to high, with an average of 5 m/day. The Tertiary sandstone has low permeabilities because of the presence of cementing material. Zone tests at Oladan and Lai yielded little water.

Effective porosity in the saturated part of the alluvium and in the Palana Sandstone is at least 7 per cent. Various lithologic logs show a relatively high proportion of clay in the zone of fluctuation of the water table, and an effective porosity of about 5 per cent should be attributed to this portion of the aquifer.

d. Depth of water table and flow regime

Depth to water table ranges from 15 m near the Luni River to about 70 m in the northern part of the basin, mainly depending on topographic conditions. Over the greater part of the basin, depth to water table is between 30 and 50 m.

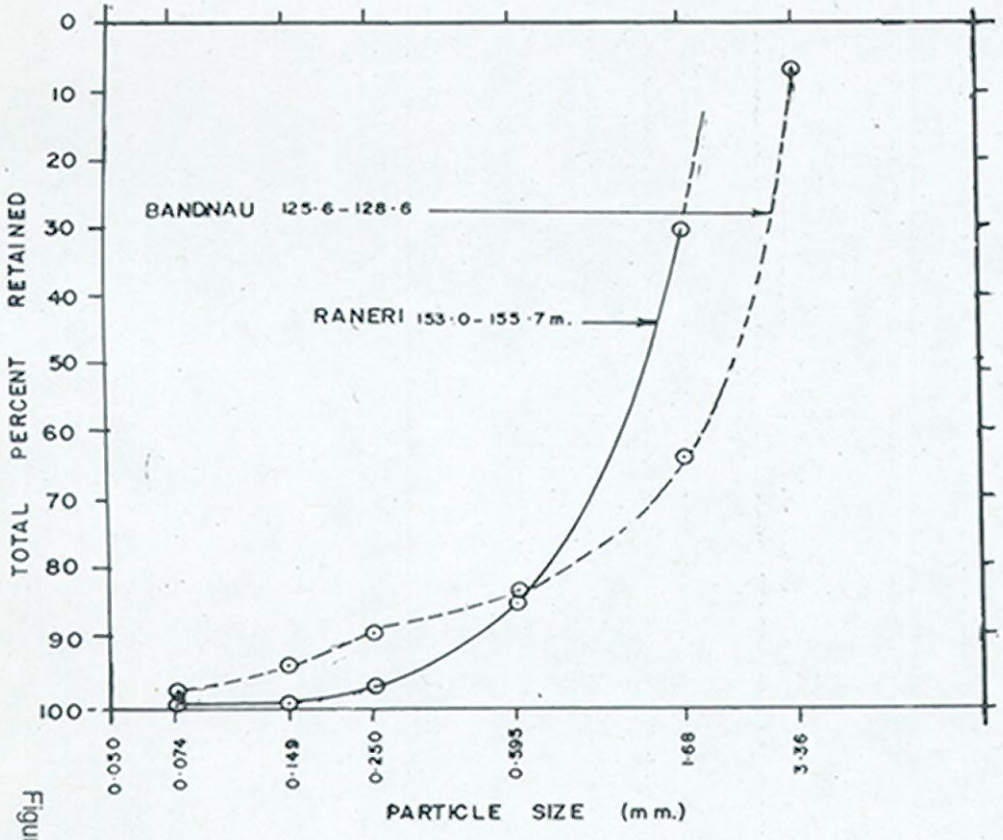
In the eastern part of the basin, ground-water flow is directed westwards, from the Aravalli range towards the centre of the basin. In the western part, the ground-water flow is directed westwards, from the Aravalli range towards the centre of the basin. In the western part, the ground-water flow assumes a southern direction in the Luni River catchment, which is limited in the north by a surface-water divide west of Degana. North of this divide, ground-water flow is deflected to the north-west, towards the aquifers of the Bikaner basin. The surface-water divide coincides, therefore, with a ground-water divide.

The average specific yield of the basement aquifer is estimated at 0.5 per cent. Depth of the water table ranges from 5 to 70 metres, depending on surface elevations. It is believed that near the centre of the Luni basin, where intense tectonic activity created faults and fractures, buried valleys and deeply weathered zones may be found which could provide more favourable conditions for ground-water occurrences.

e. Hydraulic characteristics of the aquifer

The hydraulic characteristics of the Tertiary-

GRADING ANALYSES OF SELECTED FORMATION SAMPLES FROM MUDH, BANDNAU AND RANERI WELLS, BIKANER BASIN



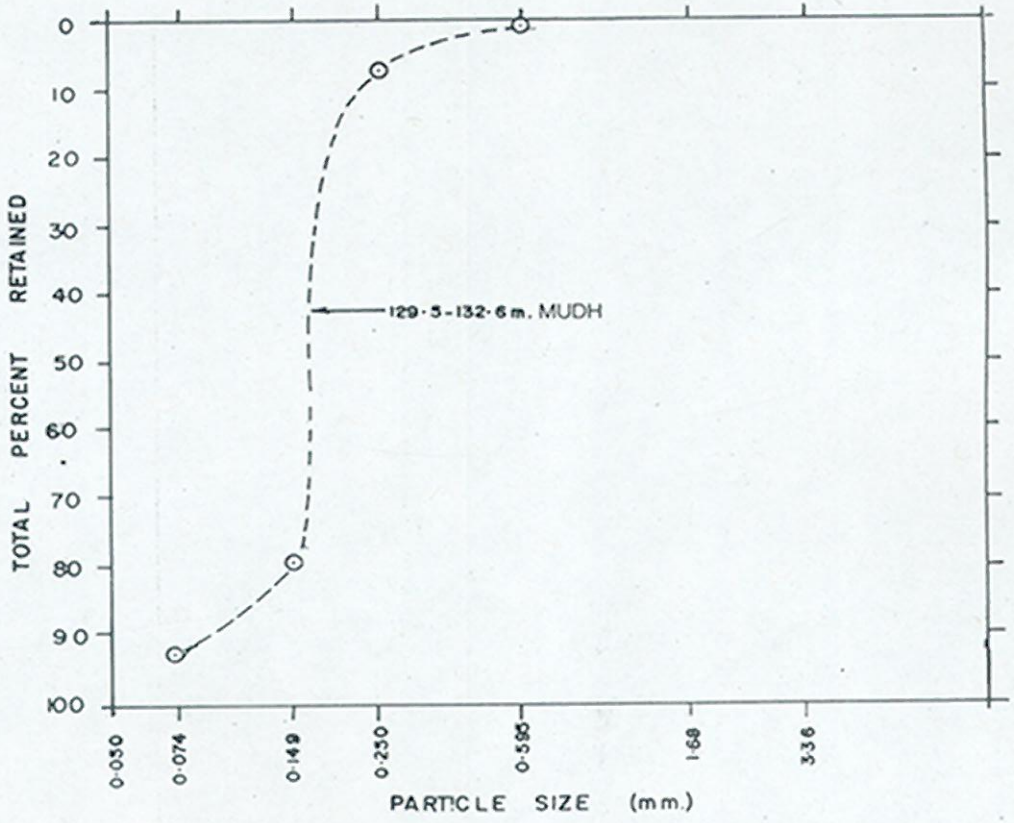


Figure 21

Quaternary aquifer system were appraised on the basis of interpretation of geologic logs, specific capacity of tubewells, data from pumping tests, and other hydrogeologic considerations.

Two pumping tests were performed in wells penetrating the alluvium aquifer of the eastern part of the basin (table 17). The results from the Badauli well test were interpreted according to the Theis method (fig. 24). Walton's solution for leaky aquifer conditions was used to interpret the data obtained from testing the Padukalan well (fig. 25). The transmissivity values obtained are 7.7 m^2/day for Badauli and 4.2 m^2/day for Padukalan. The saturated thickness of the aquifer is 32 m at Badauli and 27 m at Padukalan.

Where the aquifer is thicker than 30 or 40 metres, such as in the central part of the basin, west of the fault zone, transmissivity ranges between 100 and 800 m^2/day, with most of the values between 150 and 400 m^2/day. Values exceeding 1,000 m^2/day were found in the Kashnau-Kushera area, probably to be attributed to fractures associated with a fault zone.

4. Ground water in the Precambrian basement complex

Outcrops and shallow subcrops of the Precambrian basement effect a partial separation of the Bikaner and Sikar basins. These areas of Precambrian terrain have their own characteristics of ground-water occurrence. Rocks of the basement complex are mainly granite, phyllite, quartzite, gneiss and marble. Ground-water movement is controlled by features of secondary porosity such as fractures and joints, and also solution cavities like those known in the Makrana marble (see table 13).

A few dug wells produce some ground-water from the basement rocks but their water-yielding properties are limited. The average specific yield is estimated at 0.5 per cent.

E. Chemical characteristics of ground water 3/

1. Total salinity and geochemical character

In the eastern part of the Sikar basin, ground-water contains less than 1,000 ppm of total dissolved solids (TDS), and in some locations less than 500 ppm. Ground-water salinity increases towards the north and north-western parts of the basin, along the main direction of ground-water flow, to over 10,000 ppm. Concentrations of less than 3,000 ppm prevail over two-thirds of the basin and in one sixth they exceed 5,000 ppm. The amount of total dissolved solids is closely correlated with the chemical character of the water, changing with increasing concentration from bicarbonate type to mixed type and finally chloride type. Most of the ground water in the Sikar basin belongs to the bicarbonate and mixed bicarbonate-chloride mixed types. Chemical analysis of water from several sources are given in annexes 5 through 8.

A stratification of ground water of different quality is noted; the fresher, bicarbonate type water being found in shallow depth, mostly tapped by dug wells, and water with a higher concentration of dissolved constituents in wells reaching into greater depth (see table 18 and fig. 26).

In the Bikaner basin, total ground-water salinity in the Quaternary aquifer increases from less than 1,000 ppm in the southern, north-western and north-eastern parts to more than 10,000 ppm in the northern and north-western parts.

Where the limestone aquifer is found in shallow depth, it contains fresh water, but it is highly mineralized where the evaporites have not been removed by erosion.

In a major part of the Bikaner basin north of the Nagaur area, the Nagaur Sandstone aquifer contains water of good to acceptable quality (1,000 - 4,000 ppm TDS). However, ground water is less saline in the shallower Palana Sandstone aquifer (500 to 2,000 ppm TDS). In this aquifer, too, there is a general trend of increase in salinity in a northern and north-western direction, as well as with increasing depth.

In the Bikaner basin - as in the Sikar basin - higher total salinity correlates with predominance of chloride over bicarbonate content. A comparison of samples from dug wells, representing the shallow aquifer, with those from deeper wells confirms that in general chloride-type waters are characteristic for the deeper horizons, while bicarbonate-type waters predominate in shallow depth (fig. 27).

In the Luni basin, the Quaternary alluvium aquifer contains ground water with less than 1,000 ppm TDS only in the eastern part. In most parts of the basin, total salinity ranges from 1,000 ppm to 3,000 ppm total dissolved solids, and ground water that is even more saline is encountered in some parts (figs. 28 and 29). Project boreholes encountered fresh water where the thickness of the Quaternary deposits exceeded 200 m.

In most wells, penetrating the Tertiary sediments, total salinity near the Quaternary-Tertiary contact exceeds 3,000 ppm. Below this contact, salt content increases rapidly with depth. A borehole at Merta City, for example, showed 6,226 ppm TDS in water from the Palana Sandstone (161-167 m depth) and 18,180 ppm TDS in water from the Nagaur limestone (378-384 m depth).

3/ Suitability of ground water for irrigation is discussed in II-G.6 below.

INDIA

GROUNDWATER SURVEYS IN RAJASTHAN AND GUJARAT

GEOPHYSICAL AND LITHOLOGIC LOG

RAJASTHAN PROJECT AREA

SITE : BADAULI

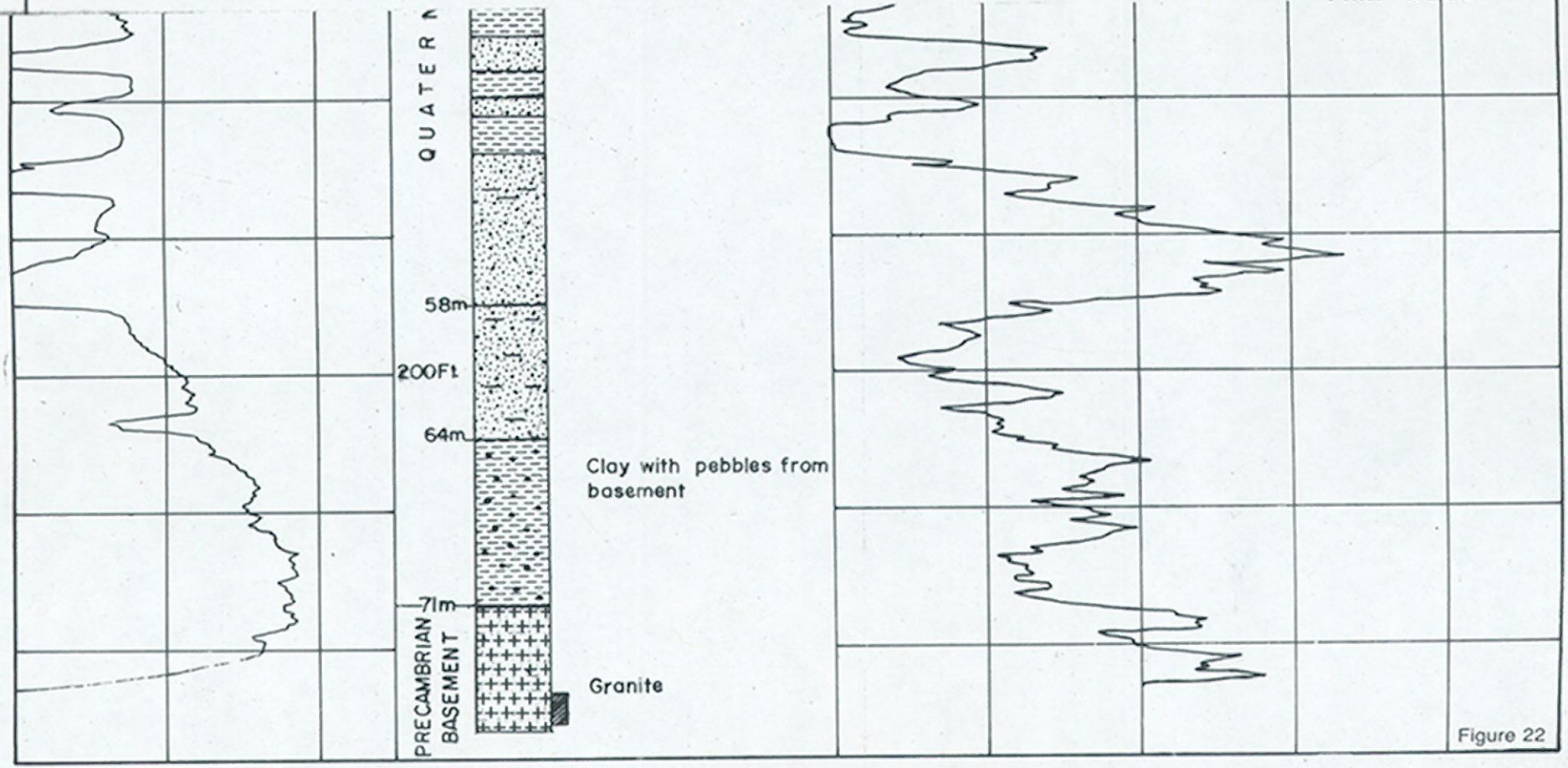


Figure 22

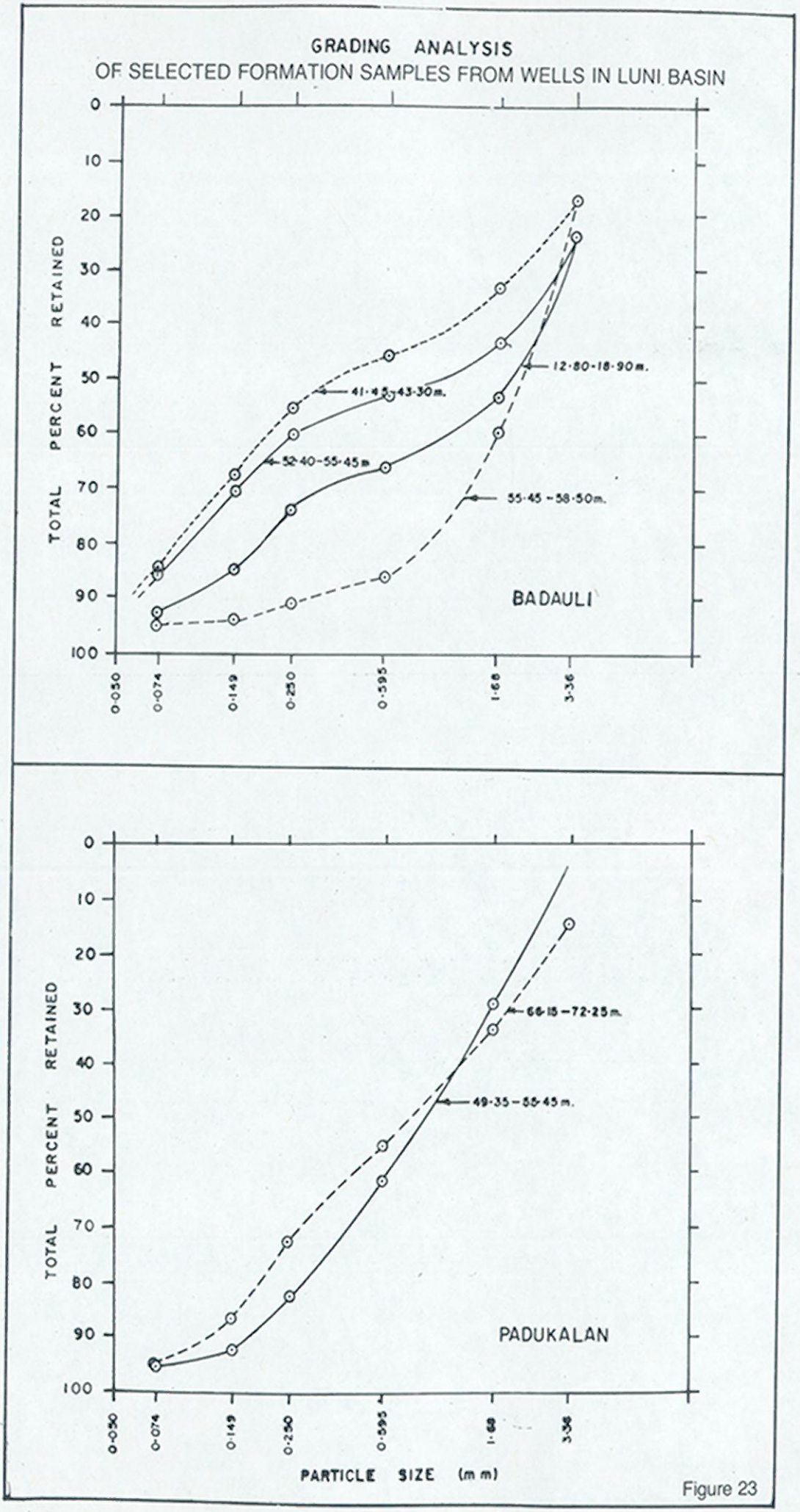

GRADING ANALYSIS
OF SELECTED FORMATION SAMPLES FROM WELLS IN LUNI BASIN
TOTAL PERCENT RETAINED
0
10
20
30
40
50
60
70
80
90
100
12-80-18-90m.
41-45-43-30m.
52-40-55-45m
55-45-58-50m.
BADAULI
0-050
0-074
0-149
0-250
0-595
1-68
3-36
66-15-72-25m.
49-35-55-45m.
PADUKALAN
PARTICLE SIZE (m m)

Figure 23

Table 17. Interpretation of pumping tests at Badauli and Padukalan, Luni Basin

Type of aquifer	Location	Pumping rate		*Specific capacity		Saturated thickness		Co-efficient of trans-missivity		Co-efficient permeability		Co-efficient of vertical permeability		Storage co-eff-icient
		m^3/h	USGPM	$m^3/h/m$	USGPM/ft	m	ft	m2/d	USGPD/ft	m/d	USGPD/ft	m/d	USGPD/ft	
Alluvium, confined@	Badauli	45.40	200	4.10	5.50	20.10	66	156	12,560	7.75	190.30	-	-	6.5×10^{-5}
Alluvium, semi-confined@	Padukalan	11.35	50	0.72	0.97	12	39.35	50	4,033	4.2	103	0.003	0.08	1.1×10^{-4}

@ Hydraulic characteristics computed from data from two observation wells.

* Specific capacity after 24 hours of pumping.

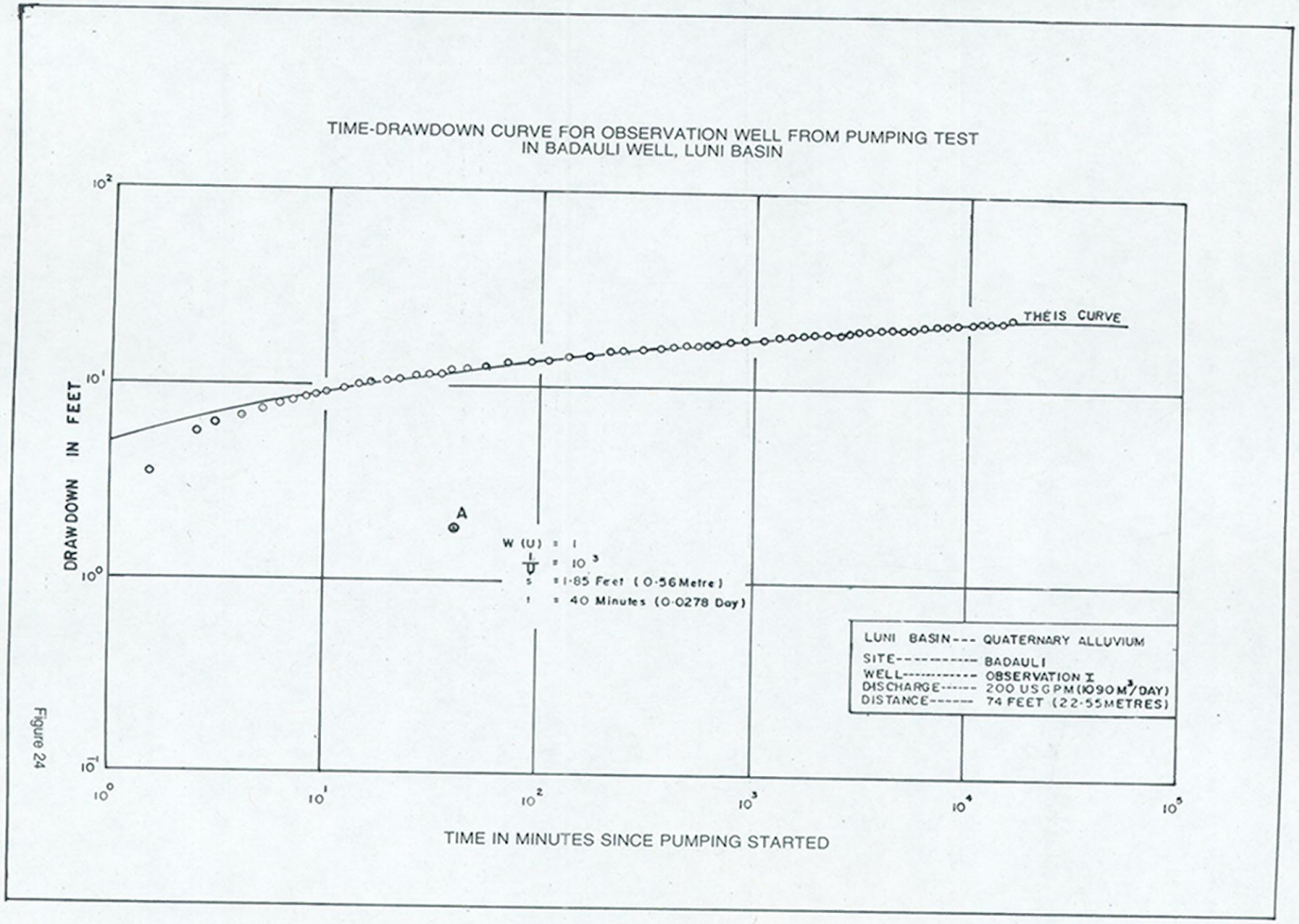

TIME-DRAWDOWN CURVE FOR OBSERVATION WELL FROM PUMPING TEST
IN BADAULI WELL, LUNI BASIN
DRAWDOWN IN FEET
TIME IN MINUTES SINCE PUMPING STARTED
THEIS CURVE
A
W (U) = 1
1/U = 10^3
s = 1·85 Feet (0·56 Metre)
t = 40 Minutes (0·0278 Day)
LUNI BASIN--- QUATERNARY ALLUVIUM
SITE---------- BADAULI
WELL---------- OBSERVATION I
DISCHARGE------ 200 US GPM (1090 M³/DAY)
DISTANCE------- 74 FEET (22·55 METRES)

Figure 24

TIME-DRAWDOWN CURVE FOR OBSERVATION WELL FROM PUMPING TEST
IN PADUKALAN TEST WELL, LUNI BASIN

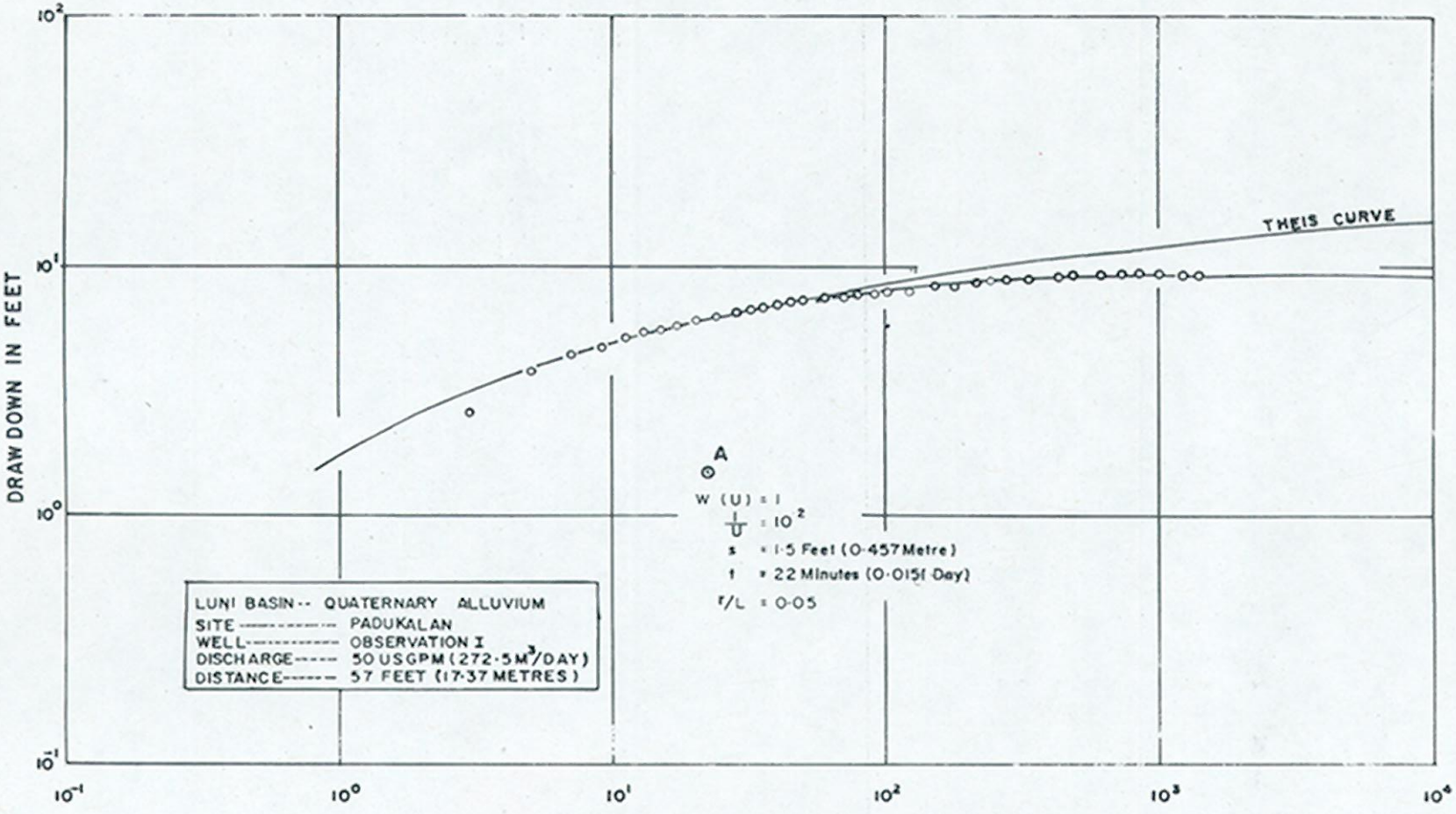
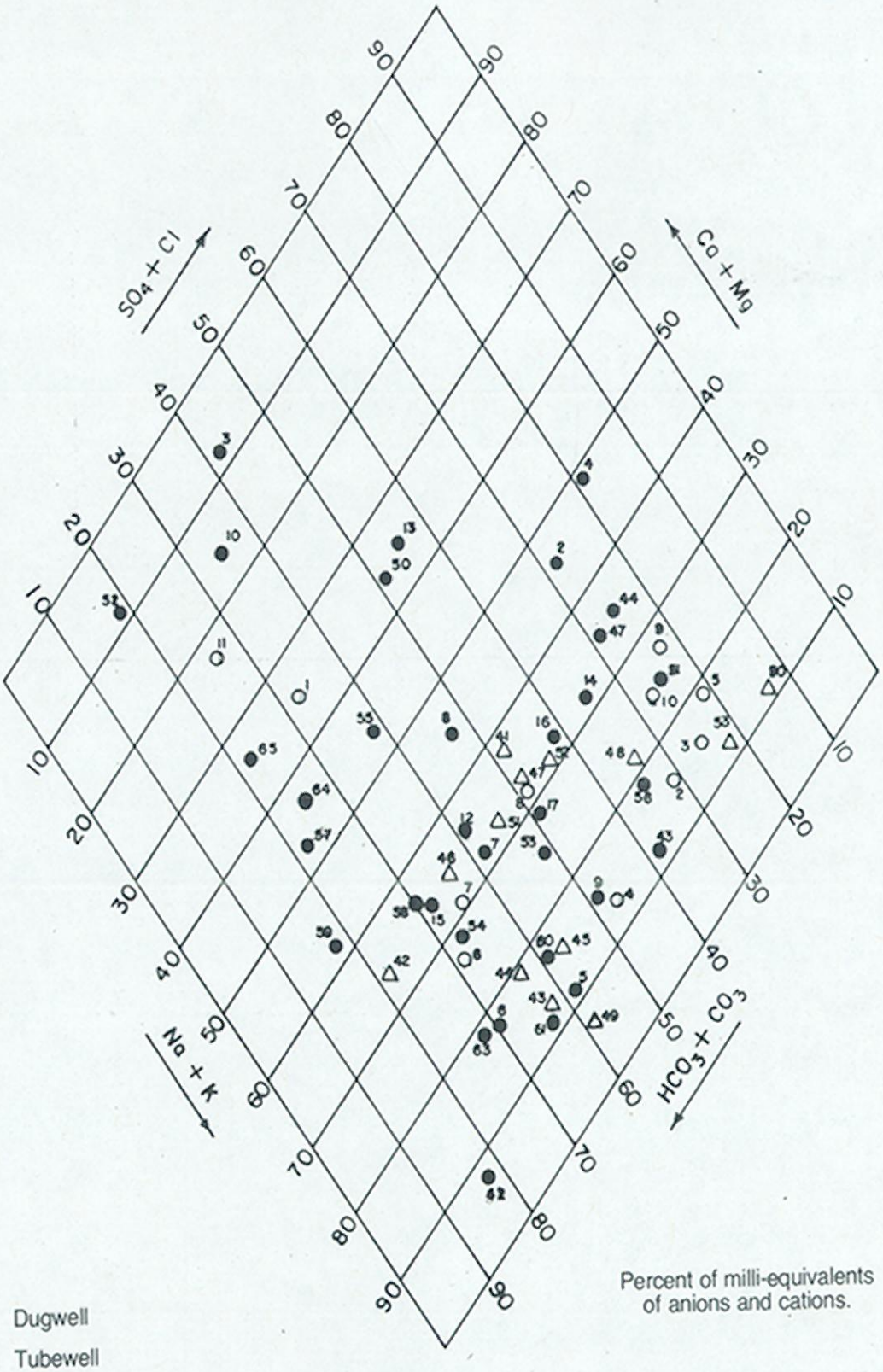


Figure 25

Table 18. Geochemical classification of ground-water samples, Rajasthan area

Basin	Aquifer	No. and per cent of samples	Tubewells			Dug wells			Total		
			HCO_3	Cl	Mixed type	HCO_3	Cl	Mixed type	HCO_3	Cl	Mixed type
Sikar	Unconfined aquifer	No	8	4	12	14	3	17	22	7	29
		%	33.3	16.7	50.0	41.3	8.7	50.0	38.0	12.0	50.0
Luni	Shallow zone	No	6	12	10	13	5	11	19	17	21
		%	21.5	43.0	35.5	44.8	17.2	38.0	33.3	29.8	36.9
	Deeper zone	No	-	2	1	-	-	-	-	2	1
		%		66.7	33.3					66.7	33.3
Bikaner	Shallow aquifer	No	2	10	13	5	4	16	7	14	29
		%	8.0	40.0	52.0	20.0	16.0	64.0	14.0	28.0	58.0
	Deeper aquifer	No	-	3	1	-	-	-	-	3	1
		%	-	75.0	25.0					75.0	25.0

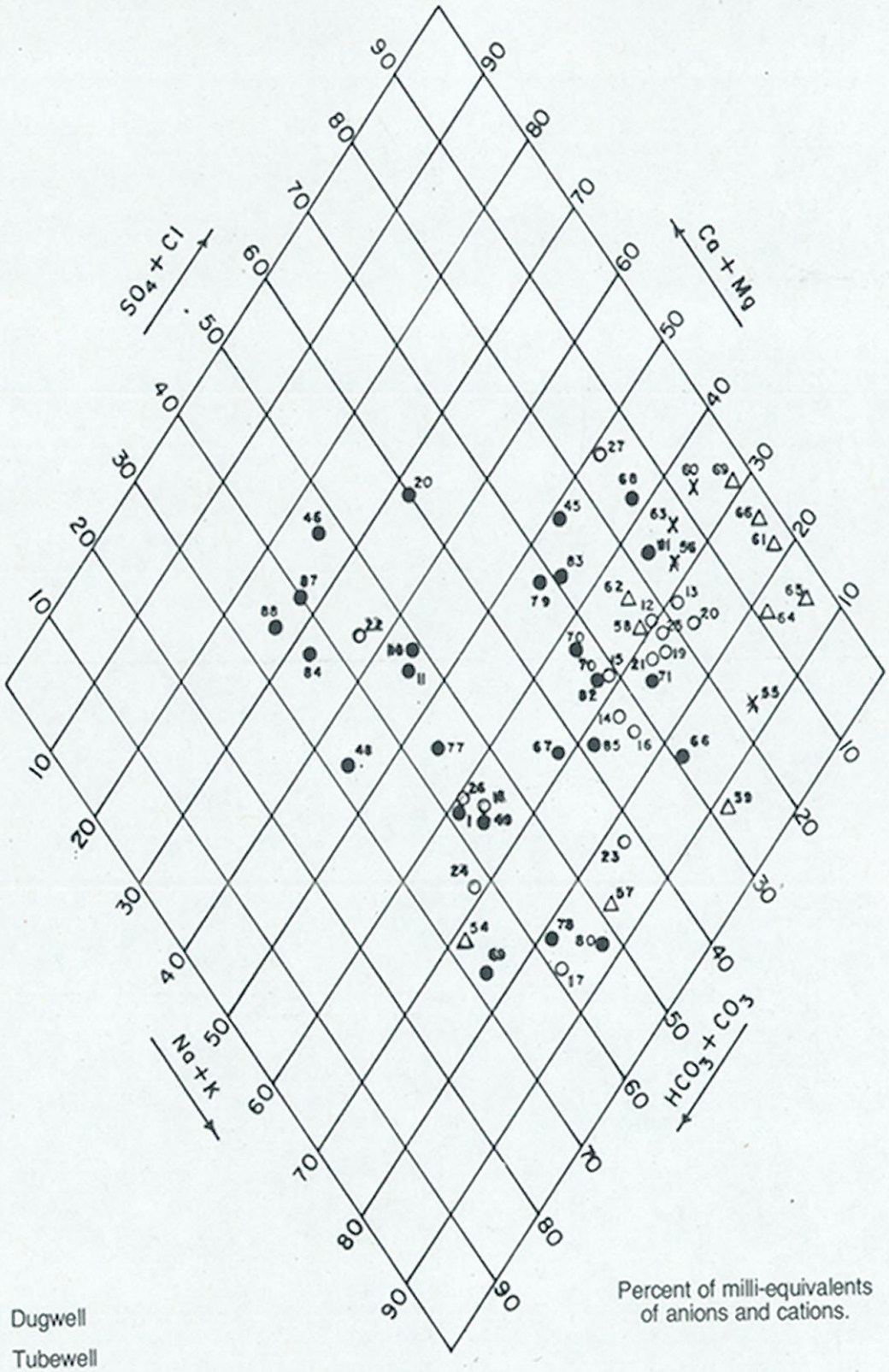
NOTE: A water sample is assigned to the HCO_3 or Cl type if one of these ions constitutes more than 60 per cent of the total of anions. Samples in which no anions exceeds 60 per cent of the total are assigned to the "mixed type".



CHEMICAL CLASSIFICATION OF GROUND-WATER SAMPLES FROM SIKAR BASIN

(Hill-Piper Diagram)

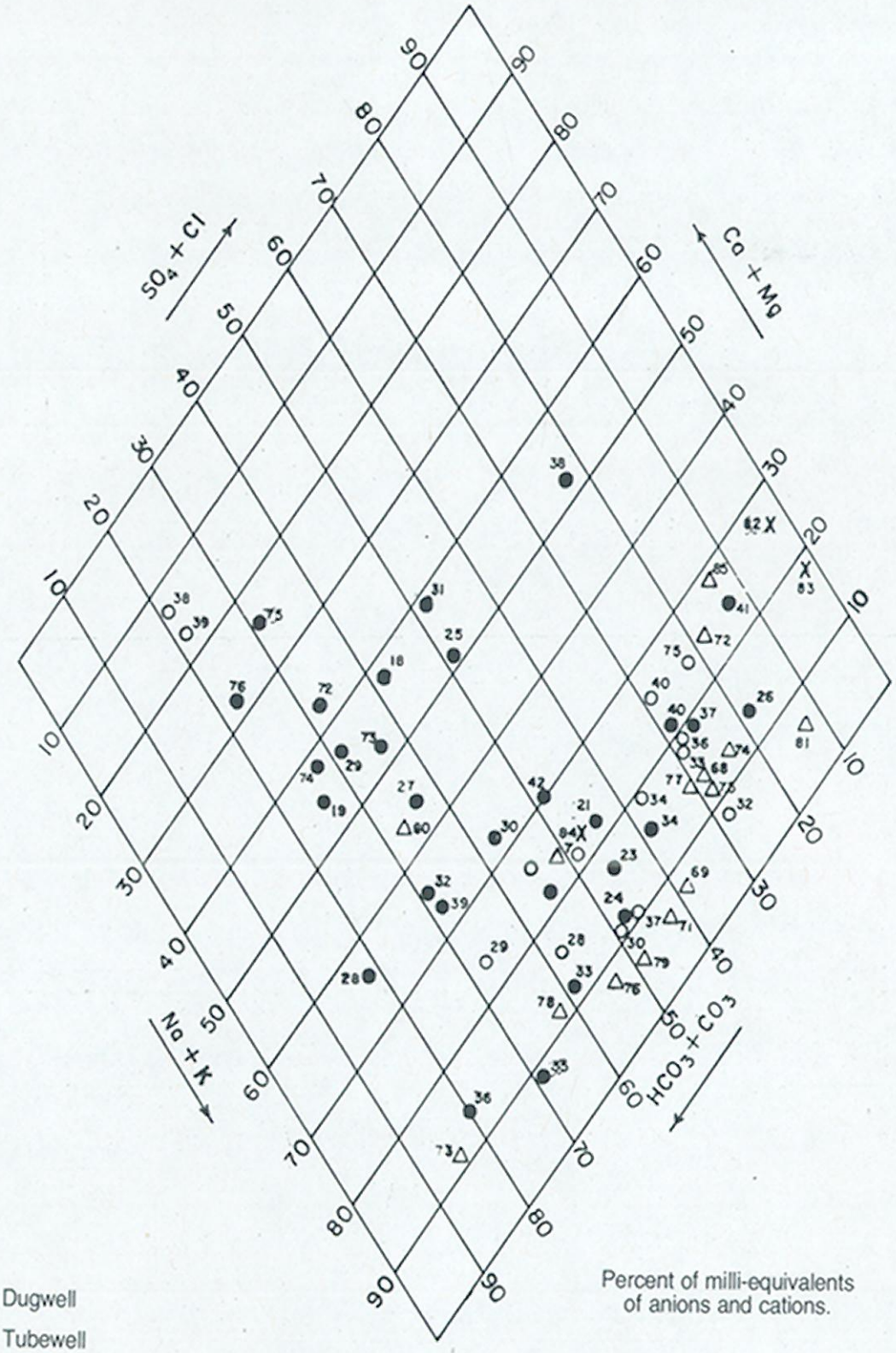
Figure 26



CHEMICAL CLASSIFICATION OF GROUND-WATER SAMPLES FROM BIKANER BASIN

(Hill-Piper Diagram)

Figure 27



Percent of milli-equivalents of anions and cations.

- Dugwell
- Tubewell
- Shallow
- Deep

} Testwell or slim hole

CHEMICAL CLASSIFICATION OF GROUND-WATER SAMPLES FROM LUNI BASIN
(Hill-Piper Diagram)

Figure 28

In the Oladan well (see annex 3) water in the Nagaur Sandstone contains 1,100 ppm TDS (76-201 m) but in the underlying Nagaur limestone (261-274 m) total salinity was 3,248 ppm.

Among the samples collected in the Luni basin, chloride, bicarbonate and mixed types of ground water are represented at about the same proportion. As in the other two basins, ground water in the phreatic aquifer becomes more chloridic in character with increasing depth (fig. 28).

The general sodium chloride character of water from deeper horizons cannot be ascribed to leaching of an evaporite sequence since a corresponding widespread high concentration of sulphate was not observed. Actually, water from the exploration boreholes of Manasir, tapping the evaporite formation, shows a very high concentration in sulphates, and an oversaturation with respect to calcium sulphate. The sodium chloride of deeper water is probably of aeolian origin. The predominant and strong south-western winds, which blow from the Arabian Sea and carry particles of salt, could be responsible for the accumulation of airborne salts in the sediments. Considering the proportions of sodium, chloride, calcium and bicarbonate, a cation exchange process, adding sodium and subtracting calcium, seems likely to have occurred.

The high fluoride concentrations found in some bodies of ground water, especially in the eastern part of the Luni basin, appears to be related to pegmatite intrusions in the Precambrian basement.

Ground water in all the basins show an unusually high content of nitrates. This ion is normally the end product of oxidation of organic matter and can accumulate in arid regions. Since the nitrate content is higher in dug wells than in tubewells, its presence appears to be due to pollution.

2. Appraisal of ground-water quality for human consumption

Total salinity

In the Rajasthan project area, water samples from 9 out of 40 tubewells tested fell within the maximum permissible limits established by WHO for total salinity (see annex 4). Ground water in less than half the project area contains less than 1,500 ppm TDS (fig. 29). People living in areas with more saline ground water have been drinking such water without any apparent ill effects except those due to a high fluoride content. Many of the inhabitants regularly drink water containing up to 3,000 ppm TDS.

According to the criterion of total dissolved solids content, ground water in the eastern part of the Sikar Basin and in the Central part of the Bikaner basin is potable, within the limit as defined as permissible by WHO (1,500 ppm TDS). Ground water in the western part of the Sikar basin exceeds this limit only slightly (2,000 ppm) but in the northern and north-western parts of the basin ground water is too saline for drinking.
The northern, western and southern peripheral areas of the Bikaner basin are also characterized by high ground-water salinities, making the water unfit for human consumption. Total ground-water salinity in the Luni basin is below the 1,500 ppm TDS limit only along its western boundary.

The ground-water salinity map (fig. 29) indicates that terrain of Precambrian subcrops within the basin is characterized by high ground-water salinity. In the Aravalli foothills, where the rate of ground-water replenishment is high, however, the salinity is relatively low.

An examination of the analyses shows that where the total dissolved solids exceed the permissible drinking water standard, other dissolved constituents also exceed the established limits. Total salinity can be utilized therefore as an indication for the general suitability of ground water for drinking.

Fluoride content

The fluoride content of drinking water should not exceed 1.5 ppm. Fluoride concentration ranges from 4 to 6 ppm in many parts of the Sikar basin and exceeds 7 ppm in certain areas (fig. 30). In the western part of the Sikar basin, fluoride values are generally higher than the permissible limit. In the Bikaner basin the fluoride content exceeds the permissible limit in only a few peripheral areas.

High concentrations of fluoride are characteristic for the Luni basin, especially in the part east of the fault, enclosed by subcrops and outcrops of the Precambrian basement, where concentrations range from 8 to 22 ppm. Some water samples are oversaturated with respect to calcium fluoride. As a result, fluorosis is common among the inhabitants.

Nitrate content

Abnormally high values of nitrates were found in certain parts of the Sikar basin, especially in dug wells, and values exceeding the permissible limit were found also in many tubewells. High nitrate concentrations were observed also in tubewells in the Nagaur area of the Bikaner basin and in the Gachhipura area of the Luni basin. In this area, higher values were found in the shallow aquiferous horizons. It is assumed that high nitrate content in dug wells originates from surface contamination.

3. Ground-water quality in relation to watering of livestock

Adopted breeds of livestock in this area are said to accept water up to 1,500 ppm TDS and even 4,000 ppm under certain circumstances. At this

level, however, some deaths occur. The safe limit for nitrate/nitrite content is generally given as 150 ppm.

It can be concluded that ground water in practically all zones with high and medium potential for ground-water development in the Sikar and Bikaner basins, as well as in the southern and south-eastern part of the Luni basin can be safely used for stock watering.

Suitability of ground water for irrigation is discussed in Section G-6 of this report.

F. Ground-water resources

1. Analysis of water-level fluctuations

According to the above-described methods (I-B-3) seasonal water level fluctuations were analysed for the computation of replenishment of the phreatic aquifers by monsoon rainfall. An example of the seasonal amplitude of fluctuations is given in figure 31.

The estimated mean specific yields, mean seasonal rise of the water table, and the resulting rate of replenishment are presented in table 19.

The resulting average annual volumes of recharge are presented in detail in tables 20 and 21 for Sikar basin and for the balance of the project area. The computations have been made for two categories of waters - water having less than 3,000 ppm TDS content which can be safely used for irrigation (good-quality water) and waters having a TDS content between 3,00 and 5,000 ppm, which are still suitable to irrigate most crops owing to the coarse texture of soils in the project area (acceptable-quality water). Areas where TDS exceeds 5,000 ppm have not been taken into consideration as this type of water is of quite limited use.

The results show that recharge in Sikar basin - about 390 MCM - exceeds recharge in the rest of the project area. Recharge in areas of this basin where water is of good quality (325 MCM) is five times higher than in areas with TDS between 3,000 ppm and 5,000 ppm.

Recharge in the Luni and Bikaner basins combined is almost equal to that of Sikar basin, despite the much larger size of the Bikaner basin.

2. Ground-water recharge according to soil moisture balance method

Soil moisture balance computations were made for an area of 14,464 km^2 in the Sikar basin and 26,398 km^2 in the Bikaner and Luni basins to obtain ground-water replenishment.

In the absence of any notable surface runoff in the Rajasthan project area, it is assumed that the computed total runoff, or "water surplus" (R) represents ground-water recharge.

Considering a root zone approximately 2 metres deep, the maximum available soil moisture, or soil moisture storage capacity, is estimated at 100 mm for the eastern part of the project area. In much of the Bikaner basin there is only a thin veneer of aeolian sands and in this case available soil moisture is probably higher at depth in the Tertiary formations. North of the project area, within the Rajasthan Canal Project, the available soil moisture is between 9.4 and 12 per cent according to a recent soil survey, or equivalent, to about 100 mm per metre soil depth. Consequently, it seems reasonable to use a value of 150 mm for the maximum water-holding capacity in the Bikaner area.

The annual totals and long-term (1907-1973) mean value of surplus water (R) are shown in table 22 for 3 stations in the project area assuming 100 and 150 mm maximum available soil moisture storage capacity. Computations were carried out for "wet" years only, that is years during which any monthly total of precipitation could possibly be assumed to create a water surplus. If the computations showed no water surplus in these selected years, this is indicated by a dash (-). For all doubtlessly "dry" years a blank space was left.

The annual water surplus at Jhunjhunu is on an average 30 mm/year assuming 100 mm available soil moisture. But recharge only occurs on an average of 3 years out of 10, and the average recharge then is 106 mm. During the 65 years of computations the highest annual recharge was in 1908, when it was 279 mm. The highest total recharge in any two consecutive years was 357 mm, which occurred in 1955-1956. The longest consecutive period without any recharge in 12 years was between 1917 and 1930.

Table 23 shows the frequencies of annual water surpluses of various magnitude for Jhunjhunu, assuming 100 mm maximum available soil moisture. The probability of exceedance is also given in per cent for some standard percentages.

It is seen that in 48 years out of 65 there is no water surplus at all, and a surplus of more than 25 mm a year occurs in 13 out of 65 years that is 20 per cent of the years. A water surplus of more than 150 mm occurs about once every 10 years.

At Bikaner, assuming 150 mm available soil moisture, the average annual "ground-water recharge" is 17 mm. "Recharge" occurs on an average in 2 years out of 10 and it is in these years on an average 93 mm.

The highest annual "recharge" was 159 mm, which occurred in 1942, and the highest "recharge" during any two consecutive years was 162 mm which occurred in 1907-1908. The longest period without any water surplus was 14 years from 1960 to 1973 inclusive.

The comparatively high annual water surplus at Bikaner is surprising since the long-term mean annual rainfall is only about half of that at Jhunjhunu. It is explained by the higher frequency of heavy

Table 19. Recharge to the various aquifers in the Rajasthan area

Aquifer	Basin	Mean water level rise (cm)	Specific yield (%)	Recharge (mm)
Quaternary aeolian sands	Sikar Basin	33	10	33
Quaternary alluvium	Luni Basin	67	5	33
Palana sandstone	Bikaner and Luni basins	19	7	13
Nagaur sandstone	Bikaner Basin	74	1	7
Nagaur limestone	Bikaner Basin	81	1	8
Precam-brian basement	Bikaner Basin	122	0.5	6

Table 20. Ground-water resources in Sikar Basin

District	Tehsil	Total area	Recharge in ground-water quality zones (ppm TDS)						Present draft		Present available resources			Increase domestic consumption til 1974	Resources available for irrigation		
			<3,000		3,000-5,000		Total < 5,000				<3,000	3,000-5,000	Total <5,000		>3,000	3,000-5,000	Total >5,000
		A	A	Q	A	Q	A	Q	A	Q	Q	Q	Q	Q	Q	Q	
Churu	Tarangar	934.9	81.2	2.68	51.4	1.70	132.6	4.38	802.3	0.69	1.99	1.70	3.69	0.87	1.12	1.70	2.82
	Rajgarh	517.2	31.5	1.04	175.1	5.78	206.6	6.82	310.6	0.35	0.45	5.58	6.03	0.44	0.01	5.58	5.59
	Churu	1,588.1	799.1	26.37	414.4	13.68	1,213.5	40.05	374.6	3.05	23.32	13.68	37.00	2.71	20.61	13.68	34.29
	Sardar-shar	1,371.0	547.0	18.05	192.3	6.35	239.3	24.40	631.8	0.95	17.10	6.35	23.45	1.10	16.00	6.35	22.35
	Ratangarh	1,583.1	1,320.6	43.58	198.9	6.56	1,519.5	50.14	63.5	2.89	40.69	6.56	47.25	2.23	38.46	6.56	45.02
	Sujangarh	678.4	184.0	6.07	245.7	8.11	429.7	14.18	248.6	1.14	4.93	8.11	13.04	1.09	3.84	8.11	11.91
	TOTAL	6,672.6	2,963.4	97.79	1,277.8	41.98	4,241.2	139.79	2,431.4	9.07	88.48	41.98	130.46	8.44	80.04	41.98	122.00
Jhun-jhunu	Jhunjhunu	1,321.2	994.6	32.82	251.9	8.31	1,246.5	41.13	74.7	6.92	26.60	8.31	34.91	3.83	22.77	8.31	31.08
	Udai-purvati	530.4	530.4	17.50	-	-	530.4	17.50	-	7.33	10.17	-	10.17	1.95	8.22	-	8.22
	TOTAL	1,851.6	1,525.0	50.32	251.9	8.31	1,776.9	58.63	74.7	14.25	36.77	8.31	45.08	5.78	30.99	8.31	39.30
Sikar	Fatehpur	1,069.8	935.6	30.67	124.3	4.10	1,059.9	34.97	10.0	6.36	24.51	4.10	28.61	2.61	21.90	4.10	26.0
	Lachhman-garh	1,219.2	1,182.7	39.03	36.5	1.20	1,219.2	40.25	-	6.45	32.58	1.20	33.78	2.85	29.73	1.20	30.93
	Sikar	1,251.0	1,191.8	39.33	-	-	1,191.8	39.33	-	14.62	24.71	-	24.71	4.31	20.40	-	20.40
	Danta-Ramgarh	457.0	391.2	12.91	-	-	391.2	12.91	-	4.90	8.01	-	8.01	1.04	6.97	-	6.97
	TOTAL	3,997.0	3,701.3	122.14	160.8	5.30	3,862.1	127.44	10.0	32.33	89.81	5.30	95.11	10.81	79.00	5.30	84.30
Nagaur	Ladnun	38.1	31.5	1.04	6.6	0.22	38.1	1.26	-	0.28	0.77	0.22	0.98	0.22	0.54	0.22	0.76
	Didwana	1,004.5	853.7	28.17	135.9	4.48	989.6	32.65	14.9	7.75	20.42	4.48	24.90	2.21	18.21	4.48	22.69
	Parbatsar	351.4	227.1	7.49	124.3	4.10	351.4	11.59	-	6.4	1.09	4.10	5.19	0.91	0.18	4.10	4.28
	Nawa	548.7	548.7	18.11	-	-	548.7	18.11	-	12.93	5.18	-	5.18	1.54	3.64	-	3.64
	TOTAL	1,942.7	1,661.0	54.81	266.8	8.80	1,927.8	63.61	14.9	27.36	27.45	8.80	36.25	4.88	22.57	8.80	31.37
GRAND	TOTAL*	14,464	9,850.6	325.1	1,957.3	64.4	11,808.0	389.7	2,541.0	83.01	242.5	64.4	306.9	29.91	212.6	64.4	277.0

A = Area in km^2

Q = Annual volume of recharge, in MCM

* Total area of Sikar basin includes 125 km^2 of basement terrain in Sikar and Danta Ramgarh tehsils

Recharge for zones with ground water of more than 5,000 ppm TDS has not been calculated

Table 21. Ground-water resources in Bikaner and Luni Basins*

District	Tehsil	Total area	Recharge in ground-water quality zones (ppm TDS) <3,000		3,000-5,000		>5,000		Total	Present draft	Present available resources (salinity in ppm TDS) <3,000	3,000-5,000	Total >5,000	Increase domestic consumption til 1974	Available resources (salinity ppm TDS) <3,000	3,000-5,000	Total <5,000
		A	A	Q	A	Q	A	Q	A	Q	Q	Q	Q	Q	Q	Q	Q
Bikaner	Lunkaransar	2,286	663	8.65	650	8.45	1,313	17.10	973	0.61	8.04	8.45	16.49	0.76	7.28	8.45	15.73
	Kolayat	1,201	1,060	13.79	99	1.29	1,159	15.08	42	2.15	11.64	1.29	12.93	2.68	8.96	1.29	10.25
	Bikaner	2,596	2,226	29.00	240	3.60	2,466	32.60	130	4.75	24.25	3.60	27.85	5.90	18.35	3.60	21.95
	Nokha	2,441	2,325	25.88	38	0.15	2,363	26.02	78	0.16	25.71	2.15	25.86	0.19	25.52	0.15	25.67
	TOTAL	8,524	6,274	77.31	1,027	13.49	7,301	90.80	1,223	7.67	69.64	13.49	83.13	9.53	60.11	13.49	73.60
Churu	Sardarshar	1,702	1,290	16.80	338	4.40	1,628	21.20	74	1.23	15.57	4.40	19.97	1.32	14.25	4.40	18.60
	Dungarhgarh	2,966	2,847	34.45	119	1.55	2,966	36.00	0	1.64	32.81	1.55	34.36	1.91	30.90	1.55	32.45
	Ratangarh	112	112	0.77	0	0	112	0.77	0	0.18	0.59	0	0.59	0.14	0.45	0	0.45
	Sujangarh	1,977	1,730	11.21	153	0.99	1,883	12.20	94	0.54	8.67	0.99	9.66	2.15	6.52	0.99	7.51
	TOTAL	6,757	5,979	63.23	610	6.94	6,589	70.17	168	5.59	57.64	6.94	64.58	5.52	52.12	6.94	59.06
Nagaur	Nagaur	2,444	1,780	18.65	319	1.81	2,099	20.46	345	2.43	16.22	1.81	18.03	2.70	13.52	1.81	15.33
	Jael	2,070	1,501	29.62	368	3.59	1,869	33.21	201	2.82	26.80	3.59	30.39	2.20	24.60	3.59	28.19
	Ladnun	1,218	808	5.38	326	2.06	1,134	7.44	84	2.59	2.79	2.06	4.85	2.02	0.77	2.06	2.83
	Didwana	665	355	2.13	122	0.73	477	2.86	188	0.92	1.21	0.73	1.94	0.31	0.90	0.73	1.63
	Parbatsar	1,242	1,204	21.63	38	0.23	1,242	21.86	0	3.72	17.91	0.23	18.14	1.38	16.53	0.23	16.76
	Merta	1,980	1,628	50.41	192	6.32	1,820	56.73	160	6.97	43.44	6.32	49.76	2.32	41.12	6.32	47.44
	Degana	1,498	1,037	25.23	334	10.05	1,371	35.28	127	5.50	19.73	10.05	29.78	2.69	17.04	10.05	27.09
	TOTAL	11,117	8,313	153.05	1,699	24.79	19,912	177.84	1,195	24.95	128.10	24.79	152.89	13.62	114.48	24.79	139.27
GRAND TOTAL		26,398	19,566	293.59	3,336	45.22	23,902	338.81	2,496	38.21	255.38	45.12	300.60	28.67	226.71	45.22	271.93

A = Area in km^2

Q = Annual volume in MCM

* including basement areas

Table 22. Estimated annual water surplus, Rajasthan area

Year	Jhunjhunu			Bikaner			Didwana		
	Annual Rainfall mm	Soil moisture capacity 150mm	Soil moisture capacity 100mm	Annual Rainfall mm	Soil moisture capacity 150mm	Soil moisture capacity 100mm	Annual Rainfall mm	Soil moisture capacity 150mm	Soil moisture capacity 100mm
1907	244		-	495	143	186	456	107	140
1908	758	224	279	458	19	45	561	149	189
1909	616	60	115	585	106	151	458	3	34
1910	446			335			300		
1911	347			153			161		
1912	532			212			416		
1913	384			180			273		
1914	421			363			291		
1915	355			167			134		
1916	532	84	139	536	12	45	616	75	100
1917	563		11	771	34	78	1,252	359	400
1918	129			53			48		
1919	300		-	481	151	177	576	143	190
1920	461			337			341		
1921	249			424			233		
1922	295			244			286		
1923	347			292			396		
1924	374		-	261	-	-	719	291	337
1925	433			186			315		
1926	523			301			371		
1927	396			257			314		
1928	286		-	304		-	420	87	118
1929	261			262			308		
1930	561	72	127	235		-	306		-
1931	435			302			271		
1932	339			213			329		
1933	467	-	13	440	79	121	399	-	-
1934	480	-	55	431	35	64	525	9	50
1935	379			344			310		
1936	308		-	484	135	177	238	-	-
1937	450			313			307		
1938	269			121			173		
1939	180			91			167		
1940	355		-	209	-	-	458	21	69
1941	248			162			197		
1942	709	107	237	695	159	221	429	21	51
1943	321			206			347		
1944	396			409			293		
1945	438			483			608		
1946	435			182			450		
1947	634	149	254	253	-	-	212	-	-
1948	372			120			265		
1949	279			316			183		
1950	484	109	164	479	128	173	379	-	38

Table 22 (continued)

Year	Jhunjhunu			Bikaner			Didwana		
	Annual rainfall mm	Soil moisture capacity 150mm	Soil moisture capacity 100mm	Annual rainfall mm	Soil moisture capacity 150mm	Soil moisture capacity 100mm	Annual rainfall mm	Soil moisture capacity 150mm	Soil moisture capacity 100mm
1951	184			220			212		
1952	212			216			243		
1953	354		54	182		-	606	236	275
1954	581			352			256		
1955	726	33	90	303		51	764	104	137
1956	777	212	267	316		-	388	10	50
1957	559	43	86	178		-	410	17	56
1958	358			208			491		
1959	457	-	22	552	119	168	430	27	51
1960	385			161			283		
1961	417			334			355		
1962	503			292			332		
1963	348			87			191		
1964	548	53	84	247	-	11	431	37	60
1965	181			161			283		
1966	506			359			315		
1967	667			317			416		
1968	307			46			444		
1969	430			114			312		
1970	474			267			383		
1971	535		15	211		-	402	0	4
1972	234		10	207		-	160		-
1973	379		5	209		-	334		-
Average (67 yrs) (1907-1973	416.6	18.3	30.3	293.8	17.0	25.4	366.1	25.3	35.1
Average (3 yrs) (1971-1973)	382.7	0	10.0	209.0	0.0	0.0	298.7	0.0	1.3

NOTES: A dash (-) implies no water surplus; no entry implies a "dry" year.

WATER-LEVEL FLUCTUATIONS IN SELECTED OBSERVATION WELLS
RAJASTHAN PROJECT AREA

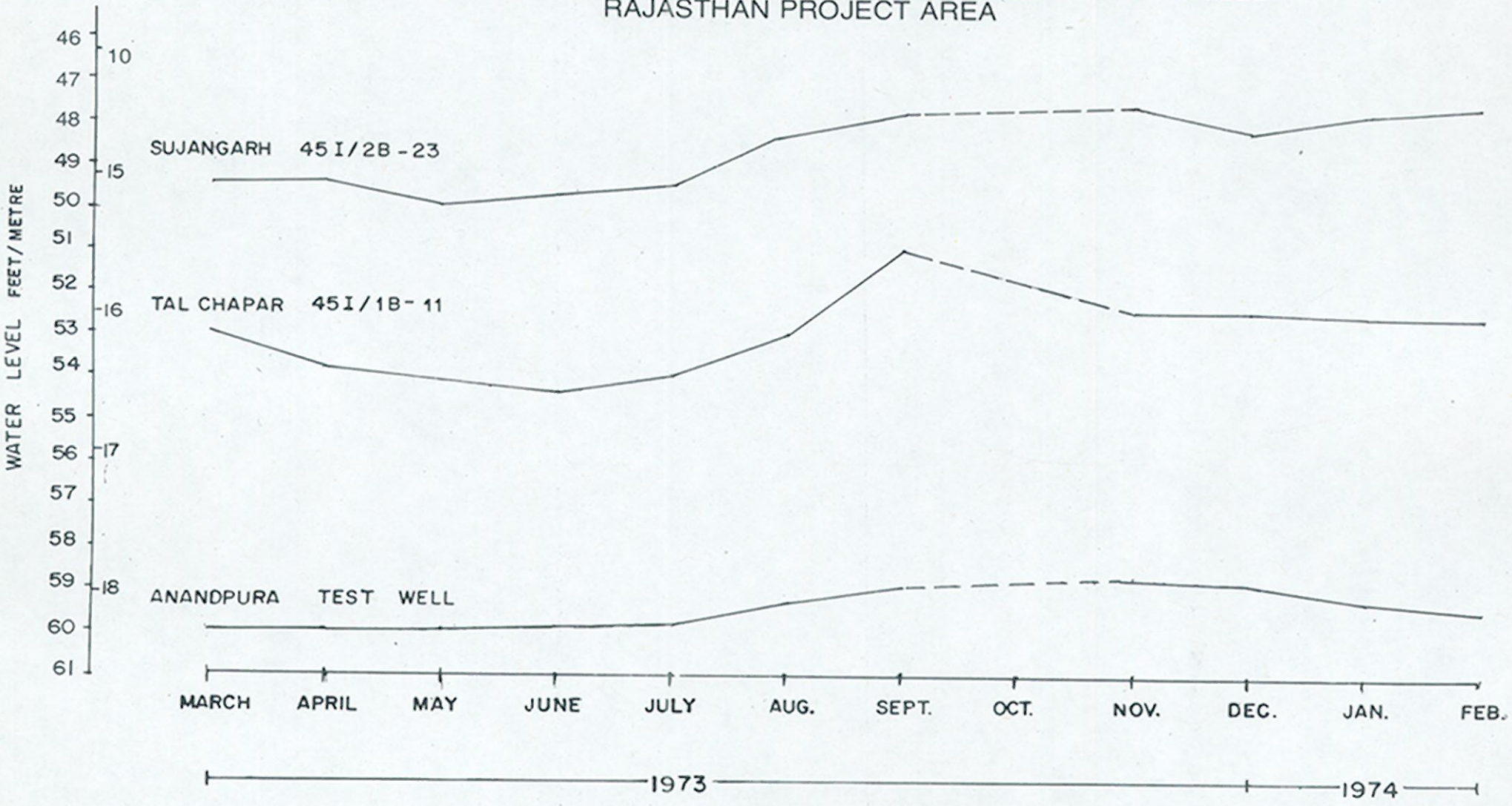


Figure 31

Table 23. Annual water surplus frequencies at Jhunjhunu 1907-72

(Soil moisture 100 mm)

No. of years with water surplus within indicated interval during the period 1907-72		No. of years with water surplus higher than indicated value in the period 1907-72		Probability of exceedance, % of years
Water surplus interval (mm)	No. of years	Water surplus (mm)	No. of years	
		275	1	
< 300	0	250	3	5%
275-300	1	225	4	
250-275	2	200	4	
225-250	1	175	4	
200-225	0	150	5	10%
175-200	0	125	7	
150-175	1	100	8	
125-150	2	75	11	
100-125	1	50	13	
75-100	3	25	13	20%
50- 75	2	1	17	
25- 50	0	0	65	
1- 25	4			
0- 1	48			

daily rainfall at Bikaner (see B.4.b). However, due to the presence of impermeable clay beds not all of this water surplus may reach the ground-water body.

At Didwana, the long-term annual water surplus is 35 mm. Since Bikaner is supposed to be representative of the arid western part and Jhunjhunu and Didwana of the eastern semi-arid part, occupying most of the Sikar basin, this means that the long-term average annual water surplus is between 17 and 35 mm over the entire project area.

The water surplus is about 6 per cent of the average annual rainfall in the arid western part and 7 per cent in the semi-arid eastern part. These percentages refer only to long-term averages and not to individual years.

The estimated annual water surplus for soil moisture of 150 or 100 mm has also been computed for 11 stations for the years 1971, 1972 and 1973 to show the areal variation (table 24). As could be expected, the areal variation is very large. This is explained by the very local nature of thunderstorms in this area. In 1973 for example, most of the annual water surplus at Nagaur, which was about 280 mm, was carried by a single storm in August. At the same time the annual water surplus at Didwana which was not hit by any cloudburst was probably zero. However, the areal average of the water surplus in the eastern part and in the western part of the area as shown in table 21 are considered as fairly reliable for the different years.

During the three project years 1971-1973 the average annual water surplus was about 40 mm on an average for the Sikar basin, assuming 100 mm available soil moisture, that is, somewhat higher than the long-term mean of about 33 mm (average of water surplus for Didwana and Jhunjhunu). For the western part of the project area, if 150 mm available soil moisture is assumed, water surplus for the three years is about 32 mm.

Actually, these computations of recharge by soil moisture budget technique are valid only when the moisture surplus percolates quickly to the water table. If infiltration capacity is lower than rainfall intensity part of the water remains on the soil and evaporates directly. If the percolation rate in the subsurface is slowed by compact materials or clay beds, evaporation can also take place during the dry season through roots of scattered trees which penetrate deeply in the soil. On account of these phenomena, values for recharge obtained by this method are too high for areas underlain by the Precambrian basement rocks, the Nagaur series and to a certain extent, the Palana sandstones of the Bikaner basin. It must also be borne in mind that the computations are based on assumptions concerning surface- and ground-water flow.

On a long-term basis, the water recharged to the ground-water table is used in part for domestic purposes and for irrigation, which increases the evaporation losses, and part of it may leave the area as ground water outflow or even as

Table 24. Estimated water surplus for 11 stations during the period 1971-1973 (in millimetres)

Area	Station	1971		1972		1973	
		Annual rainfall	Water surplus	Annual rainfall	Water surplus	Annual rainfall	Water surplus
Sikar basin and Luni basin	Churu	298	0	191	0	304	11
	Didwana	402	4	160	0	334	0
	Jhunjhunu	535	15	234	10	379	5
1/	Parbatsar	857	391	239	20	453	68
	Ratangarh	438	36	146	0	406	26
	Sikar	575	12	160	22	447	49
	Sujangarh	472	89	159	0	540	112
	Average	510	78	184	7.5	409	39
Bikaner Basin	Bikaner	211	0	207	0	209	0
	Didwana	402	0	160	0	334	0
	Dungargarh	231	0	247	0	344	8
2/	Nagaur	467	98	331	0	731	277
	Average	328	24	236	0	404	71

1/ Soil moisture storage capacity 100 mm
2/ Soil moisture storage capacity 200 mm

occasional river flow out of the area. Because of these considerations, and the nature, density and quality of basic data input, the above figures for ground-water recharge must be regarded as first approximations.

In general terms, the results obtained from the two different methods, applied for computation of average long-term ground-water recharge, in terms of millimetres of rainfall recharging the aquifer, are comparable, but the great range of variability in time and in space, due to local hydrogeologic conditions, must be taken into account. Therefore, the results obtained from both methods should be regarded as first approximations. For purposes of detailed planning, more reliable figures, based on detailed hydrogeologic water balances for specific areas should be used.

3. Ground-water withdrawals

Ground-water consumption for domestic use was computed on the basis of the population census of 1971, and assuming that the total number of heads of livestock approximately equals the number of inhabitants. The average water consumption per head of livestock is estimated at 20 litres/day. Taking into account the contribution of surface-water tanks, ground water consumption per head of inhabitant including livestock is estimated at 45.6 litres/day (10 Imp. gallons), in agreement with State Government figures.

A survey was made to ascertain the number of wells used for irrigation in each village of the various tehsils lying in the project area, the mode of pumpage (mote 4/, oil engine, electricity) of each of these wells, the average discharge and number of pumping hours for each category of wells. These data were obtained from the farmers and local and State agencies.

The details of the present draft are presented by tehsils, for Sikar basin and the balance of the project area, in annexes 9 and 10 and the summary figures are shown in table 25.

Ground-water withdrawals for irrigation are significant in the south and south-eastern parts of Sikar basin, and to a less extent in the eastern part of the Luni basin. An estimate of the expected increase in ground-water demand for human and animal consumption over the next 20 years (up to 1994) was based on an assumed 50 per cent increase in population during this period, and an increase of 50 per cent in water consumption per capita, taking into account also a 50 per cent increase in livestock population. Under these assumptions, an increase in ground-water demand of 125 per cent as compared to the present consumption is to be expected. This demand must be taken into consideration in the computation of the ground-water resources that will be available for irrigation.

4. Potential for further development of ground-water resources

a. Ground-water reserves

The aquifers in the Rajasthan project area contain large volumes of ground water that are best defined as stored ground-water reserves. A rough estimate of the magnitude of these reserves, for an area of 12,000 km^2 in the Sikar basin over which total salinity is less than 5,000 ppm, taking a storage coefficient of 7 per cent would indicate that there are 840 x 10^6 m^3 for each metre of saturated thickness of the aquifer.

Table 25. Present ground-water draft in the Rajasthan area

Basin	Total area km^2	Irrigation		Draft MCM	Domestic use MCM	Total draft MCM	Expected increase of domestic use till 1974 MCM
		Number of wells					
		with mote	with pump				
1	2	3	4	5	6	7	8
Sikar	14,464	9,747	2,658	59.35	23.66	83.01	29.91
Bikaner and Luni (including basement areas)	26,398	1,261	993	15.29	22.92	38.21	28.67
Total	40,862	11,008	3,651	74.64	46.58	121.22	58.58

4/ Mote method: any method of lifting water from an open or dug well other than by electric or oil motor, such as by Persian wheel, lifting water in skin bags or using camel or bullock power.

Taking 55 m as an average figure for the saturated thickness, and considering only half this thickness as practical for exploitation of reserves, the volume in storage is about 20×10^9 m^3.

"Mining" ground water from the aquifers in the project area could provide important volumes of water over long periods of time. The physical consequences of ground-water mining, however, have not been investigated yet, especially those related to the danger of increase in ground-water salinity. Technical, economic and environmental consequences will also have to be carefully examined. For this reason, only renewable ground-water resources have been considered for development in this study. Nevertheless, with increasing ground-water exploitation, the storage capacity of the aquifers will play an important part as a regulating factor, in view of the great variations in annual replenishment.

b. Renewable resources

Taking into account only renewable resources, and disregarding ground-water inflow, outflow and return flow from irrigation and other uses, the additional ground-water potential available for development can be defined as the difference between present ground-water withdrawals and the long-term average replenishment.

For computation of this potential, it has been assumed that the present draft takes place only in areas of good-quality ground water (less than 3,000 ppm TDS). The available resources are presented in detail in tables 20 and 21 and in annex 11.

The amount of annually available resources of good-quality water per square kilometre is significantly higher in the eastern part of the area than in the western part; it is generally between 20,000 m^3/km^2 and 30,000 m^3/km^2 in Sikar and Luni basins and between 5,000 m^3/km^2 and 12,000 m^3/km^2 in Bikaner basin. About half of this potential is located in Sikar basin, that is 307 MCM of which 242 MCM of water has less than 3,000 ppm TDS.

c. Proposals for well drilling

The development of renewable resources must be concentrated in areas where high or medium capacity wells are technically feasible; rentability computations, and eventually social incentives will influence the choice and the priority of the areas where development can be effectively carried out.

The schemes for additional development of irrigation water supplies, in terms of the most prospective regions, numbers of wells and volumes to be pumped, are presented in table 26 (see also figure 32).

Tubewells having a discharge of 150 m^3/h or more are technically feasible in areas where the aquifer is thicker than 50 or 60 metres and transmissivity is above 200 m^2/d. Areas where important withdrawal of water might induce deterioration of ground-water quality through saline encroachment are not considered for development.

Medium-capacity tubewells having a discharge of about 75 m^3/h can be expected in areas where the thickness of the aquifer ranges from 30 or 40 metres to 50 or 60 metres, and transmissivity between 100 m^2 and 250 m^2 per day.

Assuming double-crop irrigated farming, wells are expected to operate 2,000 hours per year. During the two months of maximum water demand of crops, wells would pump 18 hours per day. The expected lifetime of a well - for the purpose of economic considerations - is 20 years and a pump is assumed to serve for 5 years.

In table 27, the expected decline in the pumping level of wells over the first 20 years is presented ("maximum drawdown"), as well as the parameters that were assumed for the computation of these data, using the Theis non-equilibrium formula. Requirements for length of screened section and depth of installation of the pump are also included.

The spacing of tubewells is calculated assuming distribution on the basis of a square grid. A well location can be shifted up to 25 per cent of the distance given without appreciably changing its drawdown or affecting neighbouring wells.

In the Sikar basin, under general conditions computations show that the proposed tubewell scheme would not appreciably interfere with existing wells. At any point located one kilometre from a tubewell pumping at a rate of 150 m^3/h the expected drawdown due to pumpage in all tubewells of the scheme would be about 0.20 m after one year of pumping, 0.70 m after five years and 4.0 m after twenty years, assuming no recharge.

Pending the completion of such a scheme, production of irrigation water from existing wells could be doubled as an immediate measure by increasing annual pumping hours. The additional water would permit the extension of irrigated areas and of double cropping. Progressively, as the existing installations need replacement, they would be replaced by more efficient and economic tubewells of the proposed scheme.

In the Sikar basin in an area covering approximately 2,800 km^2, about 220 high-capacity tubewells (150 m^3/h capacity) would produce 65 MCM per year in addition to the present draft of 59 MCM. This appears to be the most favourable area for further ground-water development.

About 50 high-capacity tubewells drilled in a 1,300 km^2 area in the Bikaner basin would produce about 15.5 MCM per year in addition to present

Table 26. Ground-water development schemes with high-capacity* and medium-capacity tubewells in Rajasthan area

Basin and region	Area (km^2)	Well capacity (m^3/h)	Annual yield (MCM)*	Area covered by one well (km^2)	Spacing of wells (km)	No. of wells	Mean depth of wells (m)	Mean depth to pumping level (m)	Total annual yield (MCM)
(a) Sikar Basin									
Nawa tehsil	130	150	0.300	32.50	5.70	4	90	65	1.20
Central part	2,640	150	0.300	12.25	3.50	216	90	65	64.50
TOTAL	2,770					220			65.70
Central part	4,500	75	0.150	6.12	2.45	734	75	55	110.00
North-west (Sardarshar tehsil)	200	75		6.12	2.45	33	75	65	5.00
TOTAL	4,700					767			115.00
Total Sikar Basin	7,470					987			180.70
(b) Bikaner Basin									
Sardarshar tehsil	680	150	0.300	24.50	4.95	28	120	78	8.40
Kolayat tehsil	600	150	0.300	24.50	4.95	24	165	125	7.20
TOTAL	1,280					52			15.60
Bikaner tehsil	600	75	0.150	12.25		48	120	87	7.20
Total Bikaner Basin	1,880					100			22.80
(c) Luni Basin									
Merta City	380	150	0.300	12.25	3.50	31	90	55	9.30
Central and eastern parts	2,010	75	0.150	6.12	2.45	330	80	57	49.50
Total Luni Basin	2,390					361			58.80
Summary according to well capacity	4,430	150				303			90.60
	7,310	75				1,145			171.70
GRAND TOTAL	11,740					1,448			262.30

* Annual pumping hours: 2,000

Table 27. Characteristics of tubewells for ground-water development in the Rajasthan Area

Basin	Area	Well capacity m^3/h	Aquifer characteristics			Initial depth to water level (m)		Expected maximum drawdown (m) after:				Mean depth(m) to:	
			Transmissivity m2/d	Specific yield %	Specific capacity m3/h/m	Range	Mean depth	24 hrs (1)	1 yr	5 yrs	20 yrs	Bottom of pump bowls	Screen zone (2)
Sikar	Central and Nawa	150	230	10	11	35-55	45	13.6	18.0	18.5	27.7	66	67-90
	Central and NW	75	115	10	8	20-55	40	9.4	13.7	14.2	17.2	56	58-80
Bikaner	Bandeau	150	500	7	15	50-85	65	10.0	12.1	12.4	14.0	79	80-120
	Raneri	150	500	7	15	90-130	110	10.0	12.1	12.4	14.0	124	125-165
	Bikaner	75	150	7	7	55-90	70	10.7	14.3	14.7	17.9	88	89-120
Luni	Merta City	150	250	7	11	30-60	35	13.6	17.5	18.9	23.2	56	58-90
	Central and Eastern part	75	125	7	8	30-70	40	9.4	13.3	14.3	17.8	56	59-80

(1) Assuming continuous pumping.

(2) Including intermediary blind portions. The total screen length must be at least 18 m for 150 m^3/h capacity TW and 15 m for 75 m^3/h TW

withdrawals. Wells would have to be deeper than in the Sikar basin and pumping levels would be greater. At this stage, only a small area surrounding Bikaner, where depth to water table is moderate, is proposed for development. In the remainder of the basin covering 5,600 km^2 and capable of yielding 69 MCM of additional ground water, pumping level should be 110 m on the average, and the resulting cost of water could be prohibitive for irrigation use.

In the Luni basin, about 30 new tubewells could be constructed in the Merta City area (380 km^2). These would produce 9.3 MCM of water annually. The aquifer in this basin is more heterogeneous and still insufficiently known. Further test drilling will therefore be required.

In other parts of the project area, ground-water conditions are less favourable. But medium-capacity tubewells, that could provide 75 m^3/h on the average, can be drilled in the central and north-western parts of the Sikar basin, and can be expected to supply a total annual volume of 115 MCM. Similar wells could produce additional 23 MCM in the Bikaner basin and about 50 MCM in the Luni basin. Part of these medium-capacity wells would be located in areas where total ground-water salinity exceeds 3,000 ppm.

Where the saturated thickness of the aquifer is less than 30 or 40 metres, dug wells, or dug wells deepened by drilling only are indicated, for ground-water exploitation on a more modest scale.

In the Nagaur area, the water-yielding capacities of the Nagaur series and Jodhpur Sandstone aquifers are low, and ground-water exploitation can be contemplated only for domestic use or for irrigation on a small scale. Wells can be expected to yield only 20 m^3/h or less. In the terrain of Precambrian rocks, only very modest supplies for domestic use can be made available.

G. Pedology, land and water use

1. General characteristics of soils in the project area

The soils are generally light textured, mostly calcareous and can be classified as desert soils with the exception of some soils of alluvial origin. Some physical properties are detailed in annex 12. They have been sub-divided into six broad groups (fig. 33).

(a) Desert soils and sand dunes

(b) Calcic brown soils

(c) Non-calcic brown soils

(d) "Red" desert soils

(e) Grey-brown alluvial soils

(f) Saline soils of depressions

The arid climate with low rainfall, high temperature and evaporation has resulted in physical and mechanical disintegration of the parent material giving rise to a predominance of coarser fractions in the soils. Very little weathering has taken place and the development of soil horizon is mostly indistinct.

The soils are poor in fertility status and water retention capacity. Detailed soil profiles are given in annex 14.

a. Desert soils

Together with sand dunes (the two are shown separately on figure 33), the desert soils cover large parts of Bikaner, Churu and Sikar districts. They are light yellowish brown to yellowish brown calcareous sands of variable depth. Their hydraulic conductivity ranges up to 13.6 cm/h, while the minimum available moisture was 1.1 per cent. The large fine sand fraction reflects their mainly aeolian origin.

Representative profile of a desert soil

Sital

Site information

Soil group	:	Desert soils
Date of examination	:	11 October 1973
Location	:	Near the Panchayat Office building
Land form	:	Flat to gently undulating
Slope	:	Average 2 per cent
Land use	:	Uncultivated. Typical desert sandy area with characteristic shrubs

General information on the soil:

Parent material	:	Mainly aeolian sand
Drainage	:	Class 5/6 excessive
Moisture condition in profile	:	Dry throughout
Human influence	:	Very slight

Profile description (Munsell soil color coding)

0-140 cm.	Yellowish brown (10 YR 5/4) moist and very pale brown (10 YR 7/4) dry; sand; structureless single grain; non-sticky, non-plastic, noncoherent, moist or dry; no roots; diffuse boundary. A few $CaCO_3$ concretions present and increasing with depth.

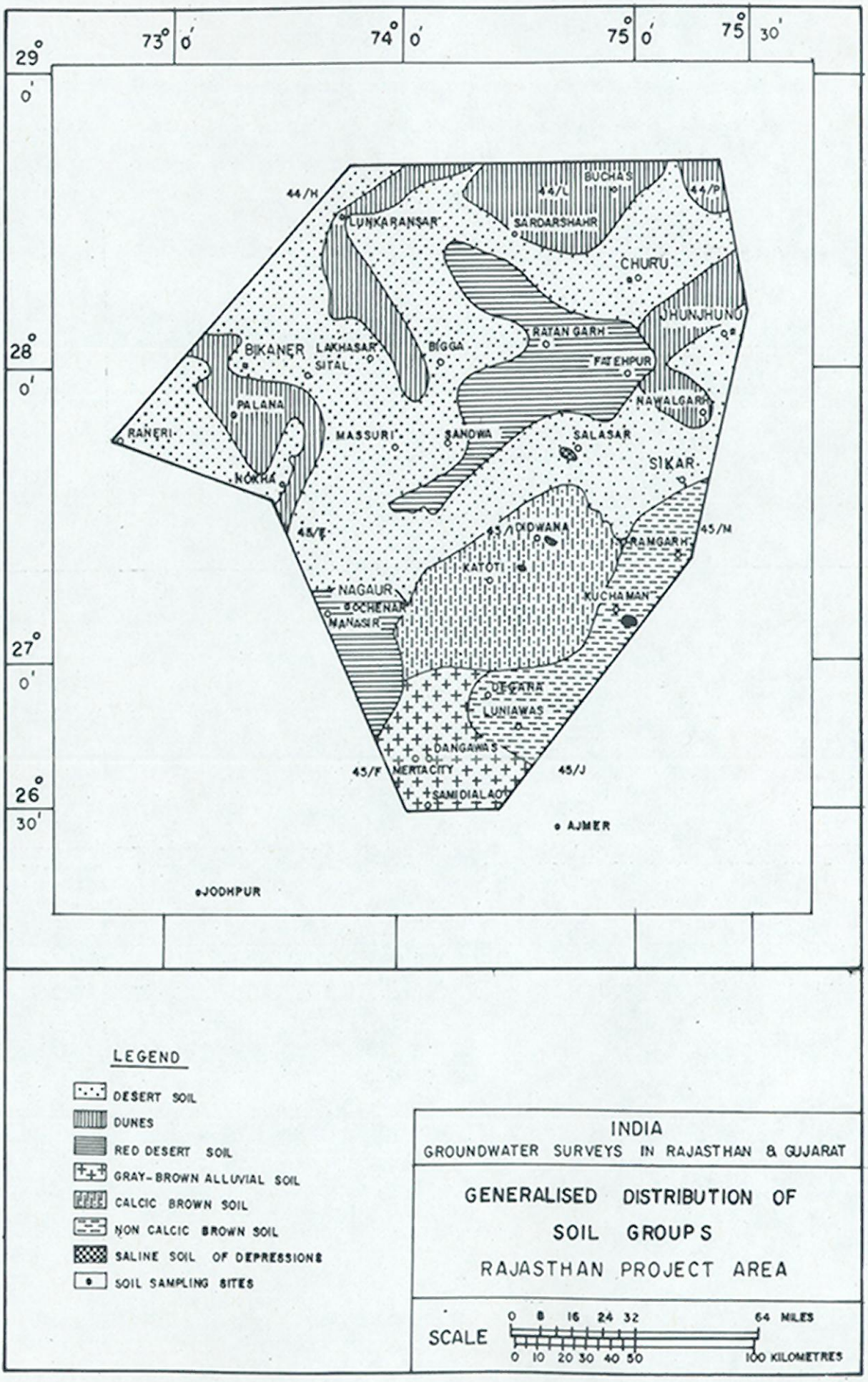

73° 0'
74° 0'
75° 0'
75° 30'
29° 0'
28° 0'
27° 0'
26° 30'
44/H
44/L
44/P
45/E
45/I
45/M
45/F
45/J
BUCHAS
LUNKARANSAR
SARDARSHAHR
CHURU
JHUNJHUNU
RATAN GARH
FATEHPUR
NAWALGARH
BIKANER
LAKHASAR
SITAL
BIGGA
PALANA
RANERI
MASSURI
SANDWA
SALASAR
SIKAR
KOLIA
DIDWANA
RAMGARH
KATOTI
NAGAUR
KUCHAMAN
BOCHENAR
MANASIR
DEGANA
LUNIAWAS
DANGAWAS
MERTA CITY
SAMBHAR LAKE
AJMER
JODHPUR
LEGEND
DESERT SOIL
DUNES
RED DESERT SOIL
GRAY-BROWN ALLUVIAL SOIL
CALCIC BROWN SOIL
NON CALCIC BROWN SOIL
SALINE SOIL OF DEPRESSIONS
SOIL SAMPLING SITES
INDIA
GROUNDWATER SURVEYS IN RAJASTHAN & GUJARAT
GENERALISED DISTRIBUTION OF
SOIL GROUPS
RAJASTHAN PROJECT AREA
SCALE
0 8 16 24 32 64 MILES
0 10 20 30 40 50 100 KILOMETRES

Figure 33

140-200 cm. Light yellowish brown (10 YR 6/4), and dry, sand; structureless massive; non-sticky, non-plastic, very friable moist, soft dry; diffuse boundary. More and slightly larger kankar nodules than horizon above.

Below 200 cm. Light yellowish brown (10 YR 6/4), moist very pale brown (10 YR 7/3), dry, sand; texture and consistence as above horizon but more calcareous.

General — A typical desert soil profile with no alluviation evident. Structureless and calcareous throughout.

b. Red desert soils

Red desert soils occur in the southern part of Churu district, the north-western part of Sikar district and in the south-western corner of the project area in Nagaur district. They are typically deep brown, non-calcareous, loamy sands and sandy loams, partially derived from sandstones and, south-west Nagaur, from alluvial deposits. Hydraulic conductivity of the profiles examined ranged from 0.5 to 2.5 cm/h. Minimum available moisture was 1.38 per cent.

Representative profile of a red desert soil

Fatehpur

Site information

Soil group	:	Red desert soils
Date of examination	:	November 1973
Location	:	Four kilometres from the town on Sikar road. In virgin land.
Land form	:	(i) Topography: slightly sloping (ii) Microtopography: numerous hummocks
Land use	:	The main crops of this area are poor millet and moong. The vegetation consists of numerous well-grown Acacia trees.

General information on the soils:

Parent material	:	Aeolian deposits and sandstones
Drainage	:	Very well drained to somewhat excessively drained
Moisture condition of profile	:	Dry throughout

Profile description

0- 35 cm. Yellowish brown (10 YR 5/4) moist and light yellowish brown (10 YR 6/4) dry; sandy loam; slightly plastic and slightly sticky; many roots present; strongly calcareous.

34-140 cm. Brown (10 YR 5/3) moist and pale brown (10 YR 6/3) dry; loamy to sandy loam; roots present; non-calcareous

c. Non-calcic brown soils

Non-calcic brown soils are found in the eastern part of the project area mainly in the Nagaur and Sikar districts. They grade from sand to sandy loam and are non-calcic except at greater depth. In colour, permeability and available moisture percentage they are similar to the desert soils, but have higher clay, silt or coarse sand fractions. They are thought to have developed from older alluvial and colluvial deposits and have a considerable overburden of aeolian sand.

Representative profile of a non-calcic brown soil

Degana

Site information

Soil group	:	Non-calcic brown
Date of examination	:	November 1973
Location	:	In a farm field outside the town on the road to Luniawas
Land form	:	Fairly flat
Slope	:	Less than 1 per cent

General information on the soil

Parent material	:	Mainly aeolian deposits
Drainage	:	Class 5 or 6
Moisture condition of profile	:	Moist below 50 cm

Profile description

0-100 cm Yellowish brown (10 YR 5/4) moist and light yellowish brown (10 YR 6/4) dry; loamy sand; friable; non-calcareous

100-130 cm Yellowish brown (10 YR 5/6) moist, loamy sand; non-calcareous

d. Calcic brown soils

The calcic brown soils form a distinct mapping unit in the north-eastern part of Nagaur district and are typically deep yellowish-brown to grey loamy sands. The minimum available moisture found in this type was 2.46 per cent and permeability ranged from 0.0 to 4.4 cm/h.

Representative profile of a calcic brown soil

Katoti

Site information

Soil group	:	Calcic brown soils
Date of examination	:	1 November 1973
Location	:	Near the village, on the road to Nagaur in cultivated land
Land form	:	(i) Physiographic position: on a raised plateau west of a limestone outcrop (ii) Surrounding land farm: gently sloping (iii) Microrelief: flat
Slope	:	Less than 2 per cent

General information on the soil

Parent material	:	Mainly aeolian deposits
Drainage	:	Moderately to well drained
Moisture condition in profile	:	Moist below plough zone

Profile description

0 - 30 cm	Yellowish brown (10 YR 5/4) moist and light yellowish brown (10 YR 6/4) dry; loamy sand; non-sticky and non-plastic; dry consistency moderately hard; slightly calcareous
30 - 90 cm	Yellowish brown (10 YR 5/4) moist, sandy loam; non-plastic; non-calcareous
90 - 110 cm	Dark brown (10 YR 4/3) moist; sandy loam, sticky and plastic, $CaCO_3$ connexions are present and increase with depth; calcareous

e. Grey-brown alluvial soils

The grey-brown alluvial soils are found in the southern part of the project area, in Nagaur district, and consist of grey-brown to very dark grey loamy sands and sandy loams of variable depth. Minimum available moisture of the samples examined was 2.94 per cent and hydraulic conductivity ranged from 1.8 to 5.8 cm/h.

In the Sikar basin mainly desert soils and non-calcareous brown to yellow soils are found increasingly covered north of Sikar town by sand and dunes. In the north-west of the basin red desert soils are also present.

In the Luni basin, soils are mostly of grey-brown alluvial type whereas in the Bikaner basin dunes and calcareous desert soils of variable depth are found. Soil profile characteristics are usually adverse in this basin, and in its western part unfavourable topographical and surface conditions are encountered.

f. Saline soils of depressions

Saline soils are found in low interdunal areas and are of fine texture. Generally they are saline or sodic having low permeability values and impeded drainage. They rarely occur in areas with favourable conditions for development of ground-water resources, and for this reason problems related to their possible reclamation are not discussed here.

2. Physical characteristics of soils

Mechanical analyses show that the soils are in general light textured ranging from sand to sandy loam. The clay content is in general low, a maximum clay percentage of 17.3 being found in samples collected at Samidialao in the belt of alluvial soils. Clay content in these soils is an important factor because of its general influence on the soil's chemical and physical properties. Clay percentage is positively correlated at a 1 per cent level with the cation exchange capacity of the soils (fig. 33).

As most of the soils are light textured, the silt content merits special attention. The amount of silt present is positively correlated with the cation exchange capacity of the soils (significant at 5 per cent level). But when the clay and silt percentages together were used for the calculation of the correlation coefficient for the above-stated relationship, the correlation was significant at 1 per cent level, clearly showing the importance of silt in these soils.

In general, the soils have good aeration and pore space (about 40 per cent) and the permeability is excessive in some cases. The highest hydraulic conductivity of these soils (13.6 cm/h) was recorded in a sample from Massuri; the lowest 0.0 cm/h in the third horizon of Katoti and 0.1 cm/h for soil

at Salasar. Although the finer fraction of these soils is not high, the exchangeable sodium percentage (ESP) is remarkably high. The sodium ion causes swelling of the soil on wetting, and this has a markedly deleterious effect on the hydraulic conductivity. The results obtained probably reflect the higher swelling pressures and consequent disruption of the aggregates owing to high amounts of exchangeable sodium on the exchange complex of the soils.

Distilled water was used for laboratory determinations and it is established that leaching with good-quality water can increase the degree of dispersion of finer fractions in soils which were previously irrigated with saline water. Leaching with saline water, particularly water containing divalent cations would tend to decrease the degree of dispersion and increase soil permeability.

The generally light texture and the mostly mineral character of the soils are also evident from the values for bulk density. Both the hydraulic conductivity and bulk density values decrease with depth as the amount of finer fractions increases. Except in areas where adverse surface factors are found, such as Raneri, intake rates are high.

3. Soil moisture

While topography, depth of profile and soil texture were taken into account while assessing suitability of land for irrigation, the most important parameters in this respect are those related to soil moisture.

Maximum moisture holding capacity was found to be greater with an increase in the percentage of the finer fractions. Measurement of available moisture per cent, i.e., the difference of moisture percentage at field capacity (0.3 atmospheres) and wilting coefficient (15.0 atmospheres) shows that most soils in the project area have a low percentage on account of the predominance of coarser fractions which can retain little or no moisture. The amount of organic matter, as well as finer soil fractions, is very low and as both these constituents are essential for satisfactory retention of moisture it is evident that only a fraction of the water as applied to the soil under present irrigation methods is available for utilization by plants. The rest of the water applied is lost mainly by deep percolation. As all these soils have high intake rates, losses by runoff are considered minimal.

The data show that in most cases, the trend is for the available moisture percentage to increase with depth along with the finer soil fractions. However, organic carbon content, which could also be a factor in raising the available soil moisture, is found to be decreasing with depth. It was observed from these data that the increase in the available moisture with depth might also be due to the lime content of the soils. The lime absorbs moisture at lower suction pressure but gives it up at higher pressures. This is not the case with the clayey soils where the moisture content is higher both at lower and higher suctions resulting in a comparatively lower percentage of available moisture.

4. Chemical characteristics

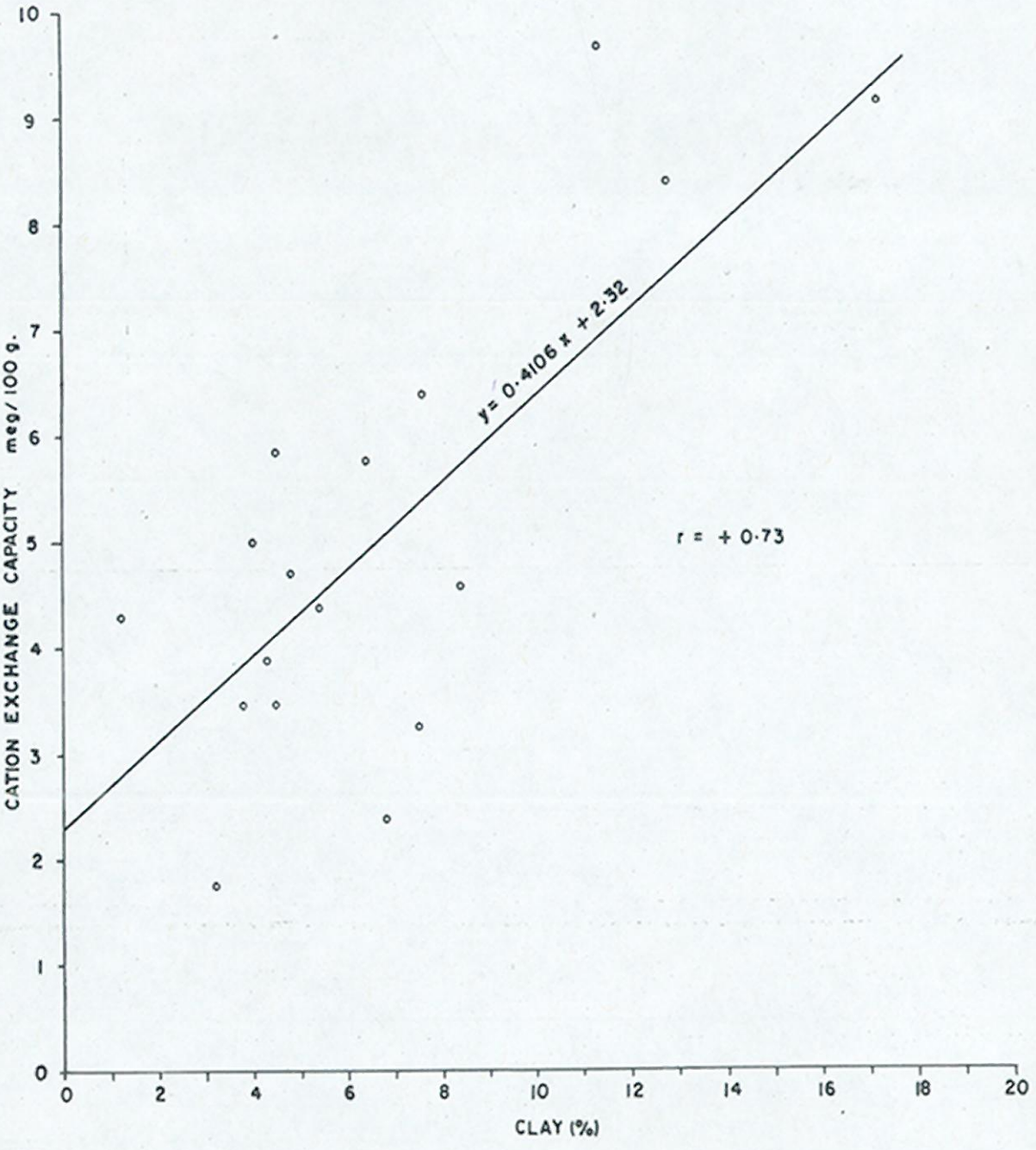
The chemical analyses of the soils are given in annex 13. The pH of the surface horizons ranges between 7.5 and 8.5 and in a number of profiles the tendency is for pH to increase with depth. This is probably mainly due to the lime content which also increases with depth. The same trend is seen with electrical conductivity (EC) values which increase with depth in many profiles especially where the deeper horizons are permeable enough to facilitate the movement of dissolved salts during irrigation or rains.

The EC of the saturation extracts is unexpectedly low in the soils examined and is though to be due to unusually high rainfall during the 1973 monsoon which must have caused an exceptional leaching of salts to the deeper layers.

Most of the soils are calcareous except in the south-eastern part of the project area. The maximum percentage of lime was found below 120 cm in the soil profile at Sardarshahr. As stated above, the lime content increases with depth, the increase being very steep in some cases where C horizons or horizons transitional from B to C which are usually highly calcareous, are encountered.

The cation exchange capacity (CEC) of the soils is low owing to the light textures and increases in proportion to the finer soil fraction alone. The low organic matter content in all these soils contributes virtually nothing to the CEC. A significant positive correlation was observed between clay content and CEC (at 1 per cent level) and silt content and CEC (at 5 per cent level) (fig. 34).

The sodium adsorption ratio (SAR) values of the saturation extract are small when compared to the ESP (exchange sodium percentage) values of the soils. The data also show that the Capon constant (Kg.) in the Capon type equation used by the U.S. Salinity Laboratory staff (1954) is completely different from sililar constants that could be derived from the present results. This might be explained by, among other factors, the lack of equilibrium in soils. Although most of the soil samples were collected from cultivated and cropped land, there is no equilibrium between the soil and the soil solution. Moreover, exceptional rains during the 1973 monsoon, which preceded the collection of the soil samples (mainly in November) must have resulted in the leaching down of the intermicellar solution in the soils resulting in a breakdown of the usual relationship between the monovalent-divalent cation ratio of the soil solution and the fraction of the exchange sites occupied the monovalent cations. Nevertheless, a significant correlation for the relationship between SAR, ESP and



Relationship Between Clay Percentage (x) And Cation Exchange Capacity (y) In Sikar Basin Soils

Figure 34

ESR (figs. 35 and 36) was observed for Sikar basin soils where tubewell irrigation is most intensive in the project area.

5. Irrigability of soils

Classification of soils as to their irrigability followed practices and criteria used by the All India Soil and Land Use Survey Organization (see tables 28 and 29).

In large parts of the project area the soils are considered unsuitable for intensive irrigation development owing to undulating topography, sloping foothills, the incidence of steep sand dunes and the saline and/or alkaline nature of interdunal areas. According to the irrigability classes suggested by the All India Soil and Land Use Survey Organization I.A.R.J., New Delhi, most of the soils of the project area fall into classes C, D and E. The main limitations for their sustained use under irrigation are light soil texture, high permeability and low available moisture holding capacity (AMHC).

The dune soils are light textured with very high hydraulic conductivity and very low AMHC in addition to the limitations imposed by steep slopes.

Unfavourable surface factors, e.g., a tendency to capping and the presence of gravel also cause serious limitations to irrigability as for example in the terrain around Raneri in the Bikaner basin. Very low permeability and high ESP may become unfavourable factors as regards irrigability of the soils at Katoti and Salasar. Nevertheless, with suitable soil and water management practices, the soils could for the most part be put under irrigation where suitable water can be made available.

Soils of irrigability class C will generally fall into Irrigable Land Class 3 (having severe limitations for sustained use under irrigation) and, where there are unfavourable local topographical factors such as excessive slope or severe restrictions with regard to land levelling, into Irrigable Land Class 4 (marginal for sustained use under irrigation). Soils of Irrigability Class D will automatically qualify for Irrigable Land Class 4 and those of Class E are regarded as non-irrigable subject in some cases to further investigation (tables 28 to 32).

These classifications do not take into account the soil cation exchange capacity, which for a suitable irrigable soil is taken as 3 meq/100 g. Soils with lower CEC have ipso facto little capacity to retain applied fertilizers and may not be at all suitable for irrigation in this area. Their productive status could be improved by soil amelioration measures coupled with careful irrigation programming, otherwise they must be regarded as economically marginal or unsuitable for irrigation agriculture.

6. Suitability of ground water for irrigation

a. Total solids

The following table presents an insight into the frequency of distribution of total ground-water salinity in tubewells - including project and pre-existing tubewells - in the Rajasthan project area.

Salinity (ppm TDS)	No. of wells
less than 500	6
500-1,000	13
1,000-2,000	25
2,000-3,000	6
3,000-4,000	5
4,000-5,000	2
more than 5,000	1

More than half the samples contain less than 2,000 ppm TDS. It is not certain, however, to what extent the samples are representative for the entire project area. Nevertheless, it appears justified to assume that in those areas where conditions for ground-water exploitation are favourable, ground-water salinity will be within the range acceptable for irrigation. Because of the light texture of the soils, the use of water with relatively high salinity for irrigation is possible.

An approximate appraisal of the salinity hazard for north Indian soils has been proposed following U.S.S.L. classification of water salinity:

C-2 - medium-salinity water (up to 500 ppm) can be safely used and plants of low to moderate salt tolerance can be grown on these soils without special practices for salinity control.

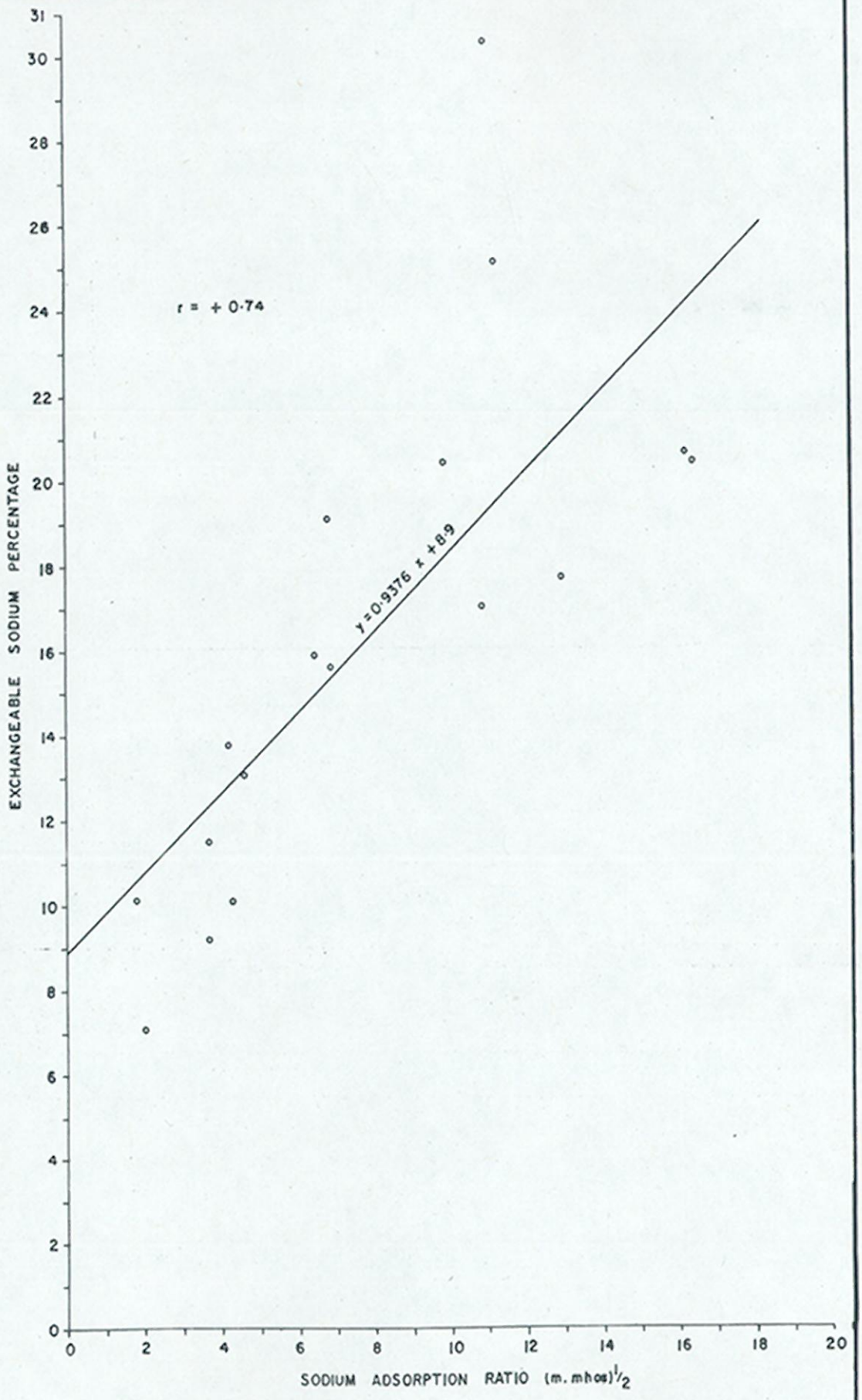
C 3 - high-salinity water (500 to 1,500 ppm) can also be used on most of these soils where plants of moderate to good salt tolerance are grown. Special management for salinity control is not expected to be necessary and the intensity of monsoon rainfall should provide the amount of leaching required.

C 4 - very high salinity water (1,500 ppm to 3,250 ppm) is not expected to pose much of a problem where crops with good salt tolerance are selected and soils are permeable. Leaching requirement is estimated at under 10 per cent and this can in most seasons be supplied by the monsoon.

In table 33, ground-water quality rating is suggested for suitability for irrigation with reference to the soils of the project area. This is purely empirical and could be used for advisory purposes in the project area. However, it should be mentioned that this suitability rating should be confirmed by extended field experiments.

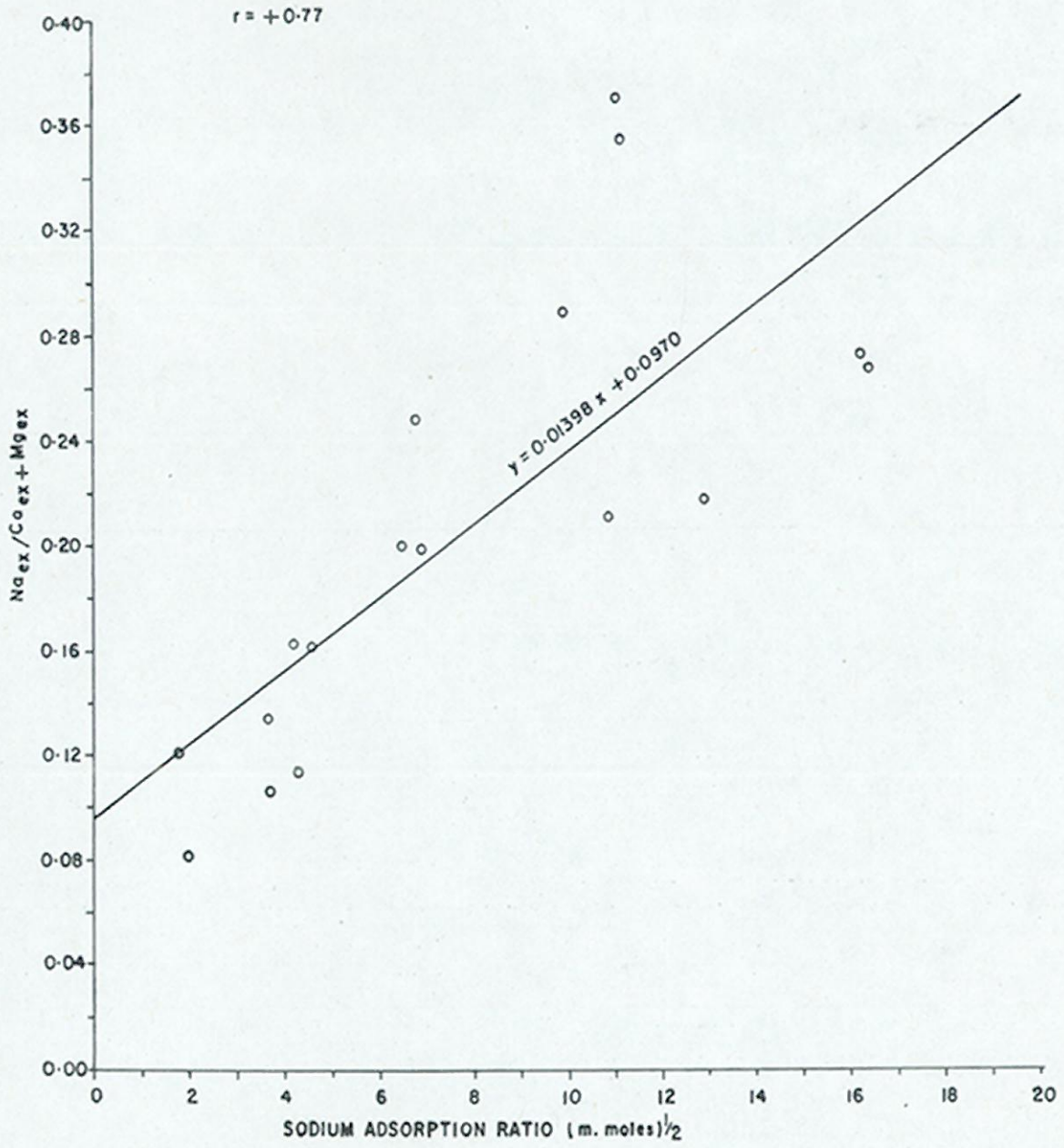
b. Sodium content

The sodium content and various parameters



Relationship Between Sodium Adsorption Ratio (x) And Exchangeable Sodium Percentage (y) In Sikar Basin Soils

Figure 35



Relationship Between Sodium Adsorption Ratio (m.moles)$^{1/2}$ (x) And $Na_{ex}/Ca_{ex}+Mg_{ex}$ (y) In Sikar Basin Soils

Figure 36

Table 28. Criteria for classifying soils into irrigability classes (1)

Soil properties	Semi-arid and arid regions				
	Irrigable soil classes				Non-irrigable soil class
	A	B	C	D	E
Effective soil depth (useful to crops) (cm)	+90 cm	45-90	22.5-45	45-22.5	7.5 cm
Texture of surface 30 cm	SL to CL inclusive	LS;clay	S;clay	S;clay	Any
Soil permeability (of least permeable layer)(mm/hr)	5.0-50 mm/hr	1.3-5.0 50-130	0.3-1.3 130-250	0.3 250	N/A
Available moisture holding capacity to 90 cm (cm)	12	9-12	6-9	2-6	2
Coarse fragments per cent cobbles or stones (75 mm)	5	5-15	15-35	35-65	+65
gravel and kankar (25-75 mm)	15	15-35	35-55	55-70	+70
Rock outcrops (distance apart in metres)	40	20	15	5	5
Salinity, S.E. (mmho)	4	4-8	8-12	12-16	+16
Percentage of terrain affected by salinity	20	20	20-50	20-50	+50
Severity of alkali problem (ESP)	-15%	-15%	+15%	+15%	
Subsoil or substrata drainage characteristics	L.S.S. is at least mod. permeable or a permeable layer of at least 6" thickness occurs immediately below the soil but within 10 ft (sand, gravel, etc.)			No mod. perm. S.S. or other perm. layer of at least 6" thickness within 10 ft. depth.	
Soil erosion status	Usually not applicable to project area				

Symbols: SL - sandy loam
LS - loamy sand
CL - clay loam
\+ - more than
\- - less than

(1) From: Department of Agriculture Handbook on Irrigation Water Management, 1971, New Delhi

Table 29. Specifications for land irrigability classes

Soil Characteristics	Irrigable Land Classes 1	2	3	4	Class 5 temporarily non-irrigable (Unclassified).	Class 6, not suitable for irrigation.
	S o i l s				Further investigations needed	Includes land not suitable and not capable of being supplied with water
Soil Irrigability	A	A to B	A to C	A to D		
	Topography					
1. Slope	1%	1-3	3-5	5-10		
2. Surface grading	No restriction or less than m^3 excavation per hectare; less than m^3 average cut and fill	Moderate restrictions	Moderate severe restrictions	Severe restrictions		

Table 30. Irrigability class of Sikar Basin soils

Location	Fatehpur	Nawalgarh	Sikar	Kuchawan	Jhunjhunu	Ramgarh	Churu
Broad soil group	Red Desert	Desert	Desert	N.C.B.*	Desert	N.C.B.*	Desert
Depth	A (> 90cm)	A	A	A	A	A	A
Texture of surface 30 cm	B (Loamy sand)	B	C (Sand)	C	B	B	C
Permeability (of least permeable layer)	A (5mm/hr)	B (65mm/hr)	B (69mm/hr)	B	A (27)	A (37)	B (60)
Available M.H.C. to 90 cm	D (5.5cm)	D (2.4cm)	E (1.5cm)	D	D (3.1)	D (2.3)	D (3.6)
Coarse fragments (< 75mm)	A	A	A	A	A	A	A
Kankar (25 - 75mm)	A	A	A	A	A	A	A
Rock outcrops (Distance apart in m)	A	A	A	A	A	A	A
Salinity (mm ho)	A	A	A	A	A	A	A
Salt affected (% area)	A	A	A	B	A	A	A
Severity of alkali problem (ESP)	C	A	A	C	B	A	C
S.S. drainage	B	A	A	A	A	A	A
Erosion status	A	A	A	A	A	A	A
Range	A-D	A-D	A-E	A-D	A-D	A-D	A-D
Soil irrigability class	D	D	E	D	D	D	D

* Non-calcic brown soils

Table 31. Irrigability class of Bikaner Basin soils

Location	Raneri	Sital	Nokha	Massuri	Bigga
Broad soil group	Desert soil	Desert	Desert	Desert	Desert
Depth	A	A	A	A	A
Texture	B	C	C	B	B
Permeability	A	B	B	C	B
Available M.H.C.	C	D	D	D	E
Coarse fragments	E	A	A	A	A
Kankar	D	A	A	A	A
Rock outcrops	B	A	A	A	A
Salinity	A	A	A	A	A
Salinity affected	A	A	A	A	A
Alkali problem	A	C	C	A	A
S.S. Drainage	D	A	A	A	B
Erosion	A-B	A	A	A	A
Soil irrigability class	E	D	D	D	E

Table 32. Irrigability class of Luni Basin soils

Location	Merta City	Samidialao	Luniawas	Degona
Broad soil group	G.B.A.	G.B.A.	N.C.B.	N.C.B.
Depth	A	B	A	A
Texture	B	A	A	B
Permeability	A (27mm/hr)	A(18)	A(39)	A(42)
Available M.H.C.	D	C	C	D
Coarse fragments	A	A	A	A
Kankar	A	D	A	A
Rock outcrops	A	A	A	A
Salinity	A	A	A	A
Salt affected	A	A	A	A
Severity of alkali problem	A	A	A	A
S.S. Drainage	B	B	B	B
Erosion status	A	A	A	A
Soil irrigability class	D	D	C	D

G.B.A. = Grey brown alluvian soils

N.C.B. = Non-calcic brown soils

Table 33. Suggested ground-water quality rating with reference to soils of project area

Per cent clay	Drainage condition of soils	Permeability of soils	Salt tolerance of crop plants	Upper safe limit of salinity of water (ppm)
20-30	Fair	Moderate, 2 to 4 cm/h	Semi-tolerant:	2,000
			Tolerant :	4,000
10-20	Moderate	Rapid, 4 to 8 cm/h	Semi-tolerant:	4,000
			Tolerant :	6,000
10 and below	Good	Excessive, 8.0 cm/h	Semi-tolerant:	6,000
			Tolerant :	8,000

related to it (SAR, RSC) are no less important than total salinity in appraising the suitability of water for irrigation on a given soil.

The following water classification according to sodium content has been adopted:

S 1 - Low-sodium water can be used on almost all soils of the project area without any danger of a sodium problem developing;

S 2 - Medium-sodium water can also be used safely on these coarse-textured soils although there may be danger of sodium accumulation in avocados and some fruits;

S 3 - High-sodium water; its continued use on the soils of the project area may call for some special management practices such as additional leaching and incorporation of organic matter and gypsum in the soil;

S 4 - Very high-sodium water, coupled with high salinity levels, as at Daulatpura, Dangawas and Degana, is not recommended for use unless soil condition can be maintained by the use of some gypsum.

In table 34 suitability of water from tubewells for irrigation on the various soils found in the project area is presented.

In the light of the fact that most of the soils have little clay, their ESP, even if it rises on irrigation to an unfavourable level, should not be a constraint for the use of brackish water. This is due to the fact that the net amount of exchangeable Na^+ per unit weight of soil is very low owing to the low CEC of these soils. However, it may be necessary to employ suitable management practices wherever the SAR of the tubewell water is high together with an unfavourable RSC (residual sodium carbonate). Water from the well at Degana Railway Station for example which has 3,512 ppm TDS, SAR of 37.2 and RSC of 12.9 would be highly detrimental on heavier soils but might be used on the lighter textured soils of that area.

In such soil-water combinations, it may be necessary to add gypsum as well as organic manure. The presence of gypsum tends to correct unfavourable SAR of ground water and the organic matter would improve the physical condition of the soils and increase their water-holding capacity. Moreover, organic matter has a higher surface charge density and has preference for divalent cations on its exchange complex over Na^+. Application of gypsum to the soil is preferred to application in water because in water gypsum tends to form hard aggregates with a consequent reduction in its chemical activity. The cost of applying gypsum directly to the soil was not determined. The cost of water treatment with gypsum has been estimated (for water of SAR 40) at about Rs 20 per acre foot of water (i.e., 0.3 tons at Rs 60 per ton) or Rs 75 for 0.5 hectare metres.

Table 34. Suitability of tubewell water for irrigation on two soil types of the project area, according to sodium content classification

Water type posing no hazard	Water type posing low hazard	Water type posing moderate to high hazard
	a. Sands	
$C_2 - S_1$	$C_4 - S_1$	$C_3 - S_4$
$C_2 - S_2$	$C_4 - S_2$	$C_4 - S_4$
$C_2 - S_3$		$C_4 - S_3$
$C_2 - S_4$		
$C_3 - S_1$		
$C_3 - S_2$		
$C_3 - S_3$		
	b. Sandy loams	
$C_2 - S_1$	$C_3 - S_3$	$C_2 - S_4$
$C_2 - S_2$		$C_3 - S_4$
$C_2 - S_3$		$C_4 - S_3$
$C_3 - S_1$		$C_4 - S_4$
$C_3 - S_2$		
$C_4 - S_1$		
$C_4 - S_2$		

Where irrigation water has a higher concentration of anions such as SO_4^{2-}, CO_4^{2-}, and HCO_3^- as

compared to Cl^-, Na^+ adsorption by the soil is higher for the same level of TDS and SAR.

On the basis of RSC, about 49 per cent of the tubewell waters sampled fall under class "unsuitable", i.e., RSC values over 2.5, but owing to the fact that the soils are coarse textured and have low CEC values the limit may be extended to 5.0 in which case the percentage of unsuitable water falls to 25. Moreover, the RSC values together with SAR and TDS should be considered in conjunction when suitability of a certain type of water for irrigation is examined. By adding gypsum to the water or to the soil, the detrimental effect of RSC could be mitigated to a considerable extent.

c. Boron

Some of the water samples from tubewells show a relatively high boron content. The highest boron content found in any of the analysed samples is 3.68 ppm (Kerap, Sikar, Basin, annex 9, no. 5). Boron content is therefore an important criterion for the suitability of ground water for irrigation in Rajasthan.

Most field crops grown in the project area fall in the semi-tolerant range, i.e., up to 2 ppm of boron in the soil solution and in these cases boron is thought to have a beneficial effect on synthetic and metabolic processes. Generally, legumes require more boron than cereal crops and have a higher tolerance. Kharif (monsoon) crops are in general more tolerant than rabi (winter) crops.

The yield of wheat and mustard is likely to decline beyond 1 ppm of boron, and barley at levels above 2 ppm.

The possibility of boron-induced iron deficiency with consequent chlorosis and reduced protein synthesis exists where the boron level in tubewell water is too high.

Studies have shown that the adverse effects depend more on the equilibrium boron concentration in the soil solution than on the boron concentration in irrigation water. Equilibrium boron concentration, for the same boron concentration in irrigation water, is higher in fine textured than in light textured soils.

As most of the soils in the project area are light textured, the boron level in the soil solution that could be expected to develop under continued irrigation would be relatively low, and therefore the upper margin of permissible boron content in irrigation water can be relatively high.

Adding organic matter to the soil can further reduce the boron toxicity hazard.

For a given level of boron concentration its rate of adsorption in the soil can rise with the pH of irrigation water. For tubewell waters with around 2,500 ppm TDS and SAR of 14 per cent adsorption tends to rise with RSC and fall when SAR decreases.

The presence of $CaCO_3$ in soil results in increased boron adsorption with a consequent lowering of water-soluble boron content. It follows that irrigation waters of somewhat higher boron concentration can be used on calcareous soils in the project area. Moreover, where the uptake of Ca by plants is high they can tolerate higher levels of boron.

The possibility of detoxication of boron in irrigation water by mixing with good-quality water is considered to be very limited in the project area. Detoxication may also be achieved by raising the pH of irrigation water by addition of gypsum, e.g., at Chenar and elsewhere, where pH values are around 7.4 and boron concentration 3 ppm.

d. Nitrate

A natural high nitrate content in irrigation water is to be regarded as an asset, because nitrogen is the main limiting factor for plant growth on the soils of the project area. Irrigation water containing 100 ppm of nitrate is estimated to supply around 100 kg/ha of nitrogen for 500 mm of water supplied.

Where high nitrate values occur, the TDS levels of water are also higher, e.g., at Nagaur the NO_3 concentration is 480 ppm with TDS of 4,090 ppm. However, this concentration is regarded as favourable as the nitrates seem to counteract the harmful effect of salinity on plant growth, the nitrate being taken up by the plant (restoring the osmotic gradient between cell sap and soil solution) and the net total salt concentration being reduced.

Nitrate mineralization in the soil is expected to be reduced where pH, salinity and ESP rise, sodium chloride and to some extent the carbonate are inimical to nitrate mineralization but the presence of soil $CaCO_3$ helps the process in calcareous soils.

Most water samples from tubewells in the Sikar basin contain 1.0 to 1.5 ppm of nitrate. In the Bikaner basin, some exceptionally high values (7.4, 7.7 ppm) were recorded from the Nagaur sandstone, but most of the samples analyzed show nitrate concentrations of less than 1.0 to slightly more than 2.0 ppm. In the Luni basin most water samples range from 0.5 to 2.5 ppm.

e. pH values

From previous observations made in Delhi, the soil pH equilibrium value was reached after 36 irrigations and it has been observed that the pH of irrigation water is more directly related to soil pH, ESP and degree of dispersion than other water properties.

Taking the pH of illite type clay as 8.5 which

is the generally accepted level for alkali formation in soil, the corresponding limit of the irrigation water comes out at 9.5 where other water properties have average values. All tubewell waters sampled are satisfactory therefore in respect of their pH values.

The constant use of alkaline tubewell waters, however, which increases the solubility and hydrolysis of $CaCO_3$ will result in the precipitation of phosphates in unavailable form.

f. Potassium

The potassium content of irrigation water should also be considered because of its value as a plant nutrient. Although the concentrations of potassium in tubewell water are not very great its presence has a positive effect on the balanced ionic environment of the root zone. Potassium may be applied to soils to counteract the possible negative effect on plant nutrition of very high sodium and calcium concentrations of ground water.

g. Magnesium

Magnesium hazard could develop in soils where $\frac{Mg}{Ca + Mg} \times 100$ is greater than 50 per cent. Out of 70 water samples analyzed, 38 have a Mg/Ca ratio of 1.

Increased Na^+ adsorption in the soil is likely through constant use of Mg-rich water and Mg^{2+} in itself can have an adverse effect on soil structure. However adsorbed Mg can easily be replaced in the soil as Ca is released from soil $CaCO_3$ reserves, with consequent displacement of Mg.

h. Fluoride

Only two of the samples taken showed fluoride concentration above the harmful limit of 10 ppm as regards crop growth. These are at Degana (12 ppm) and Kitalsar (10.8 ppm). The chances of fluorine toxicity are greater on lighter soils especially where little adsorption takes place due to alkaline conditions and low clay content.

i. Phosphates

Phosphates are known to be more beneficial in the presence of nitrogen and where nitrate rich waters are used for irrigation it would be economical to increase phosphate application from present levels.

j. Chlorides

Forty-four per cent of water samples from tubewells contain less than 250 ppm Cl which is considered safe for most field crops, whether irrigated by surface or overhead methods, although citrus and some stone-fruit crops might suffer leaf damage at 150 ppm unless low-angle sprinklers are used.

In samples from the part of the Sikar basin with high-ground water potential, chlorides range from 40 to 250 ppm.

Concentrations are similar in the Luni basin, apart from isolated pockets of very high chloride content which are generally outside the zones of highest ground-water potential.

Taking the three high-potential zones of the Bikaner basin, chloride content along the Raneri-Kolyat axis varies from 120 to 400 ppm but around Bikaner itself the average is higher. Caution should therefore be used in planning sprinklers irrigations with these waters.

Across the zone north-east of Dungargarh the chloride concentration appears to range from 80 ppm in the southern part to around 2,000 ppm on the northern fringe. Further study of this zone is therefore required before irrigation suitability can be assessed.

7. Crop selection

Selection of crops for any area must take into account their sensitivity to salinity and boron. This also applied to different varieties of the same crop. For example, among wheats the local variety Kharchia and the hybrid variety Kalyan Sona exhibit a high degree of resistance to salinity. The salt tolerance level of a crop varies considerably with its stage of growth, effective salinity in the root zone, the quality of irrigation water and the management practices used. In general, winter crops like wheat and barley are the most salt tolerant, while monsoon crops such as millet have a higher level of resistance to alkalinity. Among the more TDS-tolerant monsoon crops are maize, urd (a lentil), cotton, sorghum and daincha (a fodder).

From published data it appears that the descending order of salt tolerance at germination up to EC 16 mmho is barley, wheat, sugar beet, berseem, mustard and grama. Berseem is very salt sensitive at both the germination and seedling stages and poor germination and growth of October plantings have been recorded in Bikaner, in spite of the use of innoculants.

Among common grasses the more salt tolerant seem to be Dactyloctenium aegyptium, Dichanthium annulatum and Chloris virgata.

Generally, better germination has been found where no single ion predominates in the irrigation water.

The adverse effect of anions on sorghum at germination is stated to be in descending order HCO_3, CO_3^{2-}, NO_3, Cl^- and SO_4^{2-} up to a concentration of 16 meq/litre but at higher concentrations there appears to be no specific effect on any single ion. Data on salt tolerance at germination is probably of limited value in forecasting crop yield potentials at later growth stages.

Where irrigation water has TDS between 5,000 and 10,000 ppm, wheat has shown a decrease in growth rate, tillering, shoot height and in particular root development. However, Kalyan Sona and other salt-resistant varieties have exhibited an increased response to nitrogen up to about 8,000 ppm TDS in typical Rajasthan desert soils (Pali-CAZRI).

In terms of relative cash returns or absolute yield per acre under saline conditions winter crops are tentatively placed in descending order: barley, wheat, peas, grama and mustard.

Of the three regions of good ground-water prospects, the Bikaner and Sikar basins have a combination of fresh water and light-textured soils. Apart from the constraints mentioned previously these waters could be used for irrigation with few special management practices. High-yielding varieties of crops such as wheat, barley, mustard and grama could be grown in the winter season where soils have no serious limitations with regard to slope, depth or surface factors. In areas where these constraints are present, it might be possible to grow grasses, fodder crops and desert control plants and to provide stock watering points.

In the monsoon season hybrid millet, sorghum, beans, gingelly, groundnuts and sunflower, could be grown with irrigation by using sprinkler systems where economically feasible. In summer, vegetables, 60-day mung (green grama), guar and sunflower crops could be cultivated in limited areas depending on water availability.

Special management practices are called for in the Luni basin where more saline waters and finer-textured soils are found. These include the addition of gypsum to water or soil, breaking of hardpan horizons if present, addition of organic matter and selection of salt-resistant crops and varieties. Most of the ground water available for irrigation is not likely to produce alkalinization even over long periods of time if proper precautions are taken, because of the high porosity of the soils permitting adequate leaching and drainage. Enough leaching of accumulated salts is expected to be provided by the monsoon rains. In this connexion, the local practice of alternating irrigated crops every second or third year with winter fallow and rain-fed crops, e.g., millet has proved satisfactory.

8. Irrigation

a. Supplementary monsoon irrigation

Little if any monsoon supplementary irrigation is practiced at present in the project area except perhaps where hybrid bajra is being grown for seed.

Where ground water is available some farmers sow bajra in nurseries which can be easily irrigated if early rains fall, the crops being planted out when the rain is assured.

It is impracticable to irrigate more than very limited areas by conventional flood methods owing to the difficulty of making bunds in the standing crop and maintaining them during periods of high rainfall intensity.

As supplementary irrigation should commence soon after the last soaking rains much water wastage would occur under gravity systems as an application of 2-1/2 inches (60 mm) or so is required to achieve a reasonable distribution efficiency on uneven light-textured soils.

With a sprinkler system these problems can be overcome and the amount of water supplied can be carefully controlled increasing the application time with the number of drought days elapsed. The height of risers should be suited to the height of the crop.

As a compromise between overhead and gravity systems for supplementary irrigation, consideration can be given to:

(1) Floor irrigation with portable pipeline and portable gated pipeline. The main drawback of this method is that it requires some land levelling and construction and maintenance of border strips. Although the initial investment per hectare is less, the unit cost of water is roughly the same as for a sprinkler system owing to lower irrigation efficiency.

(2) Flood irrigation with underground pressure pipeline and portable lateral gated pipelines. The capital investment per hectare is estimated to be about 10 per cent higher than for system (1), but as the layout is semi-permanent this system has the advantage of being quicker and easier to operate.

(3) Low pressure pipeline and portable gated pipes. A pressure of about 10 psi is needed to control the gates and can be provided by hydrostatic pressure in a storage reservoir. Capital costs are about the same as in system (2) but no booster pump is required.

b. Post-monsoon, Rabi winter and summer irrigation

With additional tubewell water supplies, it is anticipated that winter cultivation of wheat, barley, green grama and mustard will increase, although soils in the project area are more suited to barley than wheat. Hybrid millet should be substituted for local varieties under both dry farming and irrigated conditions on account of its greater yields. Cultivation of sunflower strains having a good degree of drought resistance will probably increase in all three seasons and also as a late planted monsoon crop where early monsoon rains have caused failure of the main crops, e.g., millet.

More attention should be given to the production of groundnut and other oilseed crops, e.g., castor and rape. Pulses such as mung (green grama) and moth (kidney bean) have great potential as rain-fed crops provided moisture conservation methods are used and especially where supplementary irrigation is available.

Green-cropping once every 3 or 4 years is recommended. Some of the constraints to efficient irrigation are:

(1) The legal constraints imposed on land holdings, i.e., 50 acres total and 30 acres irrigated for individual holdings. The Cluster Tubewells System has been designed to resolve this problem by grouping adjacent farms into one command area;

(2) Low efficiency in conveyance and application of irrigation water;

(3) Pipe outlets are commonly 2 to 3 inches in diameter and this necessitates up to 11 irrigations on wheat on account of the too small stream of water and consequent loss of distribution efficiency.

c. Command area for one tubewell (yield 100 m^3/h)

Average pumping hours per month are taken to be 250 in winter season, i.e., 10 hours per day for 25 days or 8 hours per day for 30 days. With presently experienced failures of machinery, power and power cuts it is doubtful whether pumping hours can be assumed to increase in the near future, although 16 hours may be feasible from the farmers point of view in the peak demand season. For the main winter crops (barley, wheat and mustard) the growing season is about 120 to 140 days. During this period about 1,200 hours of pumping is expected in the early years of a new well. A 50 per cent efficiency rate is expected with maximum water demand for wheat, barley and mustard (in February/March) at 20 cm, 10 cm and 10 cm, respectively. Depending on the proportion of these crops grown the irrigable area should be around 24 hectares during the early years of a well.

As efficiency improves or where sprinkler systems are installed the winter irrigated area should increase substantially. More exact measurements of potential evapotranspiration rates are needed, together with more work on the soil moisture regimes and thermal gradient during the winter before an accurate estimate of potential irrigable areas can be made. The balance of land available in winter can be cropped with grama and this can be irrigated where possible if no winter rainfall occurs.

Fitting in a summer crop, e.g., sunflower, mung, vegetables and beans during the period of March to June would allow a further 800 hours pumping time approximately. At a discharge of 100 m^3/hour this would permit irrigation of about 20 ha of sunflower.

The monsoon growing season normally lasts less than 100 days, and supplementary irrigation would be effective only during this period. Wells would be operating during this season for about 750 hours at most.

As supplementary irrigation demand can range from 10 to 25 cm according to crop and weather an average figure would indicate an irrigable command area of approximately 42 ha.

In the case of wheat an average consumptive use factor (K) of 0.75 is taken for a good stand in the project area with monthly maxima ranging from 0.85 to 1.00, depending on the mean monthly transpiration and stage of growth of the crop.

Where crop cover is 100 per cent and K=ET max. the area commanded by one tubewell of 100 m^3/h capacity would be:

$$\frac{Q \times E_a \times h}{ET \times K} = \frac{1 \times 0.50 \times 12}{0.09 \times 1.0} = 66 \text{ acres } (27 \text{ hectares})$$

Where Q = flow
h = pumping hours per day
E_a = application efficiency
ET = max. daily evapotranspiration

Working on a maximum average design consumptive use K=0.75 then the irrigable area would be about 90 acres (37 ha.).

However, it is thought that, in general, crop stands indicate a lower figure for K and are likely to remain at this for the first 5 or 10 years. The introduction of dwarf hybrid varieties will also make it possible to apply a lower design consumptive use figure. If K=0.60 is adopted than an area up to 112 acres (45 ha) could be commanded.

d. Sprinkler irrigation

For well designed and operated systems, the actual application efficiencies obtainable can approach 85 per cent and it could be higher for night irrigation and low wind conditions. However, a design value of 70 to 80 per cent is normally used and in the project area the lower figure has been adopted.

An overhead irrigation system would, under the conditions prevailing in the project area, have a number of advantages:

(1) More even application of water on the coarse-textured soils;

(2) The feasibility of frequent light irrigations on crops with restricted root systems;

(3) The pump of the well serves the double

purpose of bringing water to the surface and providing the pressure necessary for the sprinklers;

(4) Frost protection can be provided; (for best results, of over 50 psi is needed to obtain small droplet sizes.)

(5) Sprinklers are easily and quickly transportable for supplementary monsoon irrigation, if rain fails;

(6) Obviates land levelling required for gravity irrigation;

(7) Provides better control of application rate;

(8) Provides more efficient leaching of salts because of slower application rates; (With more rapid application rates, e.g., by surface flooding, water tends to move through large soil pores only and at low suction values.)

(9) Where the irrigation water has low salt content, sprinklers can be used for environmental control, e.g., in hot periods;

(10) More efficient water distribution can be attained even with low rates of discharge;

(11) Overall savings in water consumption of 20 to 40 per cent as compared to surface irrigation methods;

(12) Fuller utilization of available land (by 3 to 4 per cent) because no canals are necessary;

(13) Possibility of application of fertilizers.

Some of the possible disadvantages of overhead systems are:

(1) Spread of some water-borne diseases; sprinklers should not therefore be used for seed production;

(2) If the irrigation water is high in Cl^- there can be marked leaf damage especially if (i) drying occurs between applications and (ii) there is foliar absorption;

(3) Moving pipes in wet conditions can contribute to disease spread and may produce some soil compaction on heavier soils;

(4) Corrosion of pipes is an ever-present danger where high-sodium waters are used and protection may be necessary, e.g., by coating, cathodic protection, or by using magnesium rods or strips and drying of pipes when not in use;

(5) Where dossolved CO_2 content is high, it would be advisable first to pump the water into a reservoir for aeration;

(6) Where suspended material is present settlement reservoirs would be necessary;

(7) Both sprinkler and perforated pipe systems can have their jets badly distorted where wind is a problem

Most small overhead systems should provide for a minimum design pressure of 35 psi which can be boosted to appropriate levels for frost protection.

Table 35 shows the lower limit of depths to which certain common crops can take moisture through their roots.

Table 35. Estimated depth of moisture extraction by mature crops on deep, well-drained soils

a. Depth of 6 feet

Lucerne
Sorghum
Suda grass
Tomatoes

b. Depth of 5 feet

Maize
Melons
Flax
Cereals

c. Depth of 4 feet

Citrus
Cotton
Sugarbeet
Pulses

d. Depth of 3 feet

Carrots
Peas
Peppers
Squash

e. Depth of 2 feet

Beans
Grass
Potatoes
Most other vegetables

For most field crops, however, it is recommended that irrigators work on a design root zone of 90 cm (3 ft depth) for economy of water use, since most plants obtain 90 per cent of their water requirements from this zone and more when their rooting pattern has been adapted to the moisture regime imposed. The relationship between available flow and irrigable area is given by the formula:

$$Q = (ET \times A)/(Ea \times h)$$

Where ET = maximum evapotranspiration rate in inches per day (=0.15 in. or 3 to 4 mm/day in winter for the project area, i.e., average for the months November to March inclusive)

A = area in acres

Ea = application efficiency (this is taken as 70 per cent for sprinkler systems; for flood schemes, 65 per cent efficiency might be achieved with lined channels)

h = average daily pumping hours

For the project area $Q = \frac{0.15 \times 40}{0.70 \times 8} = 1.08$ cusec (or about 100 m^3/h)

At peak crop demand assuming the other factors to be constant a tubewell of 150 m^3/h discharge could command 56 acres. (It is thought that ET in rabi can be as low as 0.90 inches in which case 62 acres would be commanded in an 8-hour pumping day or 93 acres where 12 hours pumping can be done at the rate of 100 m^3/h.)

Interval between irrigations assuming 50% Permissible soil moisture depletion:

$$I = \frac{(FC - WP) \times D \times a}{2 \times ET} + 2 + \frac{t}{24}$$

Where D = root zone depth assumed

a = A_s (apparent specific gravity in bulk density of soil)

t = hours of operation per application

Applying this equation to Sikar or Nagaur soils in rabi season

$$I = \frac{.05 \times 36 \times 1.5}{2 \times 0.15} + 2 + \frac{8}{24} = 11.1/3 \text{ days}$$

For very coarse soils the value of I should be reduced by one or two days, that is, to 9 or 10 days.

For individual crops these figures will be modified considerably according to:

(1) Consumptive use factor of the plant

(2) Percentage of crop cover

(3) Tolerance to soil moisture stress

(4) Critical growth periods, e.g., in wheat as regards water demand

(5) Actual root zone

(6) Any reduction in PET by the mulching effect of cultivations and the rapid drying out of the top soil.

The amount of water (d) to be delivered through the system in one irrigation should not exceed:

$$d = (ET \times I)/Ea$$

$$= (0.15 \times 10)/0.70$$

= 2.1 inches (or about 1.5 inches where ET taken as 0.09 to 0.1 inch)

The minimum required period for application of the above is given by $t = d/i$.

Where i = minimum intake rate of the soil after several hours (about 1 inch per hour on most sandy soils of the area)

The t = 2 hours, approximately, i.e., an application rate of 1 inch per hour would be permissible on these soils.

It is seen therefore that this would permit rapid coverage of crop lands in monsoon using portable sprinkler systems. However, where leaching of salts is required lower application rates would be preferable (in rabi season).

H. Economic evaluation of future expansion of irrigated agriculture, using ground water

1. Introduction

An economic study was made in the Rajasthan project area where substantial new water resources were found. Since the Sikar basin has the greatest potential for future development, much of the study refers to this area. Smaller amounts of unused ground water are available in the Bikaner and Luni basins, i.e., 22.8 million m^3 and 58.8 million m^3, respectively. The economic data for the Sikar basin are, in general, applicable to the possible development of ground water in these basins as well. The principal differences in benefits and costs will result from differences in the depth and discharge of each individual well.

The conclusions are based on available data, many assumptions and projections of present socio-economic, technological and cost conditions.

2. The present status of agriculture

a. Soils, climate and natural vegetation

The soils of the Rajasthan part of the project area are generally sandy and low in productivity. They have very small amounts of nutrients and their water-holding capacity is only about five per cent of their volume. Their depth is mostly adequate and topography is generally suited to

cultivation, although a moderate amount of levelling is needed on most of the area if gravity-flow irrigation is to be used. Probably 25 per cent of the area is not suited to development for gravity-flow irrigation because of the sand dunes.

There are wide variations from year to year and week to week within the monsoon season. Thus, irrigation during the monsoon season is beneficial to crop production during most years (about three in five) and irrigation is essential to good production during some years (about one in five).

Protection against wind erosion historically has been provided by a good natural cover of grass, shrubs and trees. Millions of cattle, sheep and goats graze in the project area gradually reducing the protective cover by overgrazing. Extensive cultivation for crop production in the monsoon season exposes the soil to damage by wind erosion. Thus, blowing sand is common in May and June and dust storms frequently rise from the area and move eastward, depleting the soil and causing inconveniences in population centres hundreds of kilometres away.

b. Population and standard of living

The level of living of the rural population is rather low. This results mainly from a high density of population in relation to the existing productive resources. The density of rural population in 1971 was 42 per square kilometre in the four districts of the project area, with the greatest density of 111.8 in the Nagaur district, allowing barely more than two hectares per person. In the Sikar basin 21.7 per cent of the holdings contained less than 3.0 hectares in 1961 and 50.1 per cent contained less than 6.0 hectares each. The total area of cultivated land allowed only 3.2 hectares per male worker in 1971 in the Sikar project area.

The condition of over-population is reflected in the levels of incomes of farmers (table 36). The annual value of crops harvested per hectare of crop land in 1969-1972 averaged Rs 336 and Rs 491, respectively, in Nagaur and Sikar districts (1973 prices). These crops had a total annual value of Rs 289 per capita of rural population in Nagaur district. These figures are based on data regarding crop production in Nagaur district, which is considered representative of the project area with respect to productivity. Sixty-nine per cent of all crop income is derived from two monsoon crops, millet and pulses. Wheat and other winter crops provide 13.1 per cent of the gross crop income, most of which is from irrigated land.

A study conducted in 1972 revealed that the average annual gross income of small farms (up to 6.4 ha) was Rs 1,457 of which 23 per cent was the value of crop products (used or sold) and 26.4 per cent was the value of livestock products and the value of animals sold. 5/ The remaining 50.6 per cent of the gross income was derived from wages.

c. Cropping practices

Extensive areas of rain-fed crops are sown each year, although yields are generally very low. Crops are planted on about 70 per cent of the land in the Sikar district, and on about 15 per cent of the land is planted in the Bikaner district. Except in Bikaner, the area planted each year continues to increase, although this results in a decline in average productivity of cultivated land. Irrigation is available for only about 2.0 per cent of the crop land in the Sikar basin and only about 0.8 per cent in the Rajasthan project area, nearly all water being taken from wells.

Crop yields are very low because of the low level of technology applied, as well as the unfavourable conditions of soils and climate. Each farmer generally has a pair of bullocks and other animals. The farming implements usually are limited to the traditional wooden plough with a steel point, a levelling board and a bamboo seed tube, the latter being used to sow the seed in the furrow behind the plough. Nearly all labour is provided by the family, since the usual ownership unit contains less than six hectares.

Where irrigation is available, each family irrigates only about two hectares, generally using bullocks for lifting the water from dug wells by ropes and buckets from depths of less than 15 metres. About 15 per cent of the villages are supplied with electric power. Irrigation is largely limited to winter crops since most cultivators seem to fear a water shortage if they irrigate monsoon crops. There is a continuing process of installing new dug wells, deepening old ones and installing mechanical pumps, as well as drilling tubewells, to enhance the supply of water for irrigation.

d. Irrigation practices

Efficiency of irrigation on the sandy soils of the project area is estimated to be at present about 40 per cent, and may be even much lower in many areas. Water courses are generally not lined, either on or off farms. Irrigators generally apply approximately equal amounts of water with each irrigation and allow equal intervals between irrigations, disregarding differences in crop requirements at different stages of growth. Nor do they give adequate consideration to the moisture depletion of the soil or its water holding capacity.

The "bund" irrigation system is used almost universally to distribute water over the fields. This system requires advance preparation of field water courses at intervals (usually two to four metres apart) by the formation of low dykes (bunds). Similar dykes are then made crosswise between the water courses to form small catch basins. The

5/ A study of the Farm Investment and Income Pattern of Farm Families in Arid Zone of Rajasthan, CAZRI, 1972.

Table 36. Annual value of crop products in Nagaur District, total and per capita

Season and crop	Yield tons a/	Price (RS/T) b/	Value per year in rupees Total (000)	Per capita c/	%
		Winter crops			
Wheat	20,400	1,250	25,500	23.03	8.0
Barley	10,200	800	8,160	7.37	2.5
Pulses	2,570	1,200	5,084	2.78	1.0
Mustard	700	2,000	1,400	1.26	0.4
Other d/	-	-	3,814	3.44	1.2
All crops	-	-	41,958	37.88	13.1
		Monsoon crops			
Millet	128,500	1,050	134,935	121.86	42.1
Groundnut	3,260	1,600	5,216	4.71	1.6
Sorghum and maize	12,600	900	11,340	10.24	3.5
Sesamum	5,080	3,000	15,240	13.76	4.8
Other d/	-	-	25,336	22.88	7.9
All crops	-	-	278,692	251.69	86.9
Yearly total	-	-	320,650	289.57	100.0

a/ Yields are averages for 1969-1972 inclusive.

b/ Prices refer to harvest season of each crop in 1973.

c/ Value per capita of rural population of 1,107,201 in 1971.

d/ It is estimated that the value of other crops produced is equal to 10 per cent of those included in this table.

irrigator removes a portion of the dyke on one side of the channel, allowing water to flow into a catchment basin until enough water has been applied within it. Then the irrigator restores the dyke for that basin and directs the flow of water into another one.

The "bund" system has three major advantages over the furrow system.

(1) It avoids the necessity of careful levelling of fields;

(2) It reduces the losses (wastages) of water by reducing the number of field water courses or furrows;

(3) It enables the irrigator to observe and control more accurately the amount of water being applied.

The major disadvantage of the "bund" system is the large amount of labour required. Not only is hand labour used to prepare the dykes and to control the flow of water, but the dykes generally interfere with the use of mechanical implements in the fields for planting and cultivation.

In the project area, hand labour is used almost exclusively for the formation of the water courses and the bunds, although bund-formers are available at low prices for use either by bullock power or by tractor power. The wastage of water is high, probably 50 to 70 per cent. Usually, the water courses are not lined and the irrigator generally allows more water to enter each basin than the soil can absorb in the root zone.

e. Management of tubewells and water supplies for irrigation

The Rajasthan State Groundwater Board owns and operates a number of tubewells supplying water for irrigation. The Board has the capability to install about 200 tubewells per year and has plans to install about 100 in 1974. It also provides assistance to private owners for installation and deepening of dug wells. Currently, it is the policy of the Board to sell each new tubewell to one or more private farmers, preferably to a group. The price of each sale usually involves a substantial subsidy to the buyer, perhaps as much as 50 per cent of the cost. Sales to groups of cultivators are to be made according to the "cluster system" which provides for land owners to borrow the needed funds from banks, using their land as collateral. This system is new and has not been fully tested in Rajasthan but it is hoped that owners of small farms will be able to establish part ownership in wells and associated facilities. Each part owner also will have some responsibility for the management of the system from which he obtains water for irrigation and he will make annual payments for operating costs and investments. The operating costs are also subsidized by the State.

The cluster system has been designed to replace the present State ownership of tubewell systems, which has not met with the desired success. The State drills the wells, installs pump sets and other facilities and invites the cultivators in the command area to utilize the water when it becomes available. The State then provides a permanent staff of more than 50 people to perform the management functions for each group of about 20 wells. However, these wells are generally under-utilized most of them operating less than 1,000 hours (each) per year whereas 2,000 hours of pumping per year probably should be considered as a minimum for good results.

It is not completely understood why the farmers fail to fully utilize water from the State-owned wells. Some possible reasons have been suggested by local officials:

(1) Inadequate involvement of agricultural officials and technicians in providing credit and technical assistance;

(2) Failure to provide certain needed facilities, such as water distribution networks;

(3) Failure of the well operator to gain the confidence of farmers in regard to the availability of adequate supplies of water at all times.

The correction of these shortcomings would enable the State to realize much greater income from the operation of its wells, while providing greater benefits to the water users. Recently, there has been a change in emphasis in regard to development projects, in the sense that a higher priority will be given to the upgrading of existing projects, while giving a lower priority to the installation of new projects. 6/

f. Possible benefits of improved technology for crop production

There is ample evidence to demonstrate the profitability of improved farm practices for the cultivation of rain-fed crops, as well as for irrigated crops.

Experimental studies in Jaipur district indicate that the yield of Mexican wheat increases from 9.0 to 16.5 kilograms per kilogram of fertilizer nutrients applied (table 37). These results provide very good pay for one kilogram of nutrients. On-farm experience, however, indicated that farmers were obtaining increased wheat yields of only 2.0 to 4.8 kg of wheat per kilogram of fertilizer applied. More studies are needed to determine

6/ Draft Report of the Rajasthan Canal Project, Vol. I, Sept., 1973.

Table 37. Effects of fertilizer on yields of Mexican wheat and hybrid millet

Location of planting and no. of irrigations	Fertilizer (kg/ha)	Yield			
		Mexican wheat		Hybrid millet	
		kg/ha	kg/kg	kg/ha	kg/kg
Hanumangarh, Jaipur a/	(N) (P) (K)				
Irrigation I	45- 15- 10	1,585	-	900	-
(3 for millet)	90- 30- 20	2,693	15.8	1,548	9.2
(7 for wheat)	136- 45- 30	3,624	13.1	1,808	3.7
	180- 60- 40	4,464	12.2	2,083	4.00
Average	113- 38- 25	3,072	13.7	1,585	5.6
Irrigation II	45- 15- 10	1,496	-	930	-
(2 for millet)	90- 30- 20	2,649	16.5	1,347	6.00
(6 for wheat)	136- 45- 30	3,549	12.7	1,780	6.1
	180- 60- 40	4,211	9.6	2,031	3.6
Average	113- 38- 25	2,976	12.9	1,522	5.2
Irrigation III	45- 15- 10	1,406	-	744	-
(1 for millet)	90- 30- 20	2,478	15.3	1,205	6.6
(5 for wheat)	136- 45- 30	3,382	12.7	1,525	4.5
	180- 60- 40	4,003	9.0	1,734	3.0
Average	113- 38- 25	2,817	12.3	1,302	4.7
Farm trials 1972-1973 b/					
(Wheat data	0- 0- 0	586	-	586	-
from Jhalawar	0- 40- 0	667	-	760	4.4
District)	20- 40- 0	740	2.5	888	5.0
Average	7- 27- 0	662	2.2	745	4.7
(Millet data	40- 40- 0	904	4.0	1,057	5.9
from Jaipur	60- 40- 0	922	3.4	1,223	6.4
District)	40- 00- 0	744	4.0	1,024	10.9
	40- 20- 0	877	4.8	1,106	8.7
	40- 60- 0	920	3.3	1,228	6.4
	60- 40- 50	1,113	3.5	1,364	7.8
	60- 60- 0	1,038	3.8	1,470	7.2
Average	44- 37- 0	931	3.8	1,210	7.6

Source: Annual Report, 1972-1973, Coordinated Agronomic Experiments Scheme, Agri. Res. Sta., Durgapura, Rajasthan.

a/ Increase in kilograms of grain per kilogram of nutrients. Treatments at Hanumangarh did not include control plantings, but only four levels of fertilizer and three levels of irrigation, i.e., the following percentages of recommended amounts per ha, 25 per cent, 50 per cent, 75 per cent and 100 per cent.

b/ Data from farm trials are the increases above the level of the control plots.

the reasons for farmers' results being less favourable than those on experimental farms. Negligence of the need for pest control or faulty irrigation practices could be the reasons.

The benefits from fertilizing millet, however, were greater on private farms than on experimental farms (table 37). This may have resulted largely from the smaller amounts of fertilizer applied by farmers. As in the case of wheat, the smaller applications generally gave higher benefit-to-cost (B/C) ratios than the larger amounts, and millet evidently responds less to heavy fertilization than does wheat. About 2.5 kg of millet are required to equal the value of a kilogram of fertilizer nutrients, and the lighter applications generally gave B/C ratios better than 2.1:1.0. The high rainfall in 1973 may also have played a part in these results.

Studies of the benefits of three different levels of irrigation indicate that five irrigations of wheat were nearly as productive as seven irrigations and one irrigation was nearly as good as three for millet. In the case of wheat, two extra irrigations (a total of 7) gave only 275 kg of additional wheat yield, about Rs 23 per 100 m^3, perhaps less than the cost of the water. In the case of millet the highest level of irrigation (3) gave an increase of 283 kg of grain for two extra irrigations (compared to one), somewhat less than the response of wheat to the two extra irrigations (considering value of the grain). Data are needed for several years to obtain results for average weather conditions.

It is significant also, that farmers' yields of wheat were only 20 or 30 per cent of the amounts produced on experimental farms, i.e., only 662 kg per hectare in Jhalawar district, compared to nearly 3,000 kg on the research farm at Hanumangarh. This was related to the lower applications of fertilizer on farmers' fields. Farmers' yields of millet were nearly equal to those on the research farm, especially the farm plantings in Jaipur district, even though farmers used smaller doses of fertilizers. Again, the good rains in 1973 were a controlling factor.

Studies of five crops demonstrate benefit-to-cost ratios of 2.46:1.00 to 5.00:1.00 for the application of improved practices in the Rajasthan Canal Project Area in 1972 (table 33). This is based on comparisons between plantings by private farmers and demonstration plots on the same farms, which were planted with improved practices by government officials. These data demonstrate the high profits available to cultivators through adoption of the "package of practices" recommended by the Extension Service of the Rajasthan Canal Project. Best results were obtained from barley, while millet yielded the lowest ratio, although a good one, 2.45:1.00 (table 38).

Rain-fed crops also are yielding good profits with improved technology, according to studies at Haryana Agricultural University. Studies in Mohindergarh district indicate benefit-to-cost ratios between 1.21 and 4.44 for selected crops (table 39). The highest ratio of 4.44 was realized from applying improved practices to produce winter peas, but barley and millet yielded ratios of 3.57 and 3.38, respectively. The low ratio of 1.21:1.00 for mustard probably indicates that this crop should not be sown without irrigation.

4. Evaluation of tubewell irrigation

a. Procedures and assumptions

Published and unpublished data provided by research institutions and administrative offices of the State of Rajasthan and the Central Government were used to estimate incomes per hectare, in order to compare costs and benefits of dry farming as compared to irrigation with tubewell water.

Evaluation of the farm costs and benefits of tubewells refers to the fifth and tenth years after water becomes available to the farmers. It is assumed that in the area commanded by a typical well, farmers will bring 24 hectares under irrigation during the first five years, mainly land sown in winter crops, and very little of monsoon crop land although the command area would cover 35 hectares. During the tenth year, it is expected that the farmers will have improved their irrigation practices, as well as their technology of production. Also it is expected that by the tenth year they will have further extended irrigation to include 30 hectares of winter crops in each well area and that they will be irrigating about 12 hectares of land sown in monsoon crops. Irrigation of spring sown crops (April, May and June), however, is not expected to be a significant factor until after the fifteenth year. Thus, the costs and returns in the tenth year are expected to be representative of the period from the fifth to the fifteenth year. The use of sprinklers would accelerate the introduction of irrigation, especially in the monsoon season.

Costs and incomes per hectare have been estimated for each important crop likely to be grown in the Sikar basin, with and without irrigation. These data are useful in evaluation of tubewells in all parts of the project area in Rajasthan. The principal differences for areas outside of the Sikar basin are the different proportions of land utilized for each crop and the lower yields of rain-fed crops, as well as the variations in depth and discharge of wells.

Costs and incomes per hectare have been calculated on the basis of the approximate prices paid by farmers in 1973 for input, and the sale prices for the products in the 1973 harvest season of each crop taken from the Government reports for Merta City, Nagaur district. The wage rate of Rs 3.00 per day is used to evaluate all labour and Rs 9.00 is assumed as the daily rate for a pair of bullocks. Traditional cultivation practices are assumed for determining farm costs and incomes, because most of the farms in the project areas are too small for use of tractors. It is recognized, however, that mechanization

Table 38. Benefits and costs of improved practices for irrigated crops

(Amounts and values are rupees and kilograms per hectare, resp.)

Item	Millet	Wheat	Barley	Peas	Mustard	Groundnut
Yield						
Control	1,058	1,670	1,125	1,438	695	N.A.
Improved	2,180	3,117	2,725	2,322	1,225	1,780
Increase	1,122	1,447	1,600	884	5,530	-
Cost						
Control	779	1,052	896	867	678	N.A.
Improved	1,248	1,495	1,039	1,066	940	1,181
Increase	469	443	143	199	262	-
Crop value						
Control	1,117	1,641	796	1,753	1,216	N.A.
Improved	2,271	2,986	1,895	2,748	2,145	3,113
Increase	1,154	1,345	1,099	995	929	-
Net Income						
Control	338	589	(-)100	886	538	N.A.
Improved	1,023	1,491	856	1,682	1,205	1,932
Increase	685	902	956	796	667	-
B/C ratio[a/]	2.46	3.04	7.68	5.00	3.55	-

Source: Annual Administrative Report, Rajasthan Canal Soil and Water Study Project, Krishi Bhavan, Bikaner, 1972-1973. "Control" data are from farmers normal plantings and "improved" data are from demonstration plots on the same farms, as the farm fields. All plantings were irrigated.

a/ Benefit-to-cost ratio is the increase in value of the crop divided by the increase in cost cultivation.

Table 39. Benefits and costs of improved technology in dry farming
(Data are Rs per hectare)

Item	Millet	Cluster bean	Winter peas	Barley	
Cost input					
Traditional	202	210	216	486	198
Improved	723	564	551	551	835
Increase	521	354	335	65	637
Gross income					
Traditional	461	730	677	1,176	628
Improved	2,223	1,482	1,828	1,408	1,396
Increase	1,762	752	1,151	232	768
Net income					
Traditional	259	519	461	690	430
Improved	1,500	918	1,277	857	561
Increase	1,241	399	816	167	131
B/C ratio	3.38	2.12	4.44	3.57	1.21

Source: Report of activities, Department of Economics, Haryana Agricultural University. Data are for the dry farming area in Mahindergarh District adjoining Rajasthan. Results with improved technology are from the Research Plantings.

can reduce the cost of tillage and harvesting operations by as much as two-thirds. Sowing wheat with fertilizer would cost Rs 12.07 per hectare using a tractor, while the traditional method with a seed tube costs about Rs 39 per hectare (table 40). In addition, the tractor drill usually places both seed and fertilizer at more proper depths and in proper amounts, so that more efficient use of seed and fertilizer can be achieved. Similar savings and efficiencies can be expected from various other machines, although these generally are not being used in the project area. These machines require greater expenditures of cash than the traditional methods, and the savings are mostly in labour and bullock power, which have little or no cash value. Thus, it is not expected that the more efficient machines will replace the traditional methods in the project area in the foreseeable future, nor is this recommended for small holdings at present. It may be concluded, however, that on larger holdings it will be possible to realize greater profits from crop production than those that would result from a simple extrapolation of the results obtained for small farms.

b. Probable cropping patterns

Cropping patterns, crop yields and level of technology during the fifth year are expected to be slightly superior to those that prevailed in the districts of Nagaur and Sikar during the period of 1969-1972. For this period, data for all, or representative, crops in regard to area sown, yield per hectare, percentage sown with fertilizer and high-yielding varieties and the amount of fertilizer applied by those using it are available. It is expected that there will be no major changes in the proportions of land allocated to the important crops in the foreseeable future. Thus, food grains and pulses will continue to occupy 95 to 97 per cent of the cultivated land, under both irrigated and dry farming conditions.

In view of the current efforts to increase milk production, problems related to the cultivation of fodder crops deserve special attention.

It must be expected that only about 3 per cent of the land to come under irrigation will be used for cultivation of fodder crops in the fifth year after water becomes available. A slight increase to about 5 per cent is expected in the tenth year, provided there will be some increase in the price for milk as compared to food crops. These assumptions are based on unofficial estimates of agricultural experts in the area which indicate that the present cultivation of fodder crops constitutes about 3.0 per cent of all irrigated land in the Sikar basin. Crops include lucerne, berseem, barley and pulses in winter, and Napier grass, millet, sorghum and pulses in other seasons. The unfavourable economic results of growing fodder crops are to blame for their restricted cultivation.

Only the profitability of milk production can be the basis for any major increase in production of fodder in the project area. A careful economic analysis, from the viewpoint of the Government, as well as a study of the farmers' costs and benefits is required. The major objective is to make the most effective use of public and private resources for increasing agricultural production and for improving the welfare of rural people in the project area. In this sense, it seems that the available water resources would better serve principal development objectives if used primarily for production of increased amounts of food crops, rather than for fodder crops. This conclusion is based on a careful analysis of the relative costs and incomes of these crops. For the purpose of this analysis Napier grass is used as a representative of all fodder crops.

Present net farm income per hectare of irrigated Napier grass is approximately equal to the average income of irrigated winter food crops. At the CAZRI research farm in Jodhpur the three year average net income per hectare of Napier grass is estimated at Rs 4,169, compared to Rs 3,742 for food crops (table 41). This is based on yields and costs obtained under carefully controlled conditions on the experimental farm which cannot be duplicated on private farms. The charge for water was only Rs 4 per 100 m^3. It is believed that results on private holdings would be similar to those on the CAZRI research farm. Prices of products also can vary greatly. The price of Rs 25 per quintal of dry Napier grass is believed to be comparable to the 1973 prices used for food crops in this comparison, and any changes since then or in the future probably won't cause major changes in the relative net incomes. It is believed also, that the price of Rs 25 per quintal of dry Napier grass requires the sale of milk at a price of at least Rs 1.20 per kg, in order to pay total costs of production. Further study of this question, however, is needed.

It appears, therefore, that farmers have about equal economic incentives to plant food crops and fodder crops, if they sell milk at Rs 1.20 per kg, and considering present charges for water from State-owned wells. It is necessary also to consider the economic advantage to the Government in providing subsidies to promote the production of fodder crops compared to food crops. The farmers in Rajasthan now only pay Rs 30 per hectare per irrigation (Rs 4 per 100 m^3 or acre-inch) although the cost to the state is about Rs 240 to provide the water to irrigate one hectare once (Rs 32 per 100 m^3). The final net economic result from one hectare of Napier grass therefore is a loss of Rs 2,131 compared to a profit of Rs 2,503 per hectare of food crops (table 41).

The final net income per hectare of Napier grass would be about equal to that of food crops, if the price of dry Napier grass were Rs 40 per quintal instead of the assumed Rs 25 (Rs 40 x 3,000= 12,000 less Rs 3,331 of farm costs and less Rs 6,300 of subsidy=2,131 per ha). Cross-bred dairy cows in the project area probably could provide a small profit on a full ration of Napier grass at Rs 40 per quintal, only if the price of milk were about Rs 1.50 per kg. (Again, this needs further st...

Under current planning, this milk price might require a substantial Government subsidy to maintain desirable retail prices of milk.

The relative abundance of land and scarcity of water in the project area requires that consideration be given to the income per unit of water, as well as per hectare of land. Napier grass and other forage crops require about 90 inches of water per year, compared to only about 20 inches for winter food crops and 10 inches for monsoon food crops, i.e., 22,500 m^3, 5,000 m^3 and 2,500 m^3, respectively, per hectare. Also, the amount of fertilizer required per hectare of Napier grass is about 340 per cent of that needed by winter food crops (table 41). Thus, cultivators can produce 3 to 4 hectares of other crops with the water and fertilizer needed to

Table 40. Comparative costs of selected agricultural operations with motorized power compared to manual labour and bullock power

Operation performed	Unit	Cost (Rs)
Sow wheat and apply fertilizer		
(a) Tractor-seed-fertilizer, drill	Hectare	12.07
(b) Bullocks	Hectare	39.08
One irrigation		
(a) Electric tubewell	Hectare	112.50 a/
(b) Bullocks and bags (mote)	Hectare	105.00
(c) Bullocks-Persian wheel	Hectare	48.46
Groundnut harvesting		
(a) Tractor-digger-shaker	Hectare	71.39
(b) Manual labour	Hectare	108.75
Spraying with insecticide		
(a) Knap sack power sprayer	Hectare	8.18
(b) Foo' sprayer	Hectare	26.90
Harvesting wheat		
(a) Tractor-mounted reaper	Hectare	28.26
(b) Manual labour	Hectare	110.25
Wheat threshing		
(a) Thresher and tractor	Quintal	3.93
(b) Threshing floor system	Quintal	10.80

Source: Report of activities, Department of Economics, Haryana Agricultural University, Hissar. Data include operating costs only.

a/ Based on data derived from the current study in Rajasthan.

Table 41. Costs and incomes per hectare of selected fodder and food crops with irrigation in Rajasthan (values in Rupees at 1973 prices)

Item	Napier grass a/	Wheat	Barley	Mustard or rape	Sun-flower	Food crops b/
A. Production costs						
Soil preparation	30	90	60	60	60	75
Purchase fertilizer	967	413	146	144	219	287
Apply fertilizer	c/	11	11	11	11	11
Layout, seed and sowing	67	196	136	48	18	143
Irrigation feeds d/	900	240	120	90	150	177
Pest control	183	20	20	60	20	28
Harvesting	875	60	45	36	30	49
Threshing	0	180	45	60	129	129
Miscellaneous (5 per cent)	151	60	36	25	30	45
Interest (5 per cent) e/	158	69	39	27	35	51
Weeding	0	90	90	30	30	73
TOTAL	3,331	1,431	823	576	732	1,068
B. Products and income						
Grain (seeds)						
Quintals	0	45	30	15	20	-
Value/quintal	0	100	80	300	250	-
TOTAL VALUE	0	4,500	2,400	4,500	5,000	-
Fodder (dry)						
Quintals	300	90	60	60	100	-
Value/quintal	25	10	10	5	5	-
TOTAL VALUE	7,500	900	600	300	500	-
C. Gross income	7,500	5,400	3,000	4,800	5,500	4,810
D. Net farm income	4,169	3,969	2,177	4,224	4,768	3,742
E. Government subsidy f/	6,300	1,680	840	630	1,050	1,239
F. Final net income	(2,131)	2,289	1,337	3,594	3,718	2,503

Source: Central Arid Zone Research Institute, Jodhpur, Rajasthan. Data are results on the research farm.

a/ Average of three years, i.e., one sowing.

b/ Weighted averages, assuming 50 per cent wheat, 20 per cent barley, 20 per cent mustard and 10 per cent sunflower.

c/ Included with pest control.

d/ Government charge at Rs 30 per irrigation, or Rs 10 per inch.

e/ Interest on operating funds at 5 per cent.

f/ Subsidy estimated at 700 per cent of fee charged, i.e., Rs 210 per irrigation, i.e., assuming a water cost of Rs 4 per 100 m^3 from State tubewells.

produce one hectare of Napier grass. As a result, the net income from water used to produce irrigated Napier grass is only Rs 19 per 100 m^3, compared to the net income of Rs 75 per 100 m^3 of water used to irrigate winter food crops. This explains the small proportion of irrigated land now sown in fodder crops.

All of the above seems to lead to the conclusion that feeding cattle with green fodder in the project area (this does not apply to straw and other by-products) is uneconomical (not profitable), both for private farmers and for the Government. This conclusion seems to be supported by current practices of cultivators in the project area. Lucerne and other green fodders are being sold at the price of Rs 0.15 per kg, which is equal to about Rs 0.50 per kg when dry. Dry leaves from trees sell at Rs 1.00 per kg. Even at these high prices, cultivators generally prefer to produce food crops, rather than fodder, especially those who suffer from a shortage of water for irrigation. Thus, there is a general shortage of high-quality fodders and many producers sell their total production of green fodder at Rs 15 per quintal, leaving only inferior fodders for their own animals.

It is recognized that Government policies regarding food production must consider dietary needs of the people, as well as the economics of production. The growth of the urban population in India requires increased production and marketing of milk for off-farm consumption.

It is believed that Government is interested in increased milk production also because this could raise the level of income and reduce the high expenditure for famine relief. But even if all available ground water would be used for irrigating fodder crops, the economic impact would remain rather small, because of the low percentage of irrigated land (1 per cent) as compared to dry farmed areas. Milk production can, however, be improved regardless of the increase of production of green fodder.

Many thousands of families in the project area could realize improved incomes and diets by improving the feedings of their native cows. These cows now produce perhaps an average of 400 kg per lactation once in four or five years. No doubt, the feeding of small amounts of oil cake and other by-product feeds would provide a substantial increase in production of milk at very low cost.

As stated by Haryana University, "It is surprising that little research and development effort is going into the improvement of milk yields from the common cattle which are subsisting largely on crop residues". 7/

c. Use of fertilizers

Chemical fertilizer probably is the most effective input for increasing yields of crops in the project area, except irrigation. Yet according to crop cutting surveys, only wheat is now receiving significant amount of fertilizer (excluding fruits and vegetables). Cultivators who used fertilizer on wheat in Pali district in 1971-1973, applied about 110 kg of plant nutrients per hectare (nitrogen, P_2O_5 and K_2O). Mexican varieties received only slightly larger applications than local varieties (table 42). The recommended amounts are 125 kg per hectare for local varieties and 260 kg for Mexican wheat. Most farmers applied nitrogen on Mexican varieties. The average total nutrients applied per hectare on all areas sown in local varieties was only 20.2 kg, compared to 45.4 kg on all land sown in Mexican varieties. These average doses were only small percentages of the recommended applications, i.e., 16 per cent for local varieties and 18 per cent for the Mexican varieties. In addition, there is a significant amount of nitrates in water from wells providing perhaps as much as 50 kg of nitrogen per hectare of wheat.

After wheat, hybrid millet is the most intensely fertilized major crop in the project area, although the average application in Pali district was only 2.1 kg per hectare of land sown in this crop in 1971-1973. Those using fertilizer applied 35.8 kg of nitrogen per hectare, but only 5.5 per cent used nitrogen and only 0.4 per cent used phosphorous (table 42). The use of fertilizer on other major crops generally has not been measured, but the amounts are believed to be negligible.

The amounts of fertilizer to be used in the project area have been projected into the future on the basis of the crop cutting surveys of wheat, millet and sorghum. In the fifth year after water becomes available in the command area of a new well, it is estimated that the amounts of fertilizer applied per hectare will exceed slightly the amounts applied in Pali district in 1971-1973 (table 43). These amounts provide the basis for estimating costs of fertilizer purchases, as well as being a factor in estimating yields of crops in the fifth year (tables 44-46).

During the tenth year of irrigation in a new well area, the amounts of fertilizer used are expected to be as much as double the amounts used in the fifth year. Thus, the projected average amount of nitrogen per hectare to be applied on irrigated winter crops is expected to increase from 14.8 kg in the fifth year to 32.5 kg in the tenth year (table 43). The amount of nitrogen applied per hectare of irrigated monsoon crops is expected to increase from 6.1 kg to 25.2 kg between the fifth and tenth years.

7/ "Foods of Animal Origin, Economics and Substitutes", A.R. Rao and I.J. Singh, Haryana Agricultural University, Hissar.

Table 42. Determination of fertilizer use during fifth year of irrigation development

Source and crop	Kg/ha Using N	Using P_2O_5	Using K	Per cent using fertilizer N	Per cent using fertilizer P	Per cent using fertilizer K	Average use of Kg/ha N	Average use of Kg/ha P	Average use of Kg/ha K
Pali District a/									
Wheat-local	50.0	48.5	10.5	34.9	5.2	2.2	17.5	2.5	0.2
Mexican	57.7	52.5	11.2	62.5	16.5	5.1	36.1	8.7	0.6
Millet local	9.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Hybrid	35.8	11.5	0.0	5.5	0.4	0.0	2.0	0.1	0.0
Sorghum	4.2	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Project plan b/									
Winter crops									
Irrigated									
Wheat-local	50	48	10	40	15	3	20	7	0
Wheat Mexican	57	52	12	70	25	10	40	13	1
Barley	25	25	10	20	10	1	5	0	0
Mustard	20	15	0	20	10	0	4	2	0
Pulses	0	10	0	0	20	0	0	2	0
Lucerne	10	20	0	20	25	0	2	4	0
Rain-fed pulses	0	0	0	0	0	0	0	0	0
Monsoon crops									
Irrigated									
Millet-local	20	5	0	30	10	0	6	0	0
Hybrid	40	20	0	50	25	10	20	5	0
Pulses	0	20	0	0	20	0	0	4	0
Sorghum	40	20	0	20	10	0	8	2	0
Groundnut	20	40	20	20	10	10	4	10	2
Fodder	40	20	0	40	20	0	8	4	0
Rain-fed									
Millet-local	0	0	0	1	0	0	0	0	0
Hybrid	10	5	0	20	10	0	2	1	0
Pulses	0	0	0	0	0	0	0	0	0
Sorghum	0	0	0	0	0	0	0	0	0
Groundnut	0	0	0	0	0	0	0	0	0
Fodder	0	0	0	0	0	0	0	0	0

a/ Data from crop cutting surveys in Pali District in 1971-1973. No crop cutting surveys were made in the project area, but Pali District is similar to the project area.

b/ Data estimated for project evaluation in the fifth year after water becomes available in command area of a well.

Table 43. Projections of fertilizer use per hectare of irrigated crops during the fifth and tenth years of development a/

(kg/ha)

Season and crop	Nitrogen		P_2O_5		K_2O	
	5th yr.	10th yr.	5th yr.	10th yr.	5th yr.	10th yr.
Winter season						
Wheat, local	20	36	7	10	0	2
Wheat, Mexican	40	72	13	24	1	6
Barley	5	16	2	5	1	1
Mustard	4	12	2	4	0	1
Pulses	0	0	0	10	0	0
Lucerne	2	20	4		0	0
Average	14.8	32.5	5.2	13.7	0.5	2.4
Monsoon crops						
Millet, local	6	16	2	8	0	0
Millet, hybrid	20	48	5	12	0	2
Pulses	0	3	4	15	0	0
Sunflower	-	40	-	25	-	4
Sorghum and maize	8	25	2	6	0	0
Groundnuts	4	18	10	28	2	4
Fodder	16	60	4	16	0	0
Average	6.1	25.2	3.7	13.8	0.2	1.2

Source: Crop cutting surveys of wheat, millet and sorghum in Pali District and observations of technicians and officials.

a/ Manure also is applied on most crops, especially fodder crops, and some nitrogen is applied in the irrigation water (as a natural component of the water).

Table 44. Fifth-year costs and incomes per hectare with and without irrigation

Season and crop	Per cent of cost a/ land per ha		Income (Rs/ha) b/ Gross	Net	Wages c/
With irrigation					
Winter season					
Wheat, local	25	840	1,200	360	300
Wheat, Mexican	20	1,130	1,945	815	360
Barley	27	690	1,200	510	285
Mustard	10	455	1,500	1,045	215
Pulses	15	505	1,147	642	215
Lucerne	3	1,255	2,500	1,245	595
All crops	100	782	1,410	628	297
Monsoon crops					
Millet, local	45	420	1,080	660	220
Millet, hybrid	10	575	1,380	805	270
Pulses	25	400	1,380	930	180
Sorghum	7	450	1,200	750	160
Groundnut	10	980	2,255	1,655	450
Fodder	3	600	2,255	1,655	450
All crops	100	494	1,272	2,682	1,406
Year - total	200	1,282	2,682	1,406	524
Average	100	638	1,341	703	262
Without irrigation					
Winter pulses	25	240	380	140	100
Winter fallow	75	0	0	0	0
All land	100	60	95	35	25
Monsoon crops					
Millet, local	54	243	405	162	160
Millet, hybrid	5	400	690	290	180
Pulses	30	270	455	185	160
Sorghum	4	300	250	-(50)	140
Sesamum	3	260	300	40	160
Groundnut	1	595	660	65	185
Fodder	3	405	375	-(30)	220
All crops	100	270	427	157	162
Year - total	200	330	522	192	187
Average	100	165	261	96	93
Increase from well					
Winter crops	100	722	1,315	593	272
Monsoon crops	100	224	845	621	65
Both seasons	200	946	2,160	1,214	337

a/ Cost includes labour and bullock power, as well as cash costs except cost of water, at 1973 prices.

b/ Income includes total value of crop products at 1973 prices.

c/ Total income to cultivators includes the value of their labour.

Table 45. Tenth-year costs and incomes per hectare with and without irrigation

Season and crop	Per cent of cost a/ land per ha		Income (Rs/ha) b/ Gross	Net	Wages c/
With irrigation					
Winter season					
Wheat, local	12	1,030	1,465	435	330
Wheat, Mexican	30	1,395	2,600	1,205	400
Barley	25	780	1,370	590	310
Mustard	13	565	1,800	1,235	235
Pulses	15	575	1,275	700	235
Lucerne	5	1,385	3,000	1,620	650
All crops	100	966	1,874	908	335
Monsoon crops					
Millet, local	30	460	1,320	860	240
Millet, hybrid	20	750	1,725	975	300
Pulses	15	445	1,425	980	190
Sorghum	10	520	1,450	930	180
Groundnut	10	1,000	1,980	980	350
Sunflower	10	690	2,150	1,460	215
Fodder (sorghum)	5	1,120	2,625	1,505	500
All crops	100	632	1,644	1,012	261
Year - total	200	1,598	3,518	1,920	596
Average	100	799	1,759	960	298
Without irrigation					
Winter pulses	25	260	510	250	110
Winter fallow	75	0	0	0	0
All land	100	65	127	62	28
Monsoon crops				191	175
Millet, local	35	276	467	191	175
Millet, hybrid	20	520	862	342	200
Pulses	25	295	570	275	175
Sesamum	8	302	450	148	175
Sorghum	4	352	340	-(12)	155
Groundnut	3	690	905	215	200
Fodder	5	470	450	-(20)	240
All crops	100	346	579	233	184
Year - total	200	346	706	295	212
Average	100	205	352	147	106
Increase from well					
Winter crops	100	901	1,747	846	307
Monsoon crops	100	286	1,065	779	49
Both seasons	200	1,187	2,812	1,625	356

a/ Cost includes labour and bullock power, as well as cash costs, except cost of water, at 1973 prices.

b/ Income includes total value of crop products at 1973 prices.

c/ The cultivator may consider increased wages as increased income, since nearly all of the farm labour is provided by the family.

Table 46. Crop yields in Sikar and Nagaur District, 1969-1972 and projections for irrigated and rain-fed crops in fifth and tenth years of development a/

Season and crop	Yield 1969-1972 (kg/ha) Sikar	Nagaur	Yield (kg/ha) 5th yr	10th yr
Winter crops				
Irrigated				
Wheat, local)	1,033	947	900	1,100
Mex.)				
Barley	1,764	1,080	1,400	1,600
Mustard	322	875	750	9,900
Lucerne (fresh)	N.A.	N.A.	25,000	30,000
Pulses)			900	1,000
Rain-fed pulses)	728	418	300	400
Monsoon crops				
Rain-fed				
Millet, local)	334	229	300	350
hybrid)			600	700
Pulses	245	232	240	300
Sorghum	315	163	250	350
Sesamum	103	77	100	150
Groundnut	507	766	400	550
Fodder (fresh)	N.A.	N.A.	5,000	6,000
Irrigated				
Millet, hybrid	N.A.	N.A.	1,200	1,500
Millet, local	N.A.	N.A.	900	1,100
Sorghum	N.A.	N.A.	1,000	1,500
Pulses	N.A.	N.A.	700	900
Groundnut	N.A.	N.A.	900	1,200
Sunflower	N.A.	N.A.	Nil	1,000
Fodder (fresh)	N.A.	N.A.	30,000	35,000

a/ Data for the two districts are from published sources and other data are projections with and without irrigation to indicate feasible improvements.

Substantial increases in use of phosphorous also are expected, but not much potash is expected to be used. Likewise, some increases in use of fertilizer are expected for rain-fed crops. In all cases, the increases in use of fertilizer are recognized as a factor in causing increased yields of rain-fed crops, as well as irrigated crops thus providing the basis for estimating the benefits from use of tubewells to provide water for irrigation in the tenth year, as well as in the fifth year of development in a command area (tables 44-46).

d. Farming costs and incomes

The incomes per hectare of land will greatly increase as a result of irrigation and related increases in other classes of input. The gross value of crop products during the fifth year should be more than five times that from similar land without irrigation where double cropping is practiced. The net income per hectare during the fifth year considering all costs except water, should be about Rs 1,406 where double cropping is practiced, compared to only about Rs 192 without irrigation (table 44). In this calculation the farmer is allowed wages of Rs 524 per hectare per year (Rs 3.00 per day) which adds to his net income, because nearly all of the farm labour is provided by his family.

During the tenth year, the benefits of a tubewell should be about one third more than the benefits during the fifth year (table 45). This is based on the assumption that the cultivators will advance rather rapidly in the extension of irrigation to monsoon crops, and improve the level of technology to a considerable extent. The levels expected in the tenth year, however, are still considerably below those already attained in many other parts of India. In the tenth year, for example, those using fertilizer are expected to apply only about half of the recommended amount on most crops and in addition about half of the cultivators are expected to sow most crops without any fertilizer, even in the tenth year. Thus, the high yielding wheat (Mexican) is expected to produce only 2,000 kg per hectare in the tenth year, whereas yields of more than twice this amount are common in research stations (table 46). Wheat, however, is the best fertilized crop in the project area, and the average of expected applications (averages on all sown land during the tenth year equals about half the currently recommended amounts.

Nevertheless, it is recognized that the realization of these results will require substantial improvements in the programmes for education and assisting the farmers in regard to both cultivation and irrigation practices. This will require co-ordination efforts in presently irrigable areas until adequate results can be assured in command areas of new wells. The co-ordination should begin with the selection of the well site.

e. Cost of water

Water discharged from a tubewell yielding 100 m^3 (one acre-inch) per hour during the fifth year of irrigation will cost about Rs 29.06 per 100 m^3 in 1973 (table 47). The cost of water from a tubewell yielding half as much water is about 50 per cent higher per 100 m^3. These costs may be compared with the rate of Rs 4.00 per acre-inch which is paid by water users to the Rajasthan Groundwater Board.

These cost estimates for water are based on conditions in the Sikar basin and prices of 1973. Also, it is assumed that a well will be operated 1,200 hours per year, which is the extent of operations expected for the present type of irrigation practices during the fifth year after irrigation begins. This would permit irrigation of about 24 hectares in winter with 50 per cent efficiency. By the tenth year, the costs per unit of water should have declined substantially, as the result of increased hours of pumping and increased area under irrigation during the monsoon season. It is assumed that it will be possible to operate a pump 1,800 hours during the tenth year, increasing the area irrigated during both the winter and monsoon seasons. A further increase in hours of pumping per day is expected as a result of irrigation of spring crops in April, May and June, and of monsoon crops in June-September. This will bring daily pumping hours to an average of 10 in the fifth year and 12 in the tenth year.

These costs of water include the cost of land levelling and construction of canals as well as all off-farm facilities and measures that will be required. It is assumed that electric power will be available for pumps, even though only about 15 per cent of the villages now have it. Other types of motors for pumping are considered too expensive and not sufficiently reliable. It is assumed that the State will equip each well, install all facilities for gravity irrigation and sell the entire system to a group of cultivators who will pay for it with equal payments over a period of 15 years with interest at 9 per cent per year. First installments are expected to be paid at the end of the third year, so that interest for these years is included as part of the investment of Rs 121,080 for a well with a depth of 90 metres and a discharge of 100 m^3 per hour.

f. Sprinkler irrigation

Sprinkler irrigation has three major advantages over the gravity system especially on the sandy soils in the project area:

(1) A sprinkler obviates the major expenditure for canals and land levelling;

(2) A sprinkler can attain an efficiency of about 70 per cent, compared to 40 to 50 per cent by current methods;

Table 47. Cost of a tubewell and irrigation facility

(Rupees at 1973 prices for a well of 100 m^3/h capacity)

Item	Without Sprinkler		With Sprinkler	
	Total	Per ha	Total	Per ha
Command area (ha)	35	600	45	467
Investments a/				
Well drilling and development	21,000	600	21,000	467
Pump, motor, etc. (installed)	18,000	514	18,000	400
Pump house and operators quarters	20,000	571	20,000	444
Water transmission facilities	17,500	500	20,000	0
Land levelling and improvement	14,000	400	4,500	100
10 per cent standby machinery	3,000	85	3,000	67
Interest three years (9 per cent) b/	27,580	788	19,618	436
Total investment	121,080	3,459	86,118	1,914
Annual costs (5th year)				
Debt payment (15 years at 9 per cent)	15,020	429	20,683	237
Management staff	5,000	143	5,000	111
Electric power (Rs 8.00/hr) c/	9,600	275	18,000	400
Maintenance of machinery	1,000	29	1,800	40
Maintenance of canals (10 per cent)	1,750	50	0	0
Miscellaneous (5 per cent)	868	25	1,240	28
Interest on O and M Funds (9 per cent)	1,640	47	2,344	52
Total	34,878	998	39,067	868
Total per 100 m^3 c/	29.06	-	17.36	-
Additional for 10th year				
Electric power (Rs 8)	4,800	137	0	0
O and M for machines (5 per cent)	1,500	43	0	0
Miscellaneous (5 per cent)	315	9	0	0
Interest on O and M funds	600	17	0	0
Total	1,215	206	0	0
Total in 10th year	42,093	12.04	39,067	868
Total per 100 m^3 c/	2,338	-	17.36	-

a/ Investment costs are based on a well at a depth of 90 metres and a discharge capacity of 100 m^3 per hour.

b/ Irrigators are expected to make the first payment on the debt at the end of the third year of irrigation.

c/ Hours of operation without a sprinkler are estimated to be 1,200 in the fifth year and 1,800 in the tenth year; with a sprinkler the hours of operation would be 2,250 in both the fifth and tenth years.

(3) Feasibility of increasing monsoon crops can be greatly increased.

The installation cost of a sprinkler system is about Rs 61,189 or about Rs 1,360 per hectare, assuming a command area of 45 ha (table 48). Also, the use of a sprinkler reduces the cost per hectare by about Rs 300 land levelling and Rs 500 per hectare for construction of water transmission facilities. Sprinkler irrigation is currently used in the semi-arid part of Rajasthan on several large private farms, as well as on Government farms, and the sprinkler system is gaining rapidly in popularity in other States of India. It is envisioned that a sprinkler system should irrigate the entire command area of a tubewell, even though the land ownership is divided among several cultivators. The management of the sprinkler system could be provided by the pump operator, and the labour for operating the system could be supplied by several teams of cultivators, each team working during certain days or hours, perhaps one or more days each week.

During the monsoon season, a sprinkler can increase the flexibility of the irrigation programme for easier adjustment to the variability of the rainfall. Thus crops may be sown at the proper time, even when the monsoon is late, and the sprinkler can be placed in operation early in a dry period during the monsoon, applying only as much water as needed to saturate the soil. In this way the command area can be irrigated completely before the crops are seriously damaged by drought. The gravity system, on the other hand, would involve a great waste of water. In addition, the sprinkler avoids the task of prepared the bunds and keeping them in repair during the monsoon season, when no one can forecast when, or whether, irrigation will be needed during the season. Thus a sprinkler system can make the irrigation of monsoon crops much more feasible and acceptable for the cultivators in the project area, and it is expected that with a sprinkler, irrigation would be extended to nearly all of the land in monsoon crops during the fifth year of irrigation in a command area.

g. Summary of costs and benefits

The benefits of irrigation with a tubewell in the tenth year will be about Rs 0.90 per rupee of cost if about 30 hectares are irrigated in winter and 12 hectares in monsoon with one well. This is based on 1973 prices and costs of an irrigation efficiency of 50 per cent. If the water is distributed by sprinklers, the efficiency should be about 70 per cent and about 84 hectares of crops could be irrigated in the tenth year, giving a benefit-to-cost ratio of 1.11:1.00 (table 49).

Without a sprinkler, it is assumed that the off-farm water courses will be lined and that some other improvements will be made, so as to increase the efficiency of water use from the present 40 per cent (or less) to about 50 per cent, in the fifth year.

Further study is needed, however, to determine more precisely the extent of feasible improvement in efficiency of the present system of irrigation. Some further improvement in efficiency (about 50 per cent) will be needed by the tenth year, at least to offset increase in crop requirements resulting from increased yields.

The projected costs and benefits of irrigation are higher per hectare for winter crops than for monsoon crops, but the benefits per unit of water are greater for irrigating monsoon crops than for winter crops (table 49). In the tenth year, the increase in net income per hectare will be about Rs 846 for winter crops compared to Rs 779 for monsoon crops, or a total of Rs 1,625 per year. In addition, the wage benefits will be about Rs 307 per hectare of winter crops and only about Rs 49 for monsoon crops. These data provide the basis for determining the amounts of costs and benefits in the command area of a well considering the relative proportion of the irrigated area in each of these two seasons.

Costs of installing and operating a well and pump are indicated, with two alternative assumptions, (a) with a conventional system and (b) with a sprinkler system (table 47). It is assumed that the total investment cost will be paid in equal annual installments during fifteen years, with interest at 9 per cent per year. Banks are prepared to grant a loan on these terms to each land owner among a group (cluster) of cultivators to purchase each well. Interest at 9 per cent on the investment costs is included during the first three years, because irrigators are expected to make their first payments on their loans at the end of the third year after water becomes available for irrigation. It may be advantageous for them to make the first payment at an earlier date to avoid further accumulation of interest charges.

Estimates for irrigable areas are based on the estimated average net requirement of 20 cm of irrigation water for all cultivated land in winter and half as much in summer. The gross amount required is determined on the basis of efficiency rates of 50 per cent for the "bund" system and 70 per cent for the sprinkler system.

A sprinkler system adds to the total cost of irrigation but provides a better ratio of benefits to costs than can be realized by the present system. It also accelerates the rate of development of irrigation, especially for monsoon crops and it increases the number of hours of pumping per day. It may be feasible to substantially increase the efficiency of the present system. If this could be 60 per cent or more, the benefits might exceed the costs in the tenth year, i.e., for a well pumping 100 m^3/h. Also efforts should be made to increase average number of hours of pumping per day, which

Table 48. Costs of a sprinkler system in a tube-well area

(Rupees at 1973 prices for a system having a capacity of 100 m^3/h)

Item	Cost per ha a/	Total cost
Investments		
Sprinkler system	889	40,000
Booster pump and motor	111	5,000
5 per cent standby materials	50	2,250
Interest for 3 years (9 per cent) b/	310	13,939
Total	1,360	61,189
Annual costs a/		
Debt payments (15 years at 9 per cent)	168	7,590
Electric power (Rs 4/hr) c/	200	9,000
Repairs and maintenance (1.0 per cent)	10	450
Miscellaneous (5 per cent)	10	472
Interest on O and M Funds (9 per cent)	2	90
Total annual cost	390	17,602
Cost per hour c/	-	7.82

a/ Values are based on a command area of 45 hectares.

b/ Cultivators would begin annual payments at the end of the third year.

c/ Values are based on pumping 2,250 hours in the fifth year and also in the tenth year, 1,500 hours in the winter and 750 hours in the monsoon season.

Table 49. Summary of annual costs and benefits of irrigation with a tubewell and sprinkler system
(Values are rupees at 1973 prices for discharge of 100 m^3/h)

Item	Value per ha		Total value	
	5th year	10th year	5th year	10th year
Farm effects of well a/				
Increased gross income	1,315	1,541	31,560	64,974
Increased cost	722	725	17,328	30,450
Increased wages	272	234	6,528	9,828
Farm effects with sprinkler b/				
Increased gross income	1,080	1,407	90,720	118,188
Increased cost	473	593	39,732	49,812
Increased wages	168	178	14,112	14,952
Cost of well				
Using present system	1,453	1,002	34,878	42,093
Using sprinkler system	455	465	39,067	39,067
Total farm and well cost				
Using present system	2,175	1,712	52,206	72,543
Using sprinkler system	938	1,058	78,799	88,879
Cost of sprinkler	210	210	17,602	17,602
Total cost with sprinkler	1,148	1,268	96,401	106,481
Benefit-to-cost ratio				
Using present system	-	-	0.60	0.90
Using sprinkler irrigation	-	-	0.94	1.11

a/ It is estimated that 24 ha will be irrigated in winter in the fifth year and that 30 ha will be irrigated in winter in the tenth year, in addition to 12 ha to be irrigated in the monsoon season.

b/ It is estimated that 42 hectares will be irrigated in the winter of the fifth year and 42 again in the monsoon. During the tenth year it is estimated that the area to be irrigated will be the same.

has been estimated to be 10 in the fifth year and 12 in the tenth year (without a sprinkler). This may be compared to less than eight hours of pumping per day by most tubewells in the project area at present.

With sprinkler irrigation, it is estimated that the pump could be operated 2,250 hours as from the fifth year, two-thirds of this total corresponding to the winter season. This will permit the irrigation of about 42 hectares twice a year, giving benefit-to-cost ratios of 0.94:1.00 and 1.11:1.00 in the fifth and tenth year, respectively. Much effort and co-operation by agricultural agencies and ground-water agencies of the State of Rajasthan will be needed in order to realize the assumed improvements.

The value of farm labour has been included in these calculations as a cost. This is considered desirable in view of the fact that the data represent average results, and many farmers will obtain less than average benefits. However, nearly all of the labour on small farms, is provided by the family of the farmer so that this represents income to the family. Thus, the value of labour might conceivably be included as a benefit, rather than a cost, increasing the benefit-cost ratio about 15 to 20 per cent (table 49). This would not apply to farms using hired labour. Employment of hired labour in connexion with tubewell irrigation is not recommended for small farms, because there are many other measures that can yield higher benefit-to-cost ratios than those of a tubewell, in many cases more than 2.0:1.0, both in dry farming and in irrigation farming.

5. Total possible effects of irrigation development

It is physically feasible to install about 1,450 new tubewells within the project area in the State of Rajasthan. These wells could supply about 262.5 million cubic metres of water per year for irrigation without interference with present pumping for irrigation and supplies for domestic uses in 1974 (table 50).

The maximum use of this ground water in the project area would permit the extension of irrigation to an additional 61,213 hectares of crops assuming 40 per cent double cropping. If this were to be accomplished, the total capital cost would be about Rs 168,030,000 for installation of wells and other irrigation facilities. This increase in irrigation would cause increases in annual production valued at about Rs 1,550 per hectare of irrigated crops, or about Rs 94,069,000 in the entire project area.

All of these evaluations are based on the costs and benefits of a well yielding 100 m^3 per hour although wells of this capacity are of doubtful economic feasibility (table 50). Lower yielding wells generally would be uneconomical, except possibly some of those whose depth would be substantially less than 90 metres assumed in these calculations. Furthermore, even the high yielding wells in Bikaner district probably will be uneconomical for irrigation of most crops, because of their depths of about 120 to 165 metres.

The economically feasible wells therefore, may be considered to be only those in Sikar and Luni basins which can discharge about 150 m^3 per hour, These wells have the possibility of irrigating about 15,330 hectares in Sikar basin and about 2,170 hectares in the Luni basin, or a total of 17,500 hectares. This would increase the total irrigated area from the present 21,300 hectares to 38,800 hectares, an increase of 82.2 per cent. It would require a capital investment of about Rs 48,050,000 and the increase in annual value of crop products would be about Rs 27,080,000 (table 50).

This need not imply that other wells will not, or should not be installed. Nor is it a recommendation that the high producing wells should be installed immediately in the Luni and Sikar basins. In fact, this analysis indicates that these wells would yield benefit-cost (B/C) ratios of only about 1.00:1.00 where the "bund" system is used for distribution of water. If sprinklers are used, the B/C ratios would be about 1.25:1.00. It is significant that the Indian Irrigation Commission recommends that acceptable projects should have B/C ratios of at least 1.50:1.00.

It seems more likely that changing economic conditions in India will cause substantial improvements in the relationship between benefits and costs for all investments for food production. These changes may eventually cause all of the possible wells to be economically feasible.

Table 50. Possible total effects of irrigation development in the Rajasthan area

Basin	Discharge (m^3/h)	No. of wells	Total water (mm^3) a/	Irrigated crops (ha) (b/	Capital cost (million rupees) c/	Annual benefit (million rupees) d/
Sikar	150	220	65.7	15,333	42.09	23.72
Sikar	75	767	115.0	26,837	73.67	41.52
Total	-	987	180.7	42,170	115.76	65.24
Bikaner	150	52	15.6	3,640	9.99	5.63
Bikaner	75	48	7.2	1,680	4.61	2.60
Total	-	100	22.8	5,320	14.60	8.23
Luni	150	31	9.3	2,170	5.96	3.36
Luni	75	330	49.5	11,552	31.71	17.87
Total	-	361	58.8	13,722	37.67	21.23
All Basins						
Best wells	150	303	90.6	21,143	58.04	32.71
Med. wells	75	1,145	171.7	40,070	109.99	61.98
All wells	-	1,148	262.3	61,213	168.03	94.69

a/ Total unused water 20 years hence.

b/ Area of irrigated crops is determined with the assumptions that the irrigated area in the monsoon season will be 40 per cent of that in the winter season, that irrigation water requirements of crops will average 25 cm in winter and 12.5 cm in summer, and that irrigation efficiency will be 50 per cent.

c/ The capital cost to install irrigation facilities is estimated with the assumptions that the wells will discharge 100 m^3/h and that 90 per cent to the command area will be irrigated in winter and 36 per cent in the monsoon season, i.e., Rs 2,745/ha of crops sown.

d/ The annual benefit is the increase in value of products (compared to rain-fed crops) during the tenth year, assuming 40 per cent double cropping on irrigated land, i.e., Rs 1,547/ha.

III. GROUND-WATER RESOURCES IN THE GUJARAT PROJECT AREA

A. Location and geography

The State of Gujarat is situated in the north-western part of India and lies immediately south of Rajasthan. The project area covers about 11,500 square kilometres (km^2) between latitudes 23°00' and 24°30' north and longitudes 71°30' and 73°00' east. The main area of study centres in the Mehsana district but includes part of the Banaskantha district. The north-eastern and western parts of the project are covered with aeolian (sand-dune) deposits over alluvium sediments. The balance of the area is agricultural land which is classified as semi-arid.

The project area is bounded by the Banas River in the north-west, the Sabarmati River in the east, and the Aravalli hills to the north. The south-western and southern boundaries are arbitrary, because there the area merges into the Gujarat Plains (Figs. 2 and 38). An index to place names in the Gujarat area is given in annex 25.

The Gujarat project area is physiographically made up of a part of the Aravalli Range in the north, but the major part of the area belongs to the Gujarat Plains. It can be divided into three distinct physiographic units: the eastern part, traversed by the Sabarmati River, the Aravalli foothills, and the central plain.

Elevations range from approximately 100 metres above sea level in the south part of the project area to over 650 metres in the Aravalli Range.

The Banas and Sabarmati and their tributaries are the principal rivers draining the Gujarat project area. They flow in a general south-westerly direction. The Sabarmati is the only river to maintain flow, in certain sections of its tract, throughout the year.

B. Climate

1. Meteorological and rainfall stations

There are 5 meteorological observatories and about 40 rainfall stations in and around the project area. For seven of the rainfall stations, records are available for more than 70 years. The rest of the stations have records for 10 to 69 years.

Mean monthly maximum and minimum temperatures are presented on table 51, and the mean annual rainfall on table 52.

2. Rainfall

In the Gujarat project area the differences in elevation above sea level exceed 600 metres, and when prepared a rainfall map, orographic effects must be taken into account (fig. 37). There is, of course, a scatter due to differences in exposure to the rain-bearing winds, but the general increase is about 20 per cent per 100-metre height difference up to 200 metres above sea level, 15 per cent between 200 and 400 metres, 11 per cent between 400 and 600 metres and about 9 per cent per 100 metres above 600 metres above sea level.

Normal annual precipitation ranges from 468 m in the extreme west and south-west to 996mm in the north-east mountainous sub-humid belt. Ninety-seven per cent of the annual rainfall occurs during the monsoon, usually June to mid-September, of which the July and August contribution is about 69 per cent of the total. Rainfall during the winter and summer months is negligible. Normal mean annual rainfall for the project area is about 672 mm. Rainfall distribution is shown in figure 38. The rainfall variability in the project area is about 43 per cent on the average. Departures and cumulative departures from normal annual rainfall at four stations for the 1901-1973 period are graphically presented in figure 39.

The monthly distribution of rainfall is shown in table 53. About 90 per cent of the annual rainfall occurs in the monsoon season, that is, in June, August and September.

Records of past droughts, defined as negative departure from the mean seasonal rainfall, show that the most severe droughts occur with a frequency of 12 per cent while the occurrence of normal droughts is 22 per cent. Rain storms during the monsoon period occur with a frequency of about 4 per cent. Extremely heavy rainfall occurred in the project area between 28 August and 5 September 1973 which caused heavy flooding in the area.

The variability of monsoon rainfall is very high in the area. A measure of the variability is the coefficient of variation which is equal to the standard deviation divided by the mean. This

Table 51. Air temperature, Gujarat area

Mean maximum temperature in °C .

Station	Record period used	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Radhanpur	1956-73	21.2	27.2	31.1	32.4	34.6	34.3	30.5	25.5	32.1	34.1	31.1	28.1
Idar	1953-73	27.6	30.3	34.9	38.8	40.6	37.4	32.2	30.5	31.9	34.5	32.2	28.8
Deesa	1951-73	27.6	28.1	33.7	35.3	39.5	37.0	30.9	29.4	31.9	34.7	31.9	28.2
Ahmadabad	1931-73	28.6	31.1	35.8	39.8	41.0	38.3	33.2	33.2	33.2	35.8	33.2	29.7
Surendra-nagar	1953-73	28.5	31.4	34.2	35.9	37.6	38.7	32.6	32.8	33.8	34.0	31.6	28.3
				Mean minimum temperature in °C .									
Radhanpur	1956-73	17.6	9.0	12.1	14.3	19.3	20.7	21.0	20.1	21.0	16.6	13.4	10.8
Idar	1953-73	14.8	16.3	20.1	23.8	25.7	26.0	24.6	23.8	22.97	21.0	19.0	16.1
Deesa	1951-73	9.3	10.6	15.6	19.7	22.2	24.5	23.2	21.2	22.3	18.4	13.4	9.6
Ahmadabad	1931-73	11.8	14.4	18.7	23.1	26.3	27.2	25.7	24.5	24.2	21.0	16.2	12.7
Surendra-nagar	1953-73	12.9	15.3	18.9	20.3	23.5	27.0	24.7	25.1	24.4	21.7	17.5	13.5

RAINFALL-ELEVATION RELATIONSHIP

for hilly regions of Gujarat project area

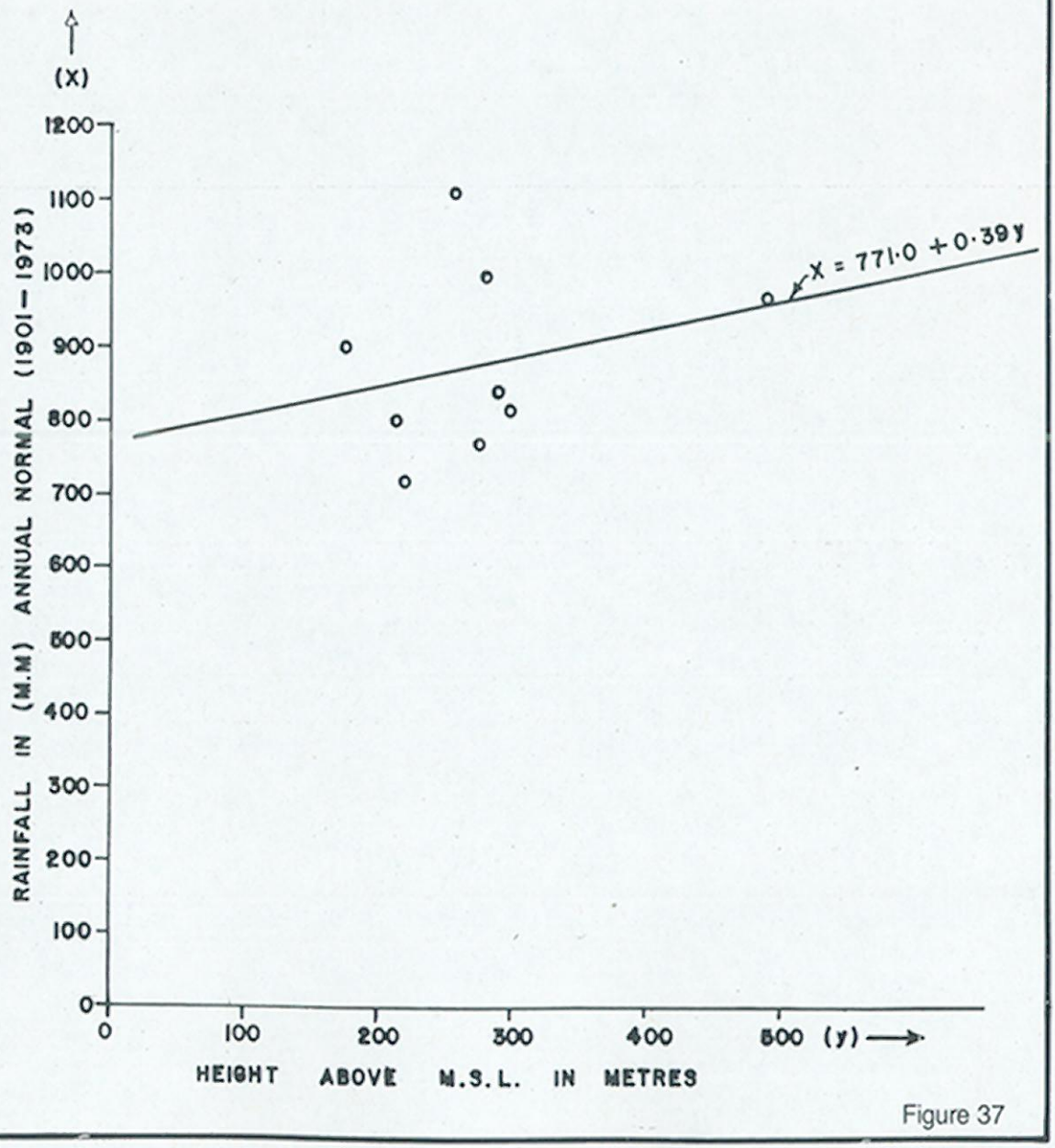


Figure 37

Table 52. Mean annual rainfall, records and extrapolation 1901-1973, Gujarat area

Station	Period of record (No. of years)	Average annual rainfall (in mm)	Adopted normal rainfall 1901-73	Maximum rainfall value	Maximum rainfall year	Minimum rainfall value	Minimum rainfall year	Ratio of maximum to normal	Ratio of minimum to normal	Remarks
1	2	3	4	5	6	7	8	9	10	11
Idar	1901-73 (73)	970.4	970.4	2175.3	1956	304.5	1915	2.24	0.31	
Palanpur	1901-73 (73)	718.7	718.7	1585.5	1907	158.0	1911	2.21	0.22	
Prantij	1901-73 (73	697.3	697.3	1373.9	1933	195.3	1911	1.97	0.28	
Tharad	1901-73 (73)	475.6	475.6	1459.2	1926	87.1	1969	3.07	0.18	
Viramgam	1901-73 (73)	571.8	571.8	1391.9	1927	156.0	1948	2.43	0.27	
Ahmadabad	1901-73 (72)	773.7	781.4	1951.0	1927	234.4	1918	2.50	0.30	1917 N.A.
Radhanpur	1901-73 (70)	497.4	489.0	1191.2	1959	103.4	1925	2.44	0.21	1964,66,69 N.A.
Deesa	1901-73 (69)	596.4	599.1	1533.4	1917	152.9	1904	2.56	0.26	1945-48 N.A.
Himatnagar	1901-73 (69)	786.8	776.1	1538.7	1944	201.2	1911	1.98	0.26	1945-48 N.A.
Mandal	1906-73 (66)	518.3	508.5	1217.2	1927	88.9	1923	2.39	0.17	1965,69 N.A.
Dantivada	1901-73 (63)	898.3	895.4	1930.1	1944	325.9	1965	2.15	0.36	1905,55-63 N.A.
Sihori	1901-69 (61)	621.4	608.8	2070.8	1932	139.9	1901	3.40	0.23	1919,49-55 N.A.
Abu Road	1923-73 (51)	770.5	769.2	1730.8	1944	185.4	1966	2.25	0.24	
Patan	1927-73 (47)	598.5	602.7	1265.9	1927	211.6	1969	2.10	0.35	
Kalol	1927-72 (46)	698.8	714.9	1553.8	1959	118.7	1971	2.17	0.17	
Mehsana	1927-73 (46)	580.3	591.4	1141.7	1927	143.0	1936	1.93	0.24	1965 N.A.
Khedbrahma	1950-73 (23)	799.7	802.3	1626.1	1956	199.9	1959	2.03	0.25	1954 N.A.
Chanasma	1955-73 (19)	547.9	579.3	1016.9	1959	120.0	1960	-	-	
Dhanera	1955-73 (19)	432.5	503.8	1028.7	1956	50.6	1968	-	-	
Harij	1955-73 (19)	463.7	490.3	1016.2	1961	104.0	1964	-	-	
Kadi	1955-73 (19)	638.9	692.6	1284.5	1959	226.3	1972	-	-	
Kankrij	1955-73 (19)	520.6	606.4	1075.5	1959	98.3	1964	-	-	
Sami	1955-73 (19)	492.1	520.3	1345.1	1959	201.2	1960	-	-	
Vijapur	1955-73 (19)	691.6	799.4	1418.3	1959	306.6	1972	-	-	
Visnagar	1955-73 (19)	598.9	692.2	1500.1	1956	124.9	1962	-	-	
Vadgam	1955-73 (19)	638.5	710.7	1598.9	1956	196.0	1972	-	-	

Table 52 (continued)

Station	Period of record (No. of years)	Average annual rainfall (in mm)	Adopted normal rainfall 1901-73	Maximum rainfall value	Maximum rainfall year	Minimum rainfall value	Minimum rainfall year	Ratio of maximum to normal	Ratio of minimum to normal	Remarks
1	2	3	4	5	6	7	8	9	10	11
Danta	1955-72 (18)	871.4	995.9	1527.2	1959	383.3	1969	-	-	
Diodar	1955-73 (18)	441.6	514.9	1116.1	1956	119.0	1971	-	-	1965 N.A.
Kheralu	1955-73 (18)	600.4	666.1	1065.6	1959	305.9	1972	-	-	1963 N.A.
Vav	1955-73 (18)	404.7	467.8	853.0	1959	59.0	1968	-	-	1966 N.A.
Sidhpur	1955-73 (18)	485.5	548.6	1145.3	1956	123.5	1960	-	-	1959 N.A.
Posina	1950-72 (17)	703.5	836.9	1118.3	1967	410.2	1951	-	-	1954,60,61,68-70 N.A.
Dehgam	1955-73 (17)	682.4	683.3	1602.2	1959	207.1	1960	-	-	1957,61 N.A.
Ransipur	1961-73 (13)	503.0	556.6	922.4	1973	291.1	1965	-	-	
Tarangahil	1961-73 (13)	920.3	920.3	1489.0	1962	294.3	1972	-	-	
Hirad	1964-73 (10)	639.9	849.9	1007.0	1967	285.6	1969	-	-	
Mansa	1964-73 (10)	582.0	785.2	1235.0	1973	291.1	1972	-	-	
Varahi	1960-69 (10)	369.7	544.9	794.8	1961	90.0	1968	-	-	1965 N.A.
Range	-	370-970	468-996	-	-	-	-	1.93-3.40	0.17-0.36	
Mean	-	626.4	672.1	-	-	-	-	2.34	0.25	

Table 53. Mean monthly rainfall distribution, 1901-73, Gujarat area

	Station	Period of record (No. of years)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1.	Idar	1901-73(73)	2.9	2.2	1.9	1.2	12.8	134.2	376.7	282.4	138.6	13.0	3.1	1.4	970.4	
2.	Palanpur	1901-73(73)	2.0	3.8	2.3	1.3	6.7	66.1	284.0	231.4	107.2	9.5	2.3	2.1	718.7	
3.	Prantij	1901-73(73)	2.6	1.8	2.0	0.6	6.6	72.7	270.9	209.3	116.7	8.9	4.1	1.1	697.3	
4.	Tharad	1901-73(73)	2.6	1.9	2.6	0.9	3.7	37.8	190.8	151.4	73.3	7.1	2.4	1.1	475.6	
5.	Viramgam	1901-73(73)	1.1	1.3	1.9	0.4	6.9	56.1	231.8	163.7	96.4	8.3	2.6	1.3	571.8	
6.	Ahmadabad	1901-73(72)	1.2	0.9	1.3	0.8	5.3	84.6	328.0	202.9	137.2	7.8	2.6	1.1	773.7	1917 N.A.
7.	Radhanpur	1901-73(70)	1.1	1.5	2.3	0.6	4.7	35.9	213.8	145.6	81.3	8.0	1.5	1.3	497.4	1964,66,69 N.A.
8.	Deesa	1901-73(69)	2.3	3.0	2.6	0.5	6.4	46.7	233.0	195.5	95.3	8.9	1.5	0.8	596.4	1945-48 N.A.
9.	Himatnagar	1901-73(69)	1.9	2.0	1.9	1.1	9.0	77.4	299.2	246.2	136.7	8.9	2.0	0.5	786.8	1945-48 N.A.
10.	Mandal	1906-73(66)	2.0	1.1	1.0	0.6	7.1	58.3	208.3	149.4	78.4	8.9	2.4	0.8	518.3	1965,69 N.A.
11.	Abu Road	1923-73(51)	4.0	1.9	2.1	3.2	6.5	71.9	302.1	256.5	98.5	5.8	2.4	2.6	770.5	1951,56 Monthly N.A
12.	Patan	1927-73(47)	1.9	1.3	2.9	0.3	4.1	62.9	255.2	164.3	91.7	7.9	3.9	2.1	598.5	
13.	Kalol	1927-72(46)	1.2	1.5	1.1	1.1	2.4	75.0	281.9	178.2	142.5	10.2	2.8	0.9	698.8	
14.	Mehsana	1927-73(46)	2.2	0.9	1.7	0.6	4.0	69.5	244.2	167.4	81.7	4.1	2.6	1.3	580.3	1965 N.A.
15.	Khedbrahma	1950-73(23)	2.1	0.0	5.3	0.8	0.7	67.9	305.1	252.3	148.9	12.6	2.4	1.6	799.7	1954 N.A.
16.	Chanasma	1955-73(19)	1.3	0.0	1.2	0.0	0.0	56.3	203.8	148.3	124.6	8.3	2.3	2.0	547.9	
17.	Dhanera	1955-73(19)	0.0	0.0	4.7	0.1	0.4	53.6	161.9	125.8	76.8	6.5	2.6	0.3	432.5	
18.	Harij	1955-73(19)	0.8	0.4	1.0	0.0	0.7	44.5	209.9	144.3	57.7	2.3	1.3	0.8	465.7	
19.	Kadi	1955-73(19)	0.6	0.1	0.6	0.0	0.3	61.1	253.7	158.8	151.1	7.3	3.4	1.9	638.9	
20.	Kankrij	1955-73(19)	0.1	0.0	4.2	0.0	0.0	46.6	196.8	136.0	123.3	9.2	4.0	0.6	520.6	
21.	Sami	1955-73(19)	1.3	0.6	1.0	0.0	0.0	47.4	189.8	136.1	107.5	5.6	2.5	0.3	492.1	
22.	Vijapur	1955-73(19)	1.0	0.1	0.7	2.1	1.4	84.1	248.9	168.2	157.7	23.9	0.8	2.7	691.6	
23.	Visnagar	1955-73(19)	1.3	0.5	1.1	0.0	1.9	71.4	222.7	141.8	135.8	15.6	6.1	0.7	598.9	
24.	Vadgam	1955-73(19)	3.0	0.1	6.4	0.0	2.8	60.4	248.3	168.3	129.2	18.1	0.3	1.6	638.5	
25.	Danta	1955-72(18)	2.8	0.8	6.6	0.7	3.2	76.4	372.4	254.3	140.8	10.0	2.9	0.6	871.4	
26.	Deodar	1955-73(18)	0.1	0.0	4.9	0.0	0.0	46.0	144.4	118.8	114.1	7.5	5.8	0.0	441.6	1965 N.A.
27.	Keralu	1955-73(18)	0.1	0.3	7.8	0.4	0.7	55.0	226.3	186.7	111.3	10.1	0.3	0.5	600.4	1963 N.A.
28.	Sidhpur	1955-73(18)	0.0	0.0	5.3	0.0	2.4	58.6	188.9	151.2	60.8	17.3	0.1	0.9	485.5	1959 N.A.
29.	Posina	1950-72(17)	2.8	0.4	4.7	1.1	2.5	67.1	262.8	221.6	100.4	13.2	2.6	3.0	703.5	54,60,61,68-70 N.A.

Table 53 (Continued)

1	Station	Period of record (No. of years)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
30.	Vav	1955-73(18)	1.1	0.0	3.9	0.0	0.3	31.4	152.2	106.5	103.7	2.8	2.8	-	404.7	1966 N.A.
31.	Dehgam	1955-73(17)	1.8	0.6	3.4	0.2	2.9	64.8	268.5	179.8	143.4	13.7	3.3	0.0	682.4	1957,61 N.A.
32.	Ransipur	1961-73(13)	0.0	0.0	0.0	0.0	0.0	44.6	186.8	182.0	89.1	0.5	0.0	0.0	503.0	
33.	Tarangahil	1961-73(13)	0.0	0.0	0.0	0.0	0.2	71.1	380.0	283.0	183.8	2.2	0.0	0.0	920.3	
34.	Hirad	1964-73(10)	0.0	0.0	8.9	0.0	0.0	41.8	277.9	209.5	101.9	0.1	0.0	0.0	639.9	
35.	Mansa	1964-73(10)	0.0	0.0	3.0	0.0	0.0	63.3	225.3	178.5	105.4	6.5	0.0	0.0	582.0	
36.	Dantivada	1964-73(9)	0.0	0.0	10.6	0.0	0.0	51.7	212.5	223.2	93.2	0.8	0.0	2.7	594.7	1965 N.A.
	Average	-	1.4	0.8	3.2	0.5	3.0	61.5	246.1	183.8	112.2	8.6	2.3	1.0	624.4	
	Percentage	-	0.2	0.1	0.5	0.1	0.5	9.8	39.4	29.4	18.0	1.4	0.4	0.2	100.0	

DEPARTURES & CUMULATIVE DEPARTURES FROM
NORMAL ANNUAL PRECIPITATION 1901-1973
AT AHMADABAD, IDAR, PALANPUR & RADHANPUR

(BASED ON NORMAL FOR THE PERIOD 1901-1973)

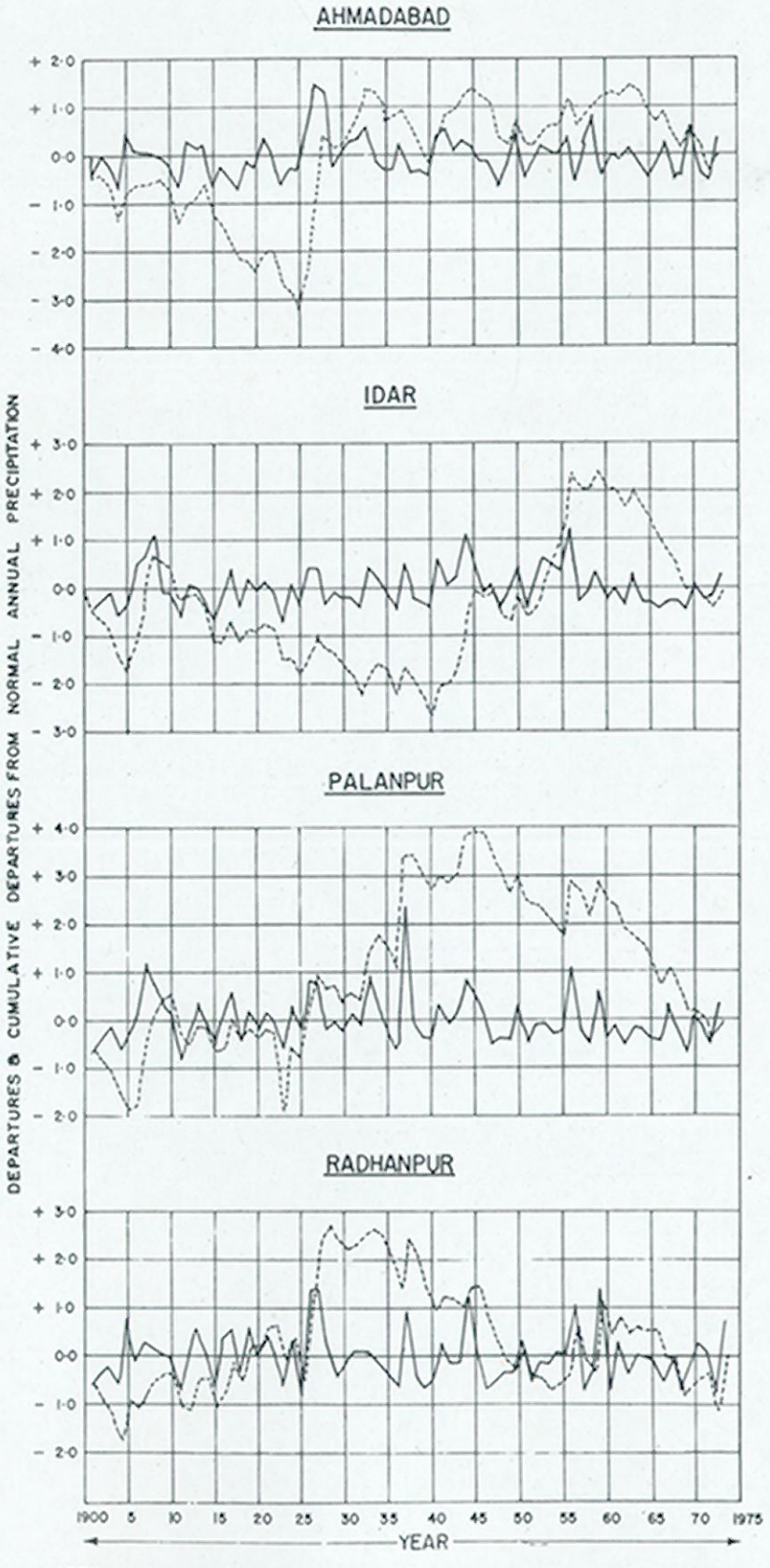


Figure 39

coefficient of variation is as high as 30 per cent for the Gujarat project area.

The monsoon rainfall is sometimes very concentrated in time. In 1973 for instance, at the end of August and the first of September tremendous amounts of rainfall fell over the north-eastern part of the Aravalli hills causing catastrophic floods near rivers and streams. Most of this rainfall fell on August 29, 30 and 31. On September first, heavy rainfall continued mainly in the north-eastern part of the project area. Khedbrahma village on the Sabarmati River received 413 mm on September first, giving a rainfall total for the four days (August 29 to September 1) of 613 mm or about 85 per cent of the long-term mean annual rainfall.

3. Evaporation

Mean long-term monthly potential evaporation calculated by the Penman method was considered representative of actual evaporation for the purpose of estimating the water surplus for groundwater recharge.

The mean annual value of potential evaporation for Ahmadabad is about 1,677 mm. Data from this station was taken as representative for the major part of the area. For the south-western semi-arid zone, potential evaporation was taken as 30 per cent higher, and for the north-eastern sub-humid area as 10 per cent lower. Data on mean monthly and annual evaporation for Ahmadabad and some other stations are given in table 10.

4. Climate classification and characteristics

The climate is, like that of the Rajasthan project area, dominated by the monsoons. The south-west monsoon lasts normally from beginning of July to middle of September. During these 2-1/2 months, the area receives more than 90 per cent of the annual rainfall. Temperatures are highest during the months of May and June, preceding the monsoon season, with a mean monthly maximum temperature of 40°C. During the monsoon, in August, daily maximum temperature drops to about 30°C. January is the coolest month, with a mean monthly minimum of about 10°C (table 51).

According to the Thornthwait classification of climate, two different climatological zones are discerned in the project area. In the north-western hill region, which covers about 10 per cent of the total area, sub-humid conditions prevail. The rest of the area - the plain - has a semi-arid climate. Extreme temperatures, erratic rainfall and high evaporation are characteristic features of this type of climate.

C. Runoff

Two major rivers drain the project area - the Sabarmati and Banas rivers. The Sabarmati flows from the Aravalli Range in the north to Ahmadabad in the south, where it leaves the project area. It forms the eastern boundary of the project area. The other major river is the Banas flowing from Mount Abu and the Aravalli Range in the north in a south-westerly direction, forming the western limit of the project area.

Two minor rivers, the Saraswati and the Rupen originate in the northern part of the project area and flow toward the south-west. The streamflow of these rivers and many of their tributaries is measured at more than 20 stream-gauging stations. Records for most of these stations are available as from 1951. Six stations were established by the project in 1972 as listed in table 54.

Table 54. Stream-gauge stations established by project

Station	Location	Type of station	Period of Record
Manpur	24°30' 72°48'	Observatory and stream gauge	Aug. '72 to July '74
Kheroj	24°14' 73°01'	Stream gauge	1972 and 1973
Memoniwas	24°09' 72°40'	Stream gauge	1972 and 1973
Sidhpur	23°54' 72°21'	Stream gauge	1972 and 1973
Shankeshwar	23°28' 71°47'	Stream gauge	1972 and 1973
Radhanpur	23°46' 71°38'	Stream gauge	1972 and 1973

At these stations, discharge measurements were carried out daily in 1973 from June 16 to October with current metres, from multi-span bridges. River stages were read from bridge piers. Discharge rating curves were established to estimate the river flow between discharge measurements. These streamflow records are considered fairly reliable.

Other measurements are less reliable, such as those of Dharoi on the Sabarmati, which was grossly in error in 1972. It should be pointed out in this connexion that no quality control or other checking has been made on the streamflow data presented in this report (table 55).

The streamflow hydrographs (figs. 40, 41 and 42) demonstrate that river flow consists of a number of short-duration flash floods with very high peaks. Flow recession after the monsoon season is in most rivers quite fast, and after a couple of months there is virtually no flow in any river except in the Sabarmati which at Ahmadabad carries some flow through the dry season. The

Table 55. Mean annual runoff data, Gujarat

River and discharge measurement station	Catchment area (km)	Total period of available records	Average annual runoff (MCM)	Maximum runoff (MCM)	Minimum runoff (year) (MCM)	Mean annual runoff for the period 1961-73 (MCM)	(mm)	Remarks
1	2	3	4	5	6	7	8	9
Sabarmati River								
Kherod (1)	2878	1972-73	1206	2318(1973)	93(1972)	634*	220*	
Khedbrahma	456	1953-73	198	466(1953)	15(1969)	134	295	Dam on Harnav River
Dharoi	4030	1957-72	606	1287(1959)	207(1969)	823	204	Khedbrahma catchment excluded
Derol	5130	1970-71	997	1617(1970)	376(1971)	-	-	-do-
Waghpur	5425	1953-62	1063	2137(1956)	392(1957)	94*	173*	-do-
Ahmadabad	7018	1951-73	1313	3887(1956)	157(1969)	1131	161	-do- Himatnagar dam catchment
Banas River								
West Banas (Sarupganj)	486	1963-72	35	54(1967)	10(1969)	50*	103*	
Abu Road (1)	996	1972-73	476	924(1973)	28(1972)	157*	158*	West Banas Dam catchment excluded
Sarotra	30	1964-72	63	289(1970)	6(1966)	-	-	
Umarkote	30	1963-71	18	47(1967)	1(1963)	-	-	
Malpur	297	1951-72	93	316(1967)	9(1969)	63*	212*	
Dantiwada	2182	1951-73	478	2910(1956)	11(1968)	230 (2)	1105	-do-

Table 55 (continued)

River and discharge measurement station	Catchment area (km)	Total period of available records	Average annual runoff (MCM)	Maximum runoff (MCM)	Minimum runoff (year) (MCM)	Mean annual runoff for the period 1961-73 (MCM)	(mm)	Remarks
1	2	3	4	5	6	7	8	9
Bhakudar	1290	1951-72	230	761(1956)	28(1969)	209	162	Dantivada catchment excluded
Deesa	1742	1952-72	562	2389(1956)	36(1969)	255*	146*	
Radhanpur (1)	3620	1972-73	1640	3250(1973)	29(1972)	-	-	-do-, runoff mostly from outside the catchment area
Saraswati River								
Memoniwas (1)	139	1972-73	86	160(1973)	12(1972)	49*	374*	
Bhakri	531	1958-61) 1970-72)	171	195(1970)	53(1960)	-	-	
Sidhapur (1)	590	1958-61 1972-73	160	428(1959)	48(1958)	61*	103*	
Patan	1441	1960-73	276	2045(1973)	13(1969)	101	70	
Annavada	1486	1957-72	157	202(1961)	8(1969)	86*	58*	
Rupen River								
Shankhaswar	1795	1972-73	35	57(1973)	13(1972)	53*	30*	Nunar and Basna dams excluded

Remarks

(1) Maintained by UNDP

(2) doubtful data

(3) * runoff for missing period of records was calculated on the basis of the nearest station with complete data. Mean runoff has not been calculated when records were doubtful.

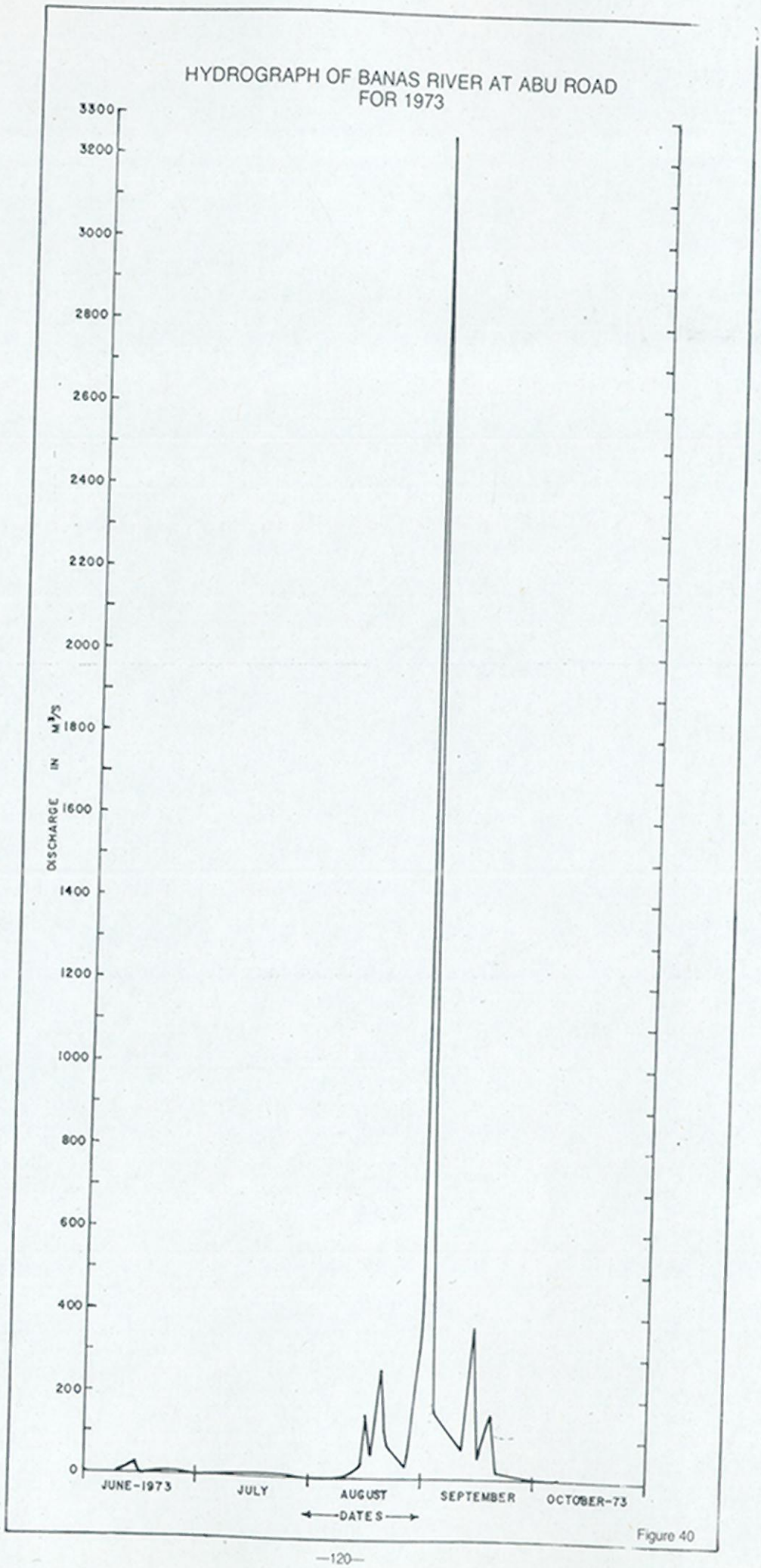

HYDROGRAPH OF BANAS RIVER AT ABU ROAD
FOR 1973
DISCHARGE IN M³/S
3300
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
JUNE-1973
JULY
AUGUST
SEPTEMBER
OCTOBER-73
DATES

Figure 40

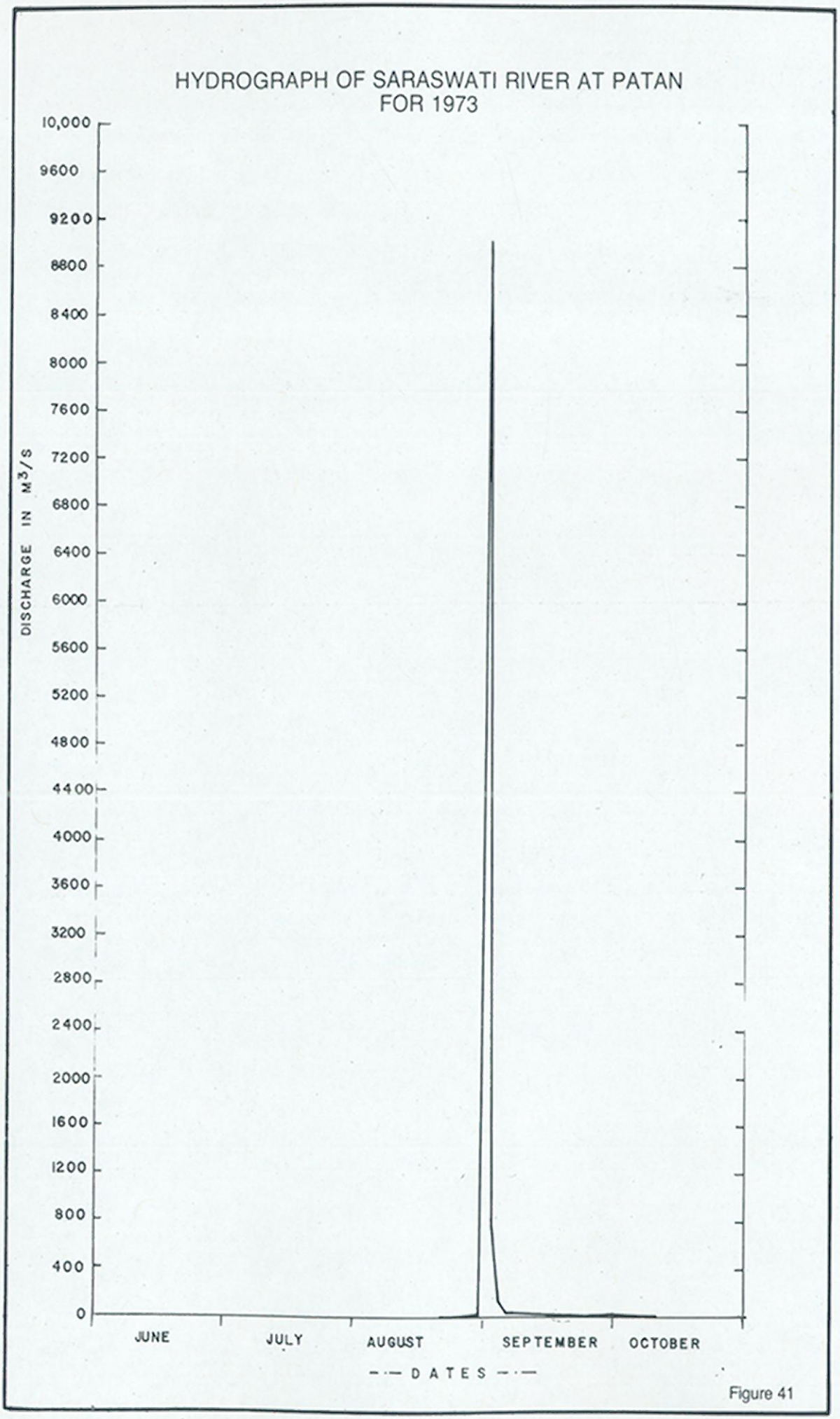

HYDROGRAPH OF SARASWATI RIVER AT PATAN
FOR 1973
DISCHARGE IN M³/S
10,000
9600
9200
8800
8400
8000
7600
7200
6800
6400
6000
5600
5200
4800
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
DATES

Figure 41

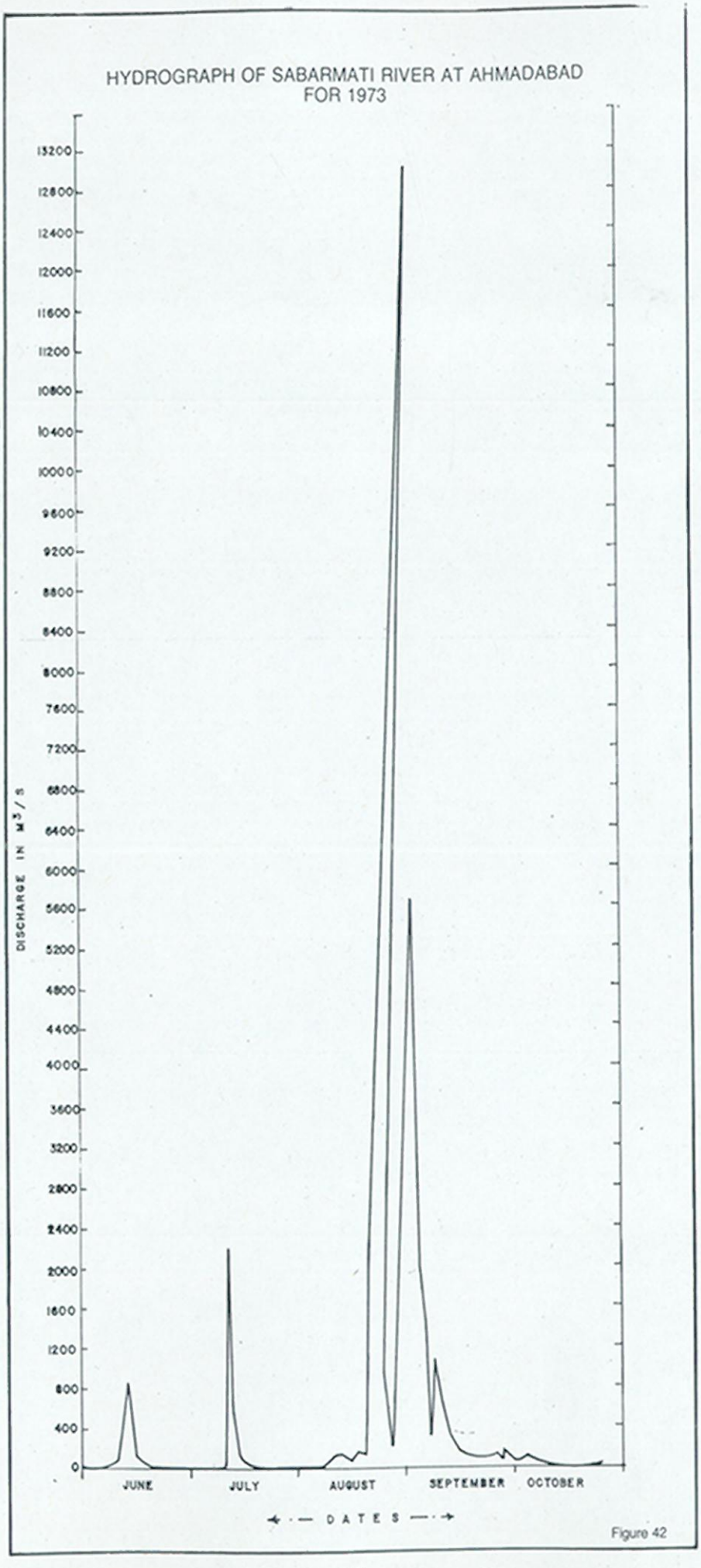

HYDROGRAPH OF SABARMATI RIVER AT AHMADABAD
FOR 1973
DISCHARGE IN M³/S
13200
12800
12400
12000
11600
11200
10800
10400
10000
9600
9200
8800
8400
8000
7600
7200
6800
6400
6000
5600
5200
4800
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
DATES

Figure 42

recession flow of the Sabarmati River at Ahmadabad amounts to 8 mm, or 5 per cent of the monsoon flow (table 56).

The mean annual runoff was computed for the 1961-1973 period. Rainfall for this period is close to normal, and it was assumed that runoff also represents long-term conditions. Gauging stations with short record periods have been compared tentatively to the nearest station having complete records (see table 57). The base flow of the Sabarmati River at Ahmadabad was included in total runoff.

Mean annual runoff is less than 100 mm in the plains, and more than 200 mm in the hill country (table 52). The runoff coefficient is also higher in the hills than in the plains (table 57). Extreme values of mean annual runoff are 30 mm in the Rupen River catchment as observed at Shankeshwar and 374 mm in the upper part of the Saraswati River catchment, upstream of Memoniwas. Variability of the annual runoff is very high and the maximum value is equal to 20 times the mean runoff as was recorded on the Banas River at Patan in 1973.

Discharge of the Sabarmati River at Ahmadabad during the flood (1 Sept. 1973) was 13,000 m^3/sec giving this single day the same values as the mean annual runoff. It must be pointed out that the unused volume of surface water is quite important, especially in the north-eastern part of the project area, and it can be utilized for artificial recharge during monsoon period to increase the groundwater resources.

E. Geology and hydrogeology

1. Geology

The project area is formed by two main structural elements - the Aravalli hills, built up by Precambrian basement rocks in the north-east, and the Cambay sedimentary basin corresponding to about 90 per cent of the project area (see geologic map, fig. 43).

The Cambay basin was formed as a tectonic graben at the end of the Mesozoic Era, through development of tensional faults accompanied by large-scale volcanic activity (Raju, 1969). The main fault system trends NNW-SSE, approximately paralleling the main trend of the Aravalli hills. The basin was subsequently filled up with Tertiary and Quaternary sediments. It is assumed that subsidence of the basin ceased in late Miocene times.

Most of the project area is underlain by thick Quaternary and Tertiary deposits forming part of the fill of the Cambay basin. These rest in the central part of the area upon Deccan Traps and on Himatnagar Sandstone in the south-eastern part.

The north-eastern part of the area coincides with the foothills of the Aravalli Range. These are built up by metamorphics of the Aravalli System, the Delhi System, and post-Delhi intrusives - all of Archean age. The geologic succession in the project area is summarized in table 58.

Previous knowledge of subsurface geologic structure was extended by data from 26 project boreholes, which penetrated the sedimentary fill of the Cambay basin to a maximum depth of 600 m. These boreholes were emplaced on north-east - south-east trending lines, so as to provide a subsurface picture on the changes of the lithological column from the Aravalli foothills towards the centre of the basin. A generalized subsurface column, with a description of the aquiferous properties of the various units, is presented in table 59.

The oldest sedimentary rocks encountered by project boreholes belong to the Himatnagar Sandstone of Cretaceous age (fig. 50). They overlie the Precambrian basement along the north-eastern limit of the Cambay basin. In the central, southern and western parts of the project area, Miocene deposits were encountered at depths ranging from 200 m to more than 550 m (annexes 16, 17). They consist of medium-grained sand, sandstone and siltstone interbedded with clay and claystone, probably deposited in a shallow marine and brackish environment. These Miocene beds grade upwards into post-Miocene and Quaternary deposits without distinct lithologic break.

2. Subsurface geology and hydrogeology of the Gujarat plain

Two major aquifer units have been identified in the Gujarat plain within the explored depth of 600 m below surface. The upper unit is mostly phreatic, but becomes semi-confined to confined in some parts of the project area. It is designated as aquifer A and consists of relatively coarse-grained sediments.

The lower unit comprises a few hundred metres of alternating sandy and argillaceous beds, forming a confined aquifer system. It is subdivided into aquifers B, C, D and E contained in post-Miocene deposits and aquifers F and G in the Miocene sediments. The post-Miocene aquifers are mainly coarse to fine sands, with occasional gravel beds (aquifer B) whereas the Miocene aquifers are mainly fine- to medium-grained sand and sandstone, interbedded with clay, claystone and siltstone (fig.44).

The Himatnagar Sandstone (Cretaceous) is a medium to fine grained poorly cemented sandstone with shale and conglomerate beds, and constitutes a local aquifer in the north-eastern and eastern part of the project area (fig. 43). It has been designated as aquifer H.

Towards the Aravalli foothill belts in the north-east of the area, the nature of the sediments is more uniform and there one signel aquiferous unit, of phreatic nature, exists. This is also the principal recharge zone of the aquifer system.

Table 56. Monsoon runoff and estimated recession runoff in the Sabarmati and Banas rivers

(in millimetres)

Year	SABARMATI				BANAS	
	Ahmadabad		Khedbrahma		Deesa	
	Monsoon runoff	Recession runoff	Monsoon runoff	Recession runoff	Monsoon runoff	Recession runoff
1973	479	23	-	-	319	11
1972	35	2	61	1	28	1
1971	54	2	120	1	45	2
1970	184	8	419	4	94	4
1969	19	1	29	0	14	0
1968	121	6	198	2	249	11
1967	141	6	196	2	222	10
1966	170	7	237	2	31	1
1965	60	3	309	3	125	5
1964	118	6	164	2	137	5
1963	351	17	623	6	188	7
1962	191	9	229	2	10	0
1961	162	8	447	4	541	21
Average (1961-73)	160	8	253	2	154	6
(In percentage)	5.0		1.0		3.9	

Table 57. Runoff coefficients, Gujarat

River	Total catchment area (km^2)	Gauging station	Period considered	Runoff coefficients		Remarks
				Ranges	Average	
1	2	3	4	5	6	7
Sabarmati	7 018	Ahmadabad	1965-1972	0.053-0.260	0.146	Catchment area of Harnav, a tributary to Sabarmati is excluded and also of Himatnagar dam site
Banas	5 802	Dantivada	1965-1972	0.027-0.097	0.059	West Banas Catchment area excluded since a dam exists there
Rupen	1 795	Sankeshwar	1972-1973	0.022-0.042	0.032	Catchment area of Nugar and Basna bunds excluded
Saraswati	1 441	Patan	1965-1972	0-0.242	0.075	-
		Memoniwas	1972-1973	0.110-0.814	0.462	-

Table 58. Geologic formations in the Gujarat area

Era	Period or epoch	Series/ formations	Description
Quaternary	Recent to Pleistocene	Alluvium	Fluvial sediments/piedmont, flood plain and valley fill deposits aeolian sand at surface.
			--------- unconformity ---------
Mesozoic	Cretaceous*	Himatnagar Sandstone	Sandstone, shale, conglomerate
			--------- unconformity ---------
Proterozoic	Precambrian	Post Delhi Intrusives	Erinpura granite, epidiorite, hornblende schist, gabbro, etc.
			--------- unconformity ---------
		Delhi System	Limestone, calciphyre, calcogneiss, calc-schist, slate, phyllite, biotite schist
			--------- unconformity ---------
Azoic	Archean	Aravalli	Phyllite, slate, schist, limestone

* Deccan Traps of Cretaceous to Paleocene age has been encountered in boreholes drilled within the project limits. Outcrops occur outside the project area.

Table 59. Geologic formations in the subsurface of the Gujarat plain and their aquiferous properties

Stratigraphy	Formation group	Lithology	Depth to top of aquifer (m)	Thickness		Remarks
				range (m)	average (m)	
Recent to post Miocene	Aquifer A	Coarse sand, gravel pebbles, medium and fine sands and clayey sand	5-71	35-125	62	Variable water quality
	Aquitard I	Clay interbedded with sand and sandy clay.	78-162	13-88	39	-
	Aquifer B	Medium to coarse sand and gravel interbedded with sandy clay	78-162	10-80	45	Generally good water quality
	Aquitard II	Clay interbedded with sand and sandy clay		13-80	37	-
	Aquifer C	Medium to coarse sand in north-east, and fine to medium in central part interbedded with sandy clay and clay	154-274	13-62	34	Generally good water quality
	Aquitard III	Clay interbedded with sand and sandy clay.		19-172	73	-
	Aquifer D	Medium sand interbedded with sandy clay	229-402	11-105	52	variable water quality
	Aquitard IV	Clay interbedded with sandy clay		11-76	44	-
	Aquifer E	Fine to medium sand and sandy clay	300-542	15-57	24	Developed in central part. Water quality good
Miocene	Aquiclude V	Grey clay and claystone		13-148	41	-
	Aquifer F	Fine to medium sand, sandstone interbedded with siltstone	200-574	7-68	39	Variable water quality
	Aquiclude VI	Clay and claystone		34-49	40	-
	Aquifer G	Fine to medium sand, sandstone interbedded with siltstone	264-513	9-124	48	Water generally saline
Paleocene	-	Basalt			267	
Cretaceous	Aquifer H	Himatnagar sandstone	214-547	98-145	121	Variable water quality

Towards the centre of the area, the argillaceous intercalations act as confining layers of various efficiency. Here, the upper phreatic aquifer (A) and six deeper, confined aquifers (B to H) are identified. In many parts, leaky conditions are noted.

Lateral changes in aquiferous characteristics, attributed to changes in the lithology of the aquifers are inferred from the interpretation of pumping tests, which in part indicated negative boundary conditions.

Aquiferous properties are generally less favourable in the deeper aquifers as compared to the more shallow ones, and in the central and south-eastern part of the area as compared to the north-eastern part.

The shallow, phreatic aquifer (A) shows the most favourable hydraulic parameters and contains the best-quality ground water in the vicinity of the recharge zone, in the north-eastern part of the area. It deteriorates towards south-west and west.

The same trend in water quality is noted also in the confined aquifers. Ground-water quality also deteriorates with increasing depth.

The phreatic aquifer (A) and the upper-most confined aquifer (B) are extensively exploited for irrigation, and in some areas the effects of excessive exploitation are noted.

The aquifer system is described in detail below (see also table 59).

3. Description of aquifers

a. Unconfined aquifer: Aquifer A

Aquifer A is the most extensive aquifer in the project area and consists of coarse- to medium- and fine-grained sand, gravel, pebbles and local lenses of sandy clay and clay.

Coarse-grained deposits prevail along the hilly tract (piedmont zone) in the north-eastern part, which covers about 1,600 km^2 (14 per cent of total area), and is the major recharge zone for the artesian aquifers system (fig. 43). Fine- to medium-grained sand, with an increasing percentage of clay, prevail in the central and south-western portion of the project area.

The thickness of the aquifer ranges from 35 metres in the north-east to 125 metres in the central part of the area. Phreatic conditions predominate in the north-eastern zone but in the central, southern and western part, semi-confined and confined conditions occur.

Ground-water flow is directed from the main recharge area in the piedmont region towards south-west. In the south-eastern part of the area, however, ground-water flows in a north-south direction, and water-level contours indicate that the aquifer is drained by the Sabarmati River. The depth to water table is 5 to 10 m in most of the plain but increases to 20-25 m in the central and south-eastern part of the project area (fig. 45).

Water-level fluctuations measured in 430 observation wells before and after the monsoon (May-June and November) amounted to 0.5 - 2.5 m. Observations also showed that water levels declined by 1.5 m in the central and south-eastern part of the project area and this decline must be attributed to heavy pumpage in this part.

Hydraulic characteristics of the aquifer were obtained from nine pumping tests. Specific capacity ranges from 31 $m^3/h/m$ to less than 1 $m^3/h/m$, and transmissivity from about 30 m^2/d to about 1,000 m^2/d (annex 15). Higher transmissivities characterize the north-eastern zone (300 - 1,000 m^2/d) while in the central and south-western zone generally lower transmissivities reflect the finer material of the aquifer (fig. 46).

b. Confined aquifers: Aquifer B

Aquifer B is the uppermost confined aquifer and extends over a great part of the project area. It consists of medium- to coarse-grained sands and gravels, locally interstratified with clay lenses, and is separated from the overlying and underlying aquifers by beds of sandy clay.

In the north-eastern foothill zone this aquifer unites with the phreatic aquifer through wedging-out of the separating clay layer. It is in this zone that recharge takes place (figs. 47 and 48). The top of the aquifer is found in depths of 78 to 162 m below surface. Its thickness ranges from 10 to 80 m, the greatest thickness being found in the central part of the area.

Depth to water level in the central and southern part of the area exceeds 20 m. In the south-western part, the piezometric surface is a few metres above ground. Water-level fluctuations were recorded by instruments at two sites in the north-eastern (recharge) zone and at two sites in the central part of the project area (figs. 49-53). Observed amplitude of seasonal fluctuations of the water table in the recharge zone was about 2 m. In the central part of the area, seasonal fluctuations were as much as 25 m (fig. 53).

Pumping tests were performed in six wells to determine well and aquifer characteristics (annex 16). Specific capacity ranges from 1.8 $m^3/h/m$ to 49 $m^3/h/m$. Transmissivity was found to be between 47 m^2/d and 3,400 m^2/d. Most transmissivity values are between 200 m^2/d and 600 m^2/d. Storage coefficients range from 0.6 to 12.3 $\times 10^{-4}$ (figs. 55 and 56).

Direction of ground-water flow is south-west (fig. 54). The quality of ground-water is generally good. This aquifer ranks second in rate of exploitation, after Aquifer A.

TIME-DRAWDOWN/RECOVERY CURVE - KARORA II (AQUIFER A)

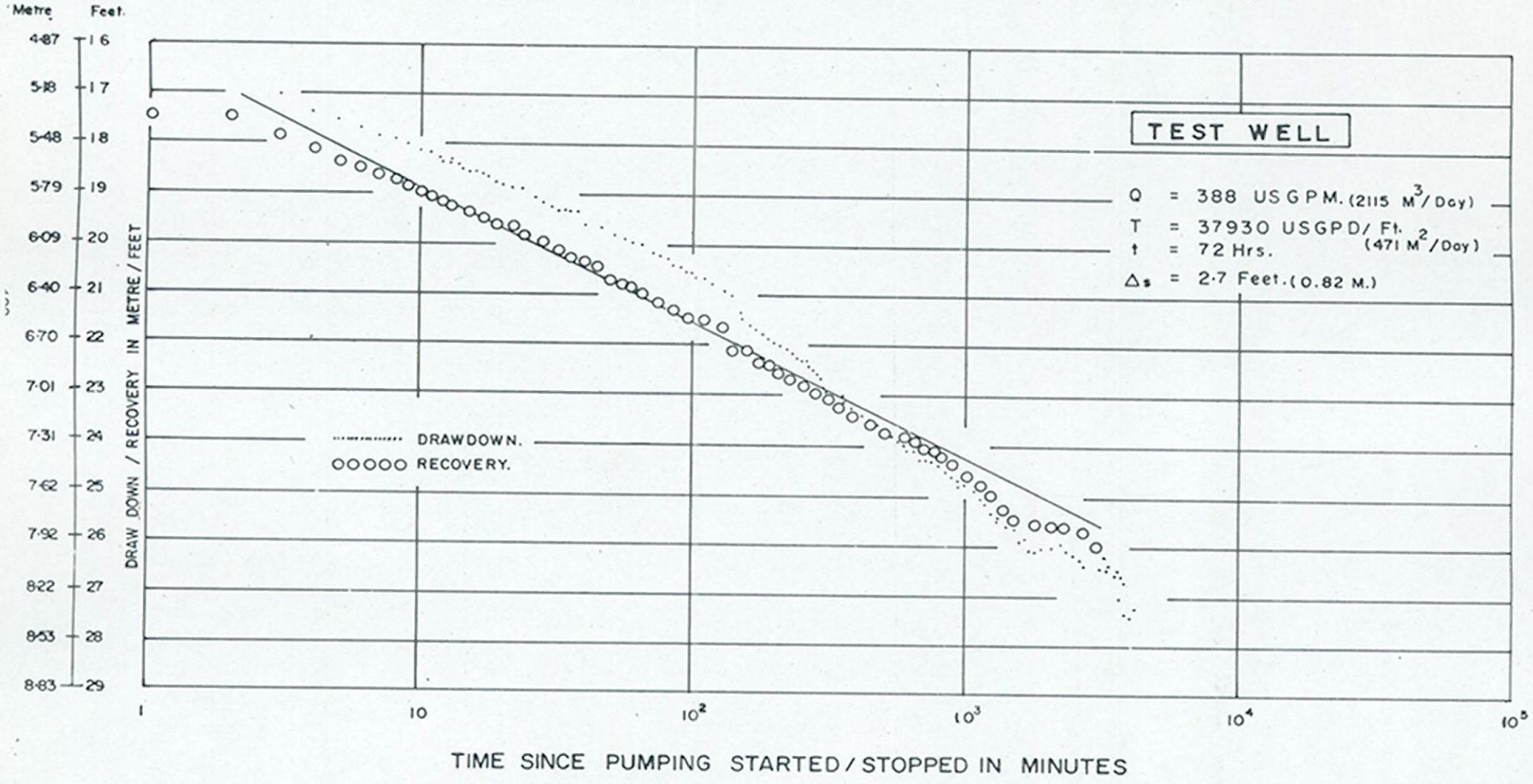


Figure 46

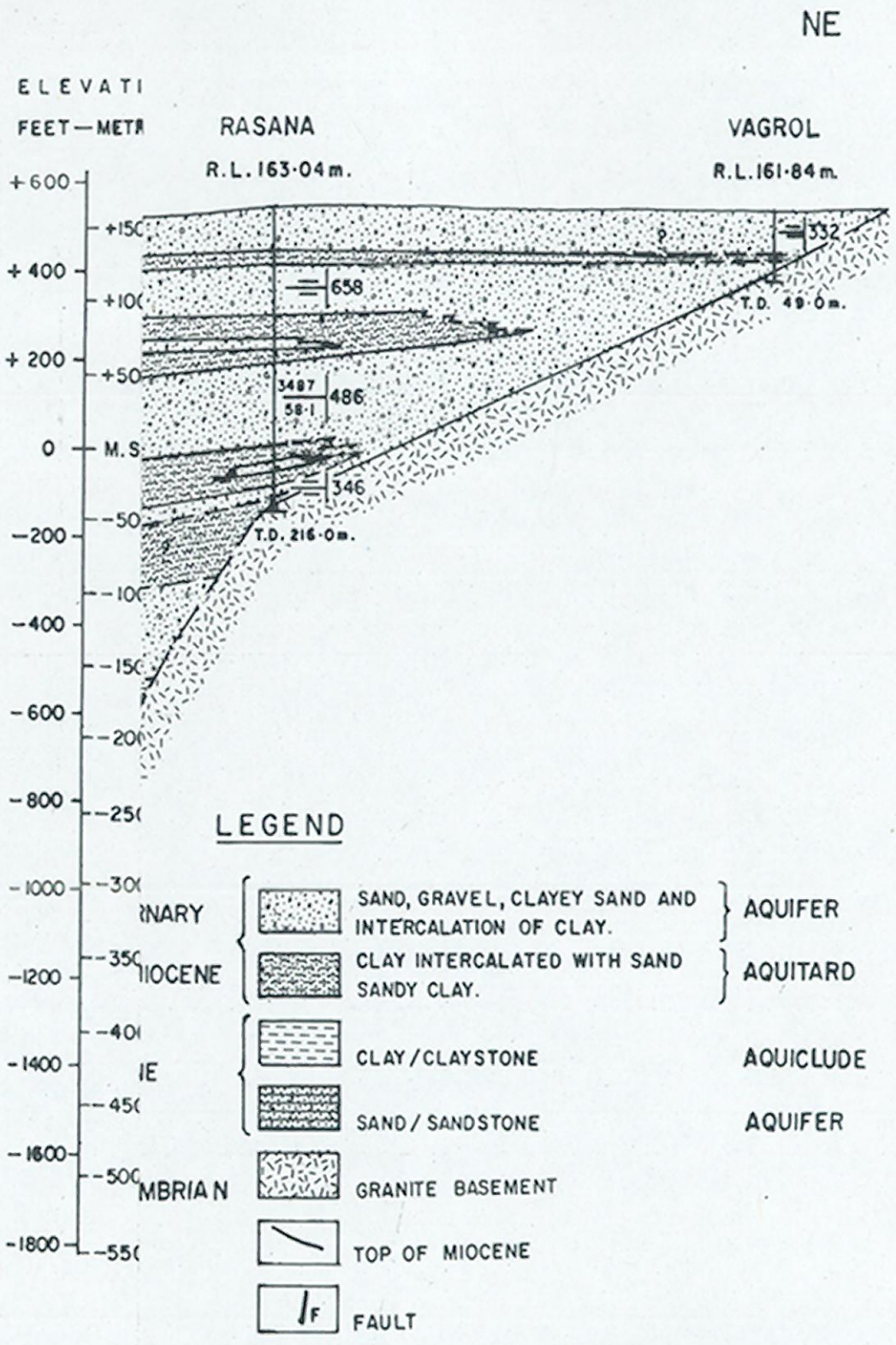

NE
ELEVATI
FEET—METR
RASANA
R.L. 163·04 m.
VAGROL
R.L. 161·84 m.
+600
+400
+200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
M.S
658
332
T.D. 49·0 m.
3487
58·1
486
346
T.D. 216·0 m.
LEGEND
SAND, GRAVEL, CLAYEY SAND AND INTERCALATION OF CLAY.
AQUIFER
CLAY INTERCALATED WITH SAND SANDY CLAY.
AQUITARD
CLAY / CLAYSTONE
AQUICLUDE
SAND / SANDSTONE
AQUIFER
GRANITE BASEMENT
TOP OF MIOCENE
F
FAULT

Figure 47

Aquifer C

Aquifer C consists of fine- to medium-grained, and locally coarse-grained, sand with several lenses of yellow clay. In the central part of the area, finer material predominates.

The aquifer is found at depths between 154 and 274 m below surface, and its thickness ranges from 13 to 62 m (table 59). Two wells penetrating this aquifer were tested to determine well and aquifer characteristics (fig. 57 and annex 15). In the Saola well, the thicknessof the aquifer was 23 m. Specific capacity was 21.3 m^2/d. The Charasan well penetrated 24 m of the aquifer, but specific capacity was only 2.8 m^3/h/m and transmissivity was 94 m^2/d.

Because of its greath depth, only a few wells produce water from this aquifer. Salinity of the ground water is variable, but generally highly saline in the western and south-western parts of the area (fig. 47).

The composite log of the Rasana I well (fig. 58) gives a comparative picture of aquifers A, B and C in the north-eastern part of the project area.

Aquifer D

Aquifer D is found in the central and south-western parts of the area. In consists of fine- to medium-grained sand interbedded with sandy clay, Its top is encountered in various part of the area in depths of about 200 to 400 m, and its thickness ranges from 11 to 105 m. Wells show subartesian conditions, with piezometric levels of 3 to 32 m below ground surface. A pumping test was carried out in the Dhinoj well (fig. 59 and annex 15). Specific capacity of the well was 1.3 m^3/h/m, and aquifer transmissivity was 69 m^2/d.

Aquifer E

Fine- to medium-grained sand with sandy clay beds constitute aquifer E. It exists only in the central part of the area and its thickness ranges from 15 to 57 m (fig. 48). It is encountered between depths of 300 and 542 m. Water levels are 5 to 15 m below surface, and water quality is variable. No pumping tests were performed in wells penetrating this aquifer.

Aquifers F and G

The two confined aquifers F and G are found in Miocene deposits, below the grey-clay marker bed defined as upper Miocene (figs. 47-49). They exist in the eastern, central and south-western parts of the area. The sediments are fine- to medium-grained sand and sandstone, interbedded with clay, claystone and siltstone. The thickness of these aquifers ranges from 7 to 68 m and 9 to 124 m, respectively.

In both aquifers, sub-artesian conditions prevail in the eastern part, and artesian conditions in the central part, where piezometric heads are more than 20 m above ground surface.

The aquifers are found in 200 to 574 m depth. Well tests were performed at three sites (Charasan PH III, Charasan PH I and Pilwai TH, see annex 16). Hydraulic parameters were computed according to the Jacob-Lohman method. Specific capacities (1.1 m^3/h/m, 1.7 m^3/h/m) and transmissivities (59 m^2/d, 70 m^2/d) are low. Water quality is variable. The aquifer has so far (1975) not been exploited.

Aquifer H

Aquifer H exists only on the north-eastern edge of the Cambay basin, corresponding to the eastern part of the project area. It consists of poorly cemented sandstone, shale and conglomerate, of 98 to 145 m thickness, known as Himatnagar Sandstone. This formation lies at depths of 214 to 577 m below the surface and its thickness ranges from 98 to 145 m. The Himatnagar Sandstone crops out on the banks of the Sabarmati River and in other localities in the south-eastern part of the area. Transmissivity and specific capacity as obtained from a test at Mahi were 86 m^2/d and 1.4 m^3/h/m respectively (annex 16). The aquifer at this site is under sub-artesian conditions. The water level is at 17 to 28 m from surface. The quality of the water is good.

Basement complex

Precambrian and Lower Paleozoic granite, volcanic rock and metamorphic gneiss, limestone and schist crop out within a limited zone along the northern and north-eastern boundary of the project area. A small amount of water is associated with joints, fractures and weathered material. These formations are of no practical interest as sources for irrigation water.

E. Chemical characteristics of ground water

Analyses of ground-water samples from the Gujarat area are presented in annexes 18-22. Many wells were repeatedly sampled in order to determine whether the water changes quality.

From the points of view of ground-water quality, and hydrochemical character of ground water, the project area can be divided into three distinct zones:

(1) A north-eastern zone, characterized by fresh water of bicarbonate type with TDS less than 1,000 ppm;

(2) A central zone, with water of a mixed, bicarbonate-chloride type, with up to 3,000 ppm, TDS;

(3) A south-western zone, with water containing more than 3,000 ppm TDS, generally of chloride type.

A progressive deterioration of water quality in a south-western direction is noted in the phreatic aquifer and in confined aquifer B (figs. 60 and 61).

Differences in the geochemical character of ground water from the different aquifers are graphically presented on separate Hill-Piper diagrams for water samples from aquifer A, aquifer B, and the deeper confined aquifers (figs. 62-64).

Water in the north-eastern zone is mostly in equilibrium with the calcium carbonate. This characteristic feature is fading in the water of aquifer A in the central zone and disappearing farther westwards.

The excess of sodium ion over chloride ion in some water samples indicates that some of the calcium of the ground water has been exchanged against sodium associated with clay minerals.

The origin of the salts contained in the more saline ground water is believed to be aeolian. Sea water entering the Rann of Kutch at times of high tides, and strong winds during the monsoon season, is probably the source of the high salinity of ground water in the south-western part of the project area. Unusually high nitrate content in water from dug wells is probably due to pollution of the phreatic aquifer. Fluoride concentrations slightly above the mean regional values may originate from the weathering of micas. In dug wells, fluoride content varies from the permissible limit (1.5 ppm) to 4.0 ppm. An unusually high fluoride content (7.88 ppm) was found in only one dug well. Water from tubewells is generally within the permissible limits for fluoride.

Ground water in the north-eastern, eastern and southern part of the project area, where total salinity remains below 1,000 ppm, is well within the limits set by WHO for human consumptions. In other parts of the area, much of the ground water in the phreatic aquifer exceeds this limit.

Ground water quality in relation to irrigation is discussed in the section of Pedology, Land and Water Use (III-G.6).

F. Ground-water resources

1. Analysis of seasonal water-level fluctuations

As in Rajasthan, the average seasonal rise of the water level during the three-year observation period (1971-1973) was considered representative for long-term average conditions, because average rainfall during this period was close to normal (about 10 per cent less). An average specific yield of 7 per cent was used for the entire area to compute the recharge for each grid and Tehsil (table 60). The average annual ground-water recharge obtained is 72 mm, or 10 per cent of the average rainfall over the area during the three years observation period. The corresponding volume of recharge over the project area is 790 MCM.

The annual ground-water increment to the confined aquifers was computed on the basis of transmissivity and hydraulic gradients in the north-eastern zone, where the phreatic and confined aquifers merge. The annual volume of replenishment of the confined aquifers thus obtained is 70 MCM.

2. Ground-water recharge according to soil moisture balance

Long-term monthly evapotranspiration data from Ahmadabad served for the computation of actual evapotranspiration.

A soil moisture holding capacity of 100 mm for sandy soils and 200 mm for sandy loam, saline and alkaline soils was adopted for the purpose of the balance computations. Sandy soils predominate in the north-eastern and centrals parts of the project area and loamy soils in the southern and south-western parts.

The project area is divided into three zones differing in rainfall, runoff and soil characteristics:

(1) A north-eastern zone with relatively high rainfall and sandy soils (100 mm available moisture holding capacity). Water surplus calculated for Deesa and Idar is representative for this zone. Runoff from Deesa, Bakhudar and Dantivada stations have been used in the balance computations;

(2) A central zone, with lower rainfall and sandy soils (100 mm AMHC). Data from Patan, Chanasma and Deesa have been selected as representative for this zone;

(3) A southern-south-western zone, with relatively high rainfall, 200 mm available moisture holding capacity, sandy loam and alkaline and saline soils. Data for Ahmadabad were used for evaporation, and data from Dharoi and Ahmadabad for runoff.

The results of the recharge computations are shown in table 62 and summarized in table 61.

The results show - as could be expected - that recharge is higher in the north-eastern zone than in the central southern and south-western zones.

Although average annual rainfall for the three-years balance period (1971-1973) is slightly less (10 per cent) than the long-term average, the recharge for these three years (108 mm) is slightly higher than the average for thirteen years (96 mm,

TIME-DRAWDOWN/RECOVERY CURVE - DHINOJ (AQUIFER D)

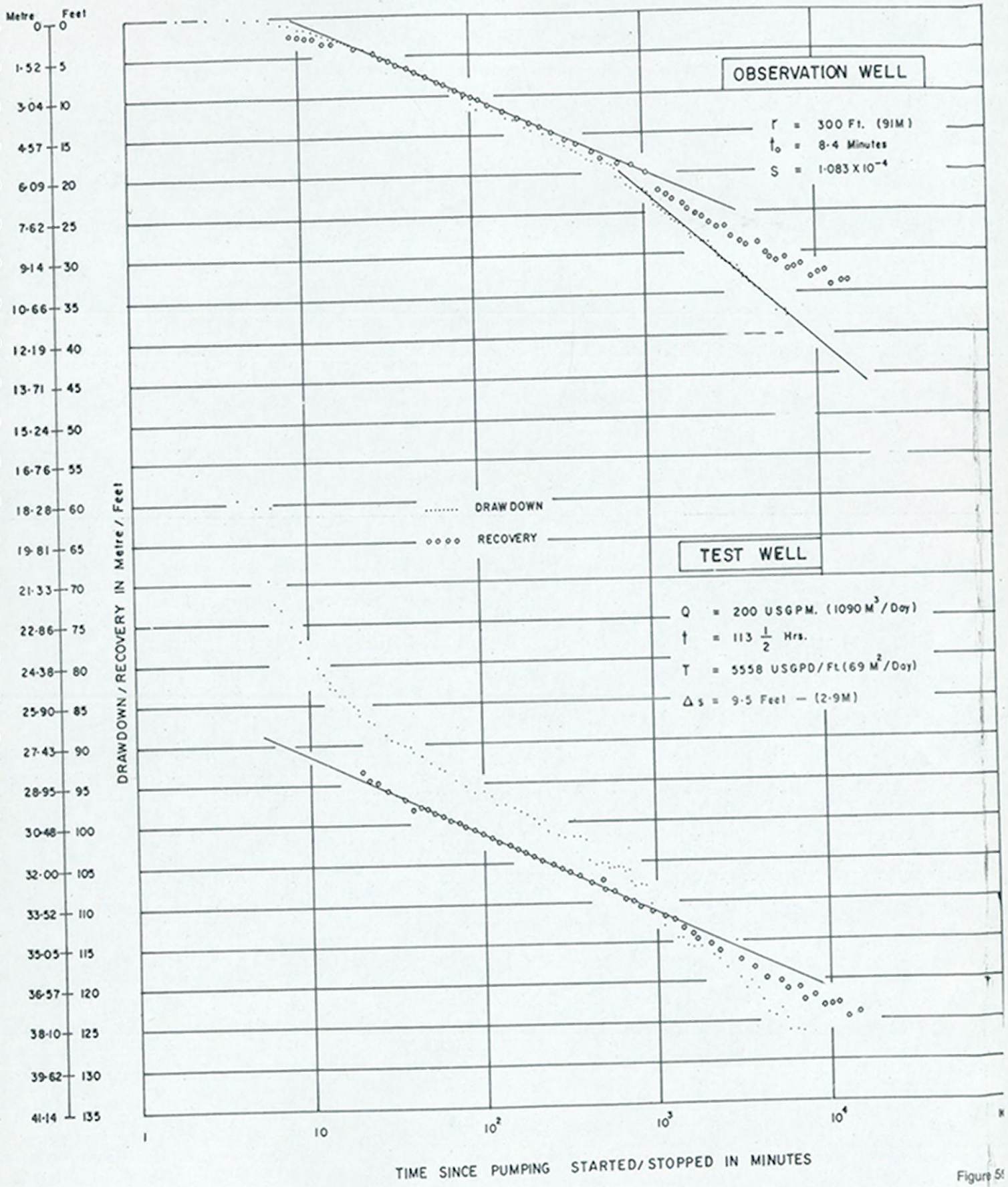
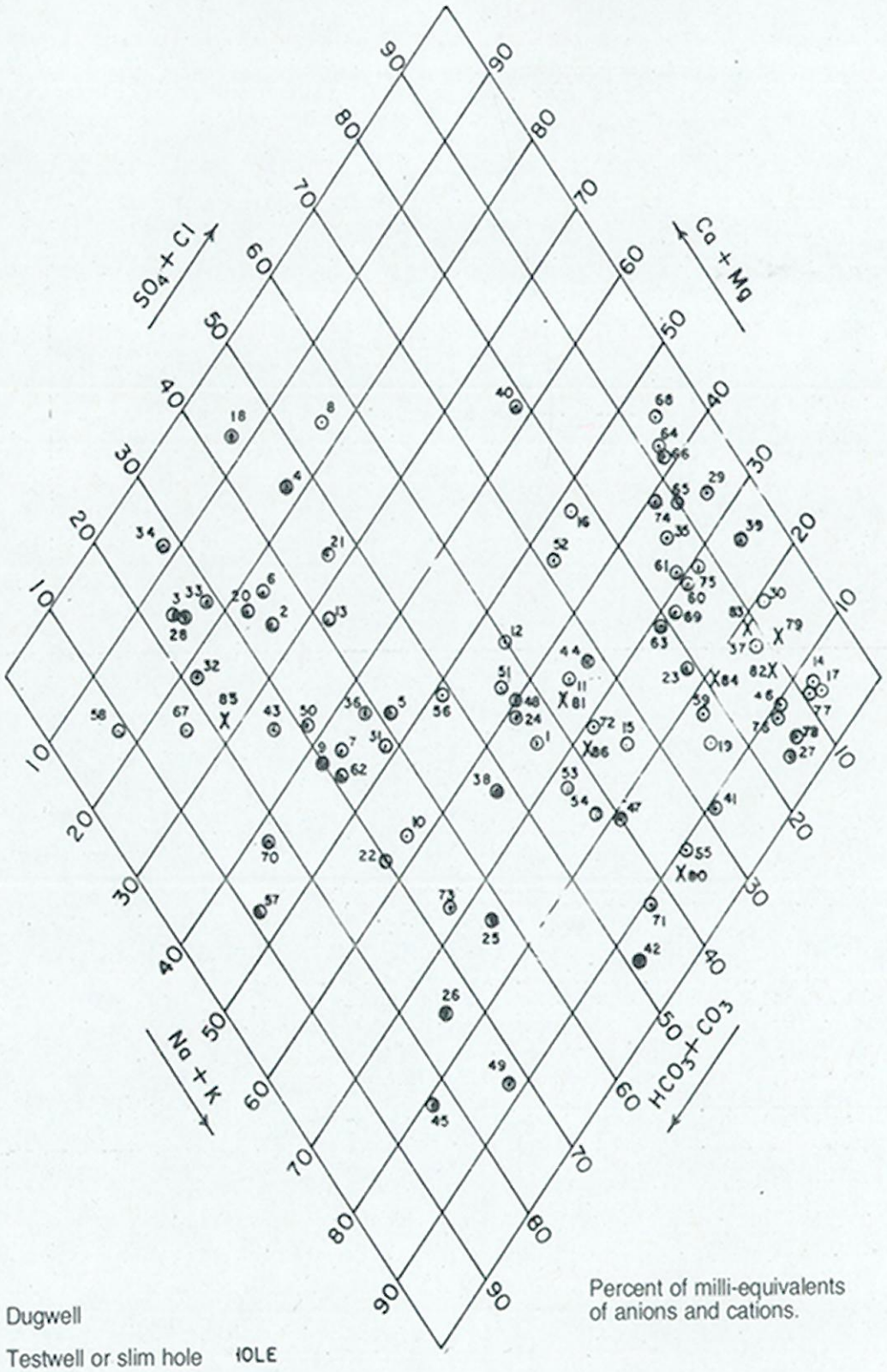


Figure 5



Percent of milli-equivalents of anions and cations.

⊙ Dugwell

X Testwell or slim hole HOLE

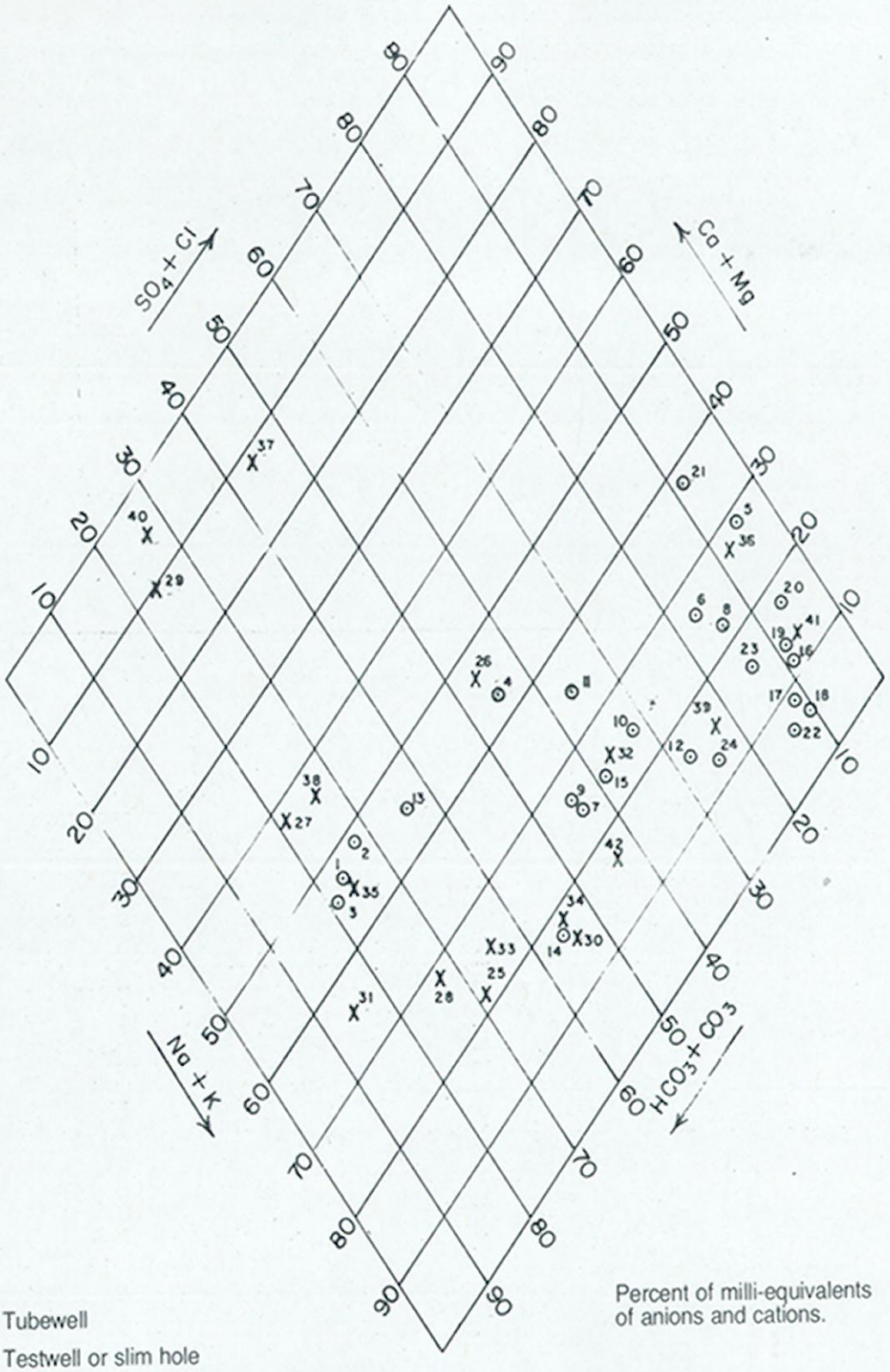
CHEMICAL CLASSIFICATION OF GROUNDWATER SAMPLES

(Hill-Piper Diagram)

AQUIFER 'A'

GUJARAT PROJECT AREA

Figure 62



⊙ Tubewell

X Testwell or slim hole

Percent of milli-equivalents of anions and cations.

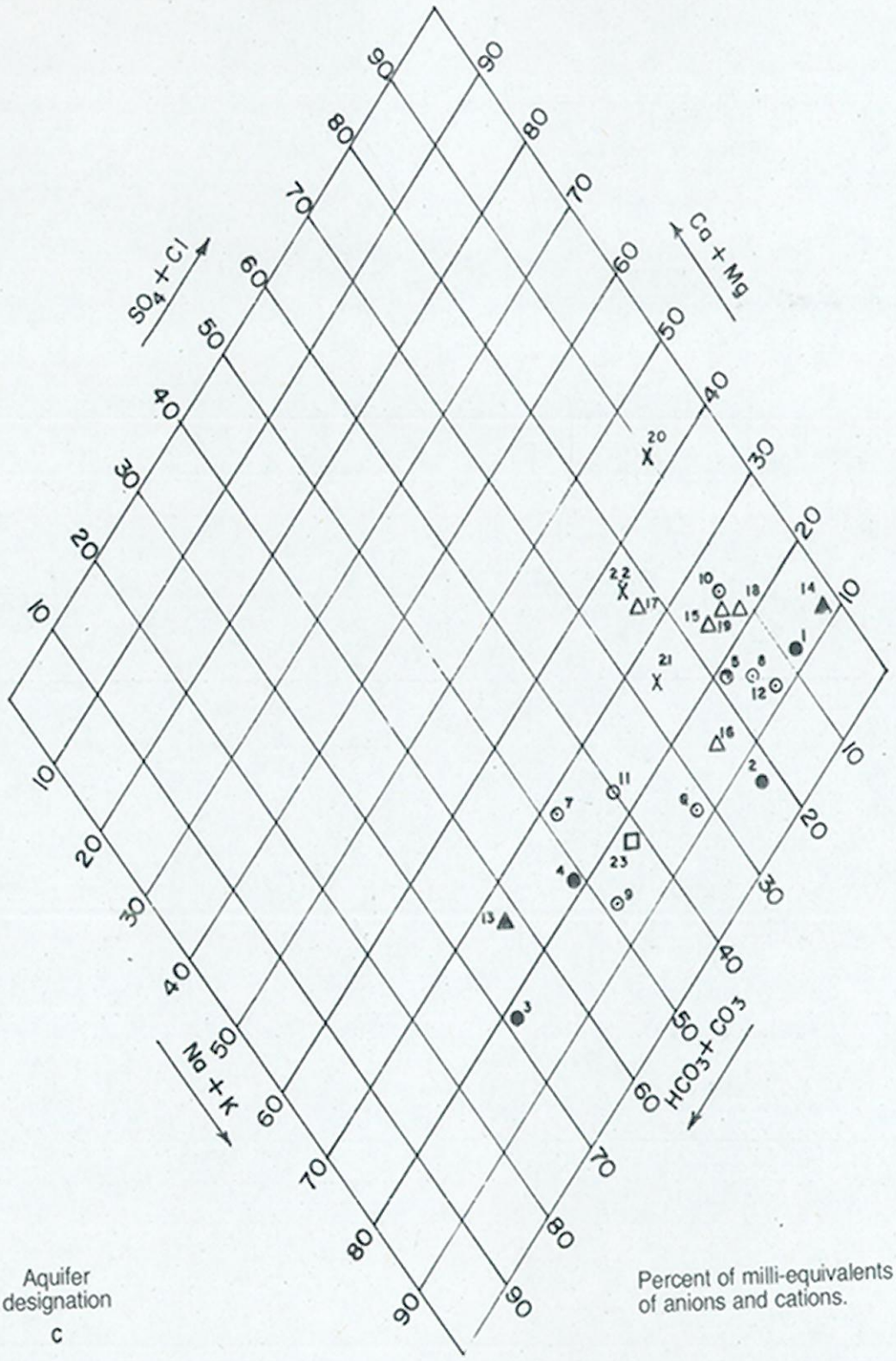
CHEMICAL CLASSIFICATION OF GROUNDWATER SAMPLES

(Hill-Piper Diagram)

AQUIFER 'B'

GUJARAT PROJECT AREA

Figure 63



CHEMICAL CLASSIFICATION OF GROUNDWATER SAMPLES

(Hill-Piper Diagram)

DEEPER AQUIFERS

GUJARAT PROJECT AREA

Figure 64

Table 60. Recharge, draft and available ground-water resources, aquifer A, Gujarat area

District	Tehsil	Area excluding basement (km^2)	Recharge 1971 (m)	Recharge 1971 (MCM)	Recharge 1972 (m)	Recharge 1972 (MCM)	Recharge 1973 (m)	Recharge 1973 (MCM)	Average 1971-73 (m)	Average 1971-73 (MCM)	Net pumpage from aquifer "A" (MCM)	Available water resources aquifer "A" aver. 71-73 (MCM)	General trend 1971-74 (June) rise/fall + - (m)
Banaskantha	Deesa	337	0.032	10.78	0.023	7.75	0.053	17.86	0.036	12.13	10.01	+ 2.12	+ 0.25
	Palanpur	912	0.058	52.95	0.039	35.61	0.152	138.78	0.083	75.78	72.47	+ 3.37	+ 0.59
	Vadgam	550	0.062	34.10	0.040	22.00	0.181	99.55	0.094	51.70	54.76	- 3.06	+ 0.19
	Danta	176	0.059	10.38	0.027	4.75	0.186	23.94	0.074	13.02	10.13	+ 2.89	+ 0.36
	Kankrej	207	0.058	12.00	0.029	6.00	0.066	13.66	0.052	10.76	4.82	+ 5.94	+ 0.36
	Total	2183		120.21		76.11		293.79	0.075	163.39	152.19	+ 11.26	
Mehsana	Patan	1047	0.076	79.57	0.048	50.26	0.115	120.40	0.080	83.76	38.31	+ 45.45	+ 0.37
	Sidhpur	671	0.090	60.39	0.043	28.53	0.097	65.09	0.076	51.00	49.17	+ 1.83	- 0.14
	Kheralu	871	0.057	49.65	0.030	26.13	0.140	121.94	0.076	66.20	65.97	+ 0.23	+ 0.09
	Vijapur	940	0.078	73.32	0.038	35.72	0.130	122.20	0.083	78.02	86.74	- 8.72	- 1.43
	Visnagar	488	0.077	37.58	0.047	22.94	0.110	53.68	0.079	38.55	35.87	+ 2.68	- 0.70
	Mehsana	791	0.061	48.25	0.038	30.06	0.096	75.94	0.065	51.41	68.75	- 17.34	- 1.74
	Chanasma	887	0.079	70.07	0.047	41.69	0.094	83.38	0.073	64.75	4.55	+ 60.20	- 0.30
	Harij	407	0.074	30.12	0.034	13.84	0.108	43.96	0.072	29.30	8.88	+ 20.42	+ 0.41
	Sami	1510	0.070	105.70	0.062	93.62	0.087	131.37	0.073	10.23	5.78	+104.45	+ 0.46
	Kadi	593	0.025	14.82	0.024	14.23	0.087	51.59	0.045	26.68	49.75	- 23.07	- 1.70
	Kalol	553	0.027	14.93	0.025	13.82	0.093	51.43	0.048	26.54	31.01	- 4.47	- 1.97
	Total	8758		584.40		370.84		920.98	0.072	626.44	444.78	+181.66	-
	Grand total	10941		705		447		1215	0.072	790.00	597.00	+193	-

Table 61. Summary of annual water surplus, Gujarat

Zone	Area excluding soil moisture		Average annual recharge				Extreme annual values	
	Basement zone (km)	Storage capacity (mm)	1961-1973 (mm)	1961-1973 (MCM)	1971-1973 (mm)	1971-1973 (MCM)	min. (mm)	max. (mm)
North-east	1,600	100	116	186	181	290	0	396
Central	5,260	100	111	584	123	647	0	198
South-south-west	4,080	200	69	282	61	249	0	357
Total plain	10,940	-	96	1,052	108	1,186	0	-

1961-1973). This is explained by the exceptionally high rainfall and favourable rainfall distribution in 1973.

3. Ground-water withdrawals

Computations of pumpage for irrigation have been made by using the following methods:

(i) Determination of number of wells for each tehsil and mode of discharge (mote, oil engine, electric motor), daily pumping hours and period of irrigation;

(ii) Determination of area on which certain crops are grown and their water requirements (more specifically, number of irrigations and amount of water applied for each irrigation).

The first method gives the most accurate water draft figure and the second method was used only as a comparative tool. Basic data were collected from the irrigation department of each tehsil (taluka) and from the state government agencies. Figures for the average discharge of the various types of wells were obtained from local enquiries, sample survey and discussion with government officials. It was found that the average daily pumping time is six to eight hours and about 800 hours per irrigation season. The average discharge of tubewells fitted with electric motor or oil engine, pumping water from confined aquifer B was estimated at 45 m/h. An average discharge of dug-cum-bored well fitted with electric motor or oil engine was estimated at 23 m^3/h and average discharge of a dug well by the mote method is 4.5 m/h.

Annual volumes of water withdrawn were computed separately from the phreatic aquifer A and for the confined aquifer B (table 63).

The figures obtained for pumpage from aquifer A by the two methods - 857 MCM and 770 MCM - are in reasonable agreement. Draft from aquifer B is estimated at 89 MCM.

Return flow from irrigation was taken as 20 to 35 per cent, depending upon soil types, and was deducted from the volumes pumped from the phreatic aquifer A. Net withdrawals from this aquifer for irrigation are therefore 556 MCM per year. To this, human and animal consumption of 41 MCM must be added to obtain the total net withdrawals from the phreatic aquifer, amounting to 597 MCM.

4. Potential for additional development

The difference between mean annual recharge and present withdrawals is defined as a renewable water resource which can be exploited without depleting the ground-water reservoir.

Thus, the difference between the mean annual recharge of 790 MCM and the present net withdrawals of 597 MCM, or 193 MCM per year, can be considered as additional development potential, to be derived from aquifer A (see table 60). Because of water-quality considerations, however, not all of this water can be used (table 64).

In Gujarat, water with a total salinity of more than 2,000 ppm is, with few exceptions, not used for irrigation. However, certain crops can be grown under irrigation with water of up to 5,000 ppm TDS. The potential for additional development of ground water of up to 5,000 ppm salinity is estimated at 135 MCM per year.

About 90 per cent of this potential is located in the western and south-western parts of the project area where soils are loamy and alkaline, and only relatively fresh water, with a salinity no greater than 2,000 ppm TDS should be used on these soils. About 86 per cent (36 MCM) of the additional ground water with less than 2,000 ppm TDS available for development is located in this area and could be used for irrigation if proper drainage is provided for.

The volume of water with 2,000-3,000 ppm TDS available for development amounts to 53 MCM. Most of these resources (98 per cent) are located

Table 62. Annual water surplus from soil moisture balance computations, Gujarat

Year	AHMADABAD			PATAN				IDAR			DEESA			CHANASMA		
	Annual rainfall (mm)	Annual runoff (mm)	Recharge (soil storage capacity) (200 mm)	Annual rainfall (mm)	Annual runoff (mm)	Recharge (soil storage capacity) (100 mm)	Recharge (soil storage capacity) (200 mm)	Annual rain fall (mm)	Annual runoff (mm)	Recharge (soil storage capacity) (100 mm)	Annual rainfall (mm)	Annual runoff (mm)	Recharge (soil storage capacity) (100 mm)	Annual rainfall (mm)	Annual runoff (mm)	Recharge (soil storage capacity) (100 mm)
1961	831	305	0	784	148	179	92	*972	465	-	943	183	358			
1962	757	154	105	317	33	55	0	605	287	0	250	0	10			
1963	915	204	264	599	131	174	77	1264	673	158	495	328	0			
1964	698	116	88	446	69	27	0	662	252	0	448	63	74			
1965	456	52	0	*440	110	-	-	665	314	21	428	76	49			
1966	609	19	168	322	10	21	0	598	229	0	490	35	159			
1967	986	81	357	757	77	173	79	749	195	0	894	254	352			
1968	392	67	5	388	159	0	0	645	202	232	-	-	-			
1969	470	12	38	212	8	0	0	469	33	23	280	16	61			
1970	1222	308	324	510	33	198	116	1050	445	139	454	66	35			
1971	478	31	44	491	43	115	26	726	134	189	384	60	10			
1972	345	10	0	412	15	163	43	758	66	396	341	31	89	406	8	157
1973	1045	279	213	753	77	171	74	1324	709	217	938	208	189	648	31	219
Average	708	126	124	495	66 (70)**	106	42	807	295 304**	115	529	110	116	527	20	188

* Daily rainfall data not available

** Including runoff of the year without daily rainfall data

Table 63. Ground-water draft data, Gujarat area

District	Tehsil	Area		Under irrigation	Tubewells (Aquifer B)		Dug-cum-bored wells		Dug wells		Draft according to aquifers			Return flow		Net draft from aquifer A	People and livestock consumption	Net total draft	
		Total (km^2)	Without basement (km^2)	(km^2)	No.of wells	Draft (MCM)	No.of wells	Draft (MCM)	No.of wells	Draft wells	Aquifer B (MCM)	Aquifer A (MCM)	Total A+B (MCM)	%	(MCM)	(MCM)	(MCM)	Aquifer A incl.human consumption (MCM)	Aquifers A+B (MCM)
Banaskantha	Deesa	337	312	55	6	0.22	700	12.88	476	1.71	0.22	14.59	15.03	35	5.26	9.33	0.68	10.01	10.23
	Palanpur	1124	913	206	3	0.11	3132	75.17	6483	31.12	0.11	106.29	106.40	35	37.24	69.05	3.42	72.47	72.58
	Vadgan	565	550	161	4	0.14	4312	79.34	587	2.11	0.14	81.45	81.59	35	28.56	52.89	1.87	54.76	54.90
	Danta	485	176	69	-	-	307	5.65	2359	8.49	-	14.14	14.14	35	4.95	9.19	0.94	10.13	10.13
	Kankrej	207	260	26	30	1.10	300	5.52	360	1.73	1.10	7.25	8.35	35	2.92	4.33	0.49	4.82	5.92
	Total	2718	2211	517	43	1.57	8751	178.56	10265	45.16	1.57	223.72	225.29		78.93	144.79	7.40	152.19	153.76
Mehsana	Patan	1047	1047	307	225	8.1	2893	53.23	1334	4.80	8.10	58.03	66.13	35	23.15	34.88	3.43	38.31	46.41
	Sidhpur	671	671	162	218	7.85	2280	54.72	5324	19.16	7.85	73.88	81.73	35	28.61	45.24	3.90	49.17	57.02
	Kheralu	953	871	131	26	0.94	3429	63.09	9344	33.64	0.94	96.73	97.67	35	34.18	62.55	3.42	65.97	66.91
	Vijapur	940	940	368	168	6.05	5230	96.23	9056	32.60	6.05	128.83	134.88	35	47.21	81.62	5.12	86.74	92.79
	Visnagar	488	488	197	341	15.35	1650	49.50	863	4.51	15.35	54.01	69.36	30	20.81	33.20	2.67	35.87	51.22
	Mehsana	791	791	302	343	12.35	4295	79.03	5176	18.63	12.35	97.66	110.01	30	33.00	64.66	4.09	68.75	81.10
	Chanasma	887	887	123	498	17.93	490	9.02	286	1.03	17.93	10.05	27.98	30	8.39	1.66	2.89	4.55	22.48
	Harij	407	407	69	138	4.97	608	11.19	-	-	4.97	11.19	16.16	20	3.23	7.96	0.92	8.88	13.85
	Samil	1510	1510	30	22	0.79	292	5.37	7	0.03	0.79	5.40	6.19	20	1.24	4.16	1.62	5.78	6.57
	Kadi	593	593	140	141	5.08	2759	50.77	2472	8.90	5.08	59.67	64.75	20	12.95	46.72	3.03	49.75	54.83
	Kalol	553	553	126	242	8.71	1342	24.69	3750	13.50	8.71	38.19	46.90	20	9.38	28.81	2.20	31.01	39.72
	Total	8840	8758	1955	2362	88.12	25268	496.84	37612	136.80	88.12	633.64	721.76		222.15	411.49	33.29	444.78	532.90
	Grand total	11558	10969	2472	2405	89.69	34019	675.40	47877	181.96	89.69	857.36	947.05		301.08	556.28	40.69	597.0	686.66

Aquifer A: i) Dug-cum-bored wells
Estimated average discharge is 23 m^3/hr (30 m^3/hr in Palanpur Tehsil) and average pumping time is 800 h /well/yr (Visnagar 1000 h /well/yr)

ii) Dug wells
Estimated average discharge is 4.5 m^3/hr (6 m^3/hr in Visnagar, Palanpur and Kankrej tehsils) and average pumping time is 800 h /well/yr

Aquifer B: Estimated average discharge of tubewell is 45 m^3/h and total pumping time 800 h /well/yr (1000 h /well/yr in Visnagar tehsil)

Table 64. Summary of additional potential for development, Gujarat

District	less than 2,000 ppm TDS (MCM)	2,000-3,000 ppm TDS (MCM)	3,000-5,000 ppm TDS (MCM)	More than 5,000 ppm TDS (MCM)	Total (MCM)
Banaskantha	8.1	1.3	1.9	-	11.3
Mehsana	35.8	51.9	35.7	58.1	181.5
Total	44 (rounded)	53	38 (rounded)	58	193 (rounded)

also in the south-western and western part of the project area. It is assumed that water of this quality can be used for most crops and for livestock and human consumption. More saline water (3,000-5,000 ppm TDS), of which 38 MCM can be made available, can be used for irrigation only under special soil conditions.

The confined aquifer system receives 70 MCM of mean annual recharge. Present draft from aquifer B amounts to 89 MCM per year. The excessive exploitation makes itself noted in declines of water tables in the central and south-eastern part of the area (fig. 59). Water levels have declined 20 m and more in 14 years (figs. 61 and 65). The deeper confined aquifers do not show good prospects for development because of variable water quality, generally low transmissivity and low specific capacity of wells and considerable drilling depth required (150-580 m). In addition, the influence of pumping from aquifer B is noted in aquifers C, D and E (figs. 51 and 53) because of leakage between these aquifers.

It appears that present draft from aquifers A and B in the central and south-eastern part of the area must be reduced by about 25 per cent in order to prevent further decline of water levels. In the north-eastern, south-western and western parts of the area, water with less than 2,000 ppm TDS can be developed for small local irrigation schemes.

Water that is more saline (2,000-5,000 ppm TDS) can be developed in the south-western and western part of the area, provided that soil conditions are considered, management practices can be improved and economic feasibility can be assured.

5. Mathematical model studies

a. General

A mathematical aquifer model was established for the Gujarat project area, in order to obtain conclusions related to the future management of ground-water resources in this area, or to firm up and better quantify conclusions already available from water balance and other hydrological studies described in the preceding section of this report.

Aquifer simulation techniques using mathematical models have proven to be useful tools for aquifer investigations and management studies, even in cases where available data are lacking in completeness and quality.

In the frame of the present project, this study has also been of value as an important instrument of training.

The mathematical model applied for studying the Gujarat project area uses techniques designed to solve problems related to a multiple-layer aquifer system, with leakage between layers in a part of the area and a zone in which the aquifer is not subdivided, to be called in this report "common zone" (see fig. 66).

The model was programmed in FORTRAN IV language and designed for a large-memory, high-speed computer (IBM 360/44).

b. Theoretical development

In solving the time-dependent equation of flow in an area involving many varying properties such as transmissivity, storativity, recharge and extraction, use is made of the method of finite differences to solve the equation:

$$\nabla \cdot T \nabla h + Q = S(\partial h/\partial t) \qquad (1)$$

This equation is the general parabolic differential equation governing the motion of ground water through porous media. As can be seen, the above equation contains three basic terms: $\nabla \cdot T \nabla h$ is the term which determines subsurface inflow and outflow (from Darcy's law). Q is a flux term incorporating natural inflow, outflow, well extractions, artificial recharge, consumptive use, evapotranspiration and leakage into or out of the system. $S(\partial h/\partial t)$ is simply the term describing the time dependent change of storage. Term one, $(\nabla \cdot T \nabla h)$, is controlled by water-level and piezometric-surface maps combined with transmissivity maps. Term three, $S(\partial h/\partial t)$, is governed by storativity contour maps and, from calculated heads at any time, determines the drawdown at any node. Term two, the flux term Q, is composed of two major terms: net pumping (pumping extraction minus artificial recharge minus return flow from irrigation) and natural inflow (composed of natural

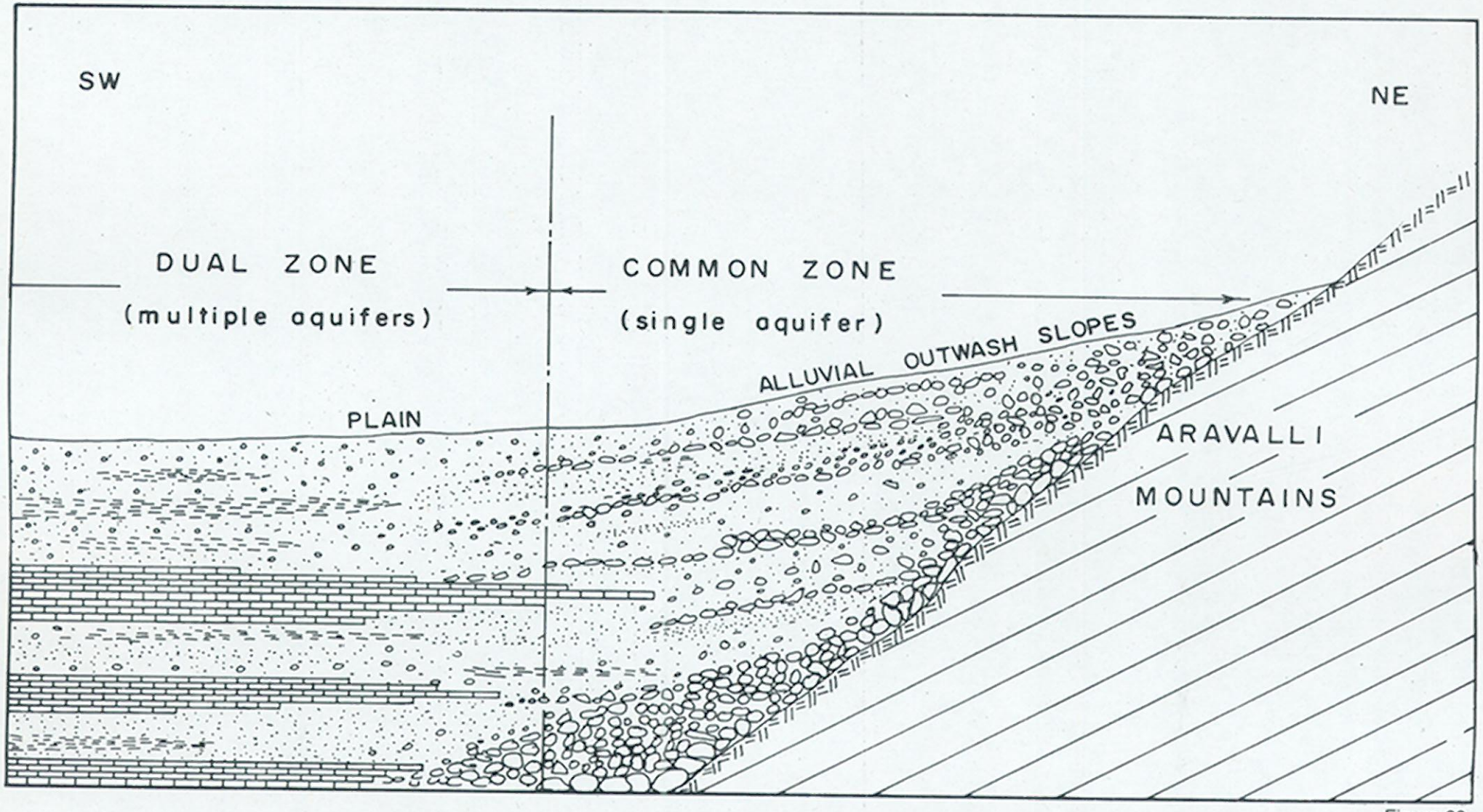


Figure 66

SCHEMATIC SECTION SHOWING DUAL-AQUIFER SYSTEM CONCEPT

subsurface inflow minus outflow plus leakage plus net precipitation minus evapotranspiration). The first major term, net pumping, is coded into the model directly based on selected operations or historical records. The second major term, natural inflow, is obtained from the numerical solution of Poisson's equation, i.e.:

$$\partial/\partial x \{T_x \partial h/\partial x\} + \partial/\partial y \{T_y \partial h/\partial y\} + QQ = 0 \qquad (2)$$

where QQ is the natural inflow. From initial water-level and piezometric-surface maps, along with transmissivity contour maps from each aquifer, Poisson's equation can be solved for the natural flux QQ at each mode. This, in turn, is used as necessary input to equation (1).

This method of QQ input reduces the danger of the water-level and piezometric surface changing in time due to bad guessing at natural influx data. If historical water-level data are available, then an equation of QQ as a function of time could be easily constructed and a more accurate approach to regional ground-water fluctuation obtained.

By generating the natural flux term QQ internally, the model has the capability of recharging itself, so to speak, both during and after cessation of pumping. What this means, for example, is that in all of the model runs where pumping is on for only a portion of the time, recovery of the well fields is directly dependent upon the ability of the natural recharge to "fill in the holes". This fact can be illustrated by comparing the recoveries in areas near the base of the mountains (where natural recharge is high) with the areas away from the mountains where natural recharge is low. It will be noticed in all cases, recovery is much faster in the areas closer to the source of recharge.

The final solution involves solving equation (1) numerically using space-centred central differences and time-centred Crank-Nicholson differencing. The Thomas Algorithm coupled with the Del-Squared Aitken relationship are used to solve the finite difference scheme over the chosen grid network.

The Algorithm solution technique was then programmed into FORTRAN IV language and solves with the aid of an IBM System 360/44 large memory high-speed computer located at the Indian Meteorological Centre on Lodi Road in Delhi.

A detailed treatment of the complete theoretical development is out of the scope of this report, but is available in a supplementary report. 8/

c. Physical description of the model

The Gujarat mathematical model physically consists of a deck of computer cards which translate into machine language a numerical solution technique (algorithm) whereby a simultaneous set of partial differential equations are identified by the method of finite differences and solved by repeated arithmetic calculations with the aid of a high-speed digital computer. The model requires various classes of input which are functions of geohydrologic parameters as well as engineering requirements. Based on a particular set of input, the model will in turn compute the appropriate output for any desired time period.

The Gujarat model consists of two layers, each layer containing 16 nodes in the east-west direction and 14 nodes in the north-south direction. The grid system is square, measuring 10,000 m on each side (fig. 67). It was felt that a grid size of 10,000 by 10,000 m was necessary to model such a large area as is enclosed in the Gujarat project. Any smaller grid size would be incompatible with available data, and any larger grid size would violate the approximations basic to the finite-differencing technique.

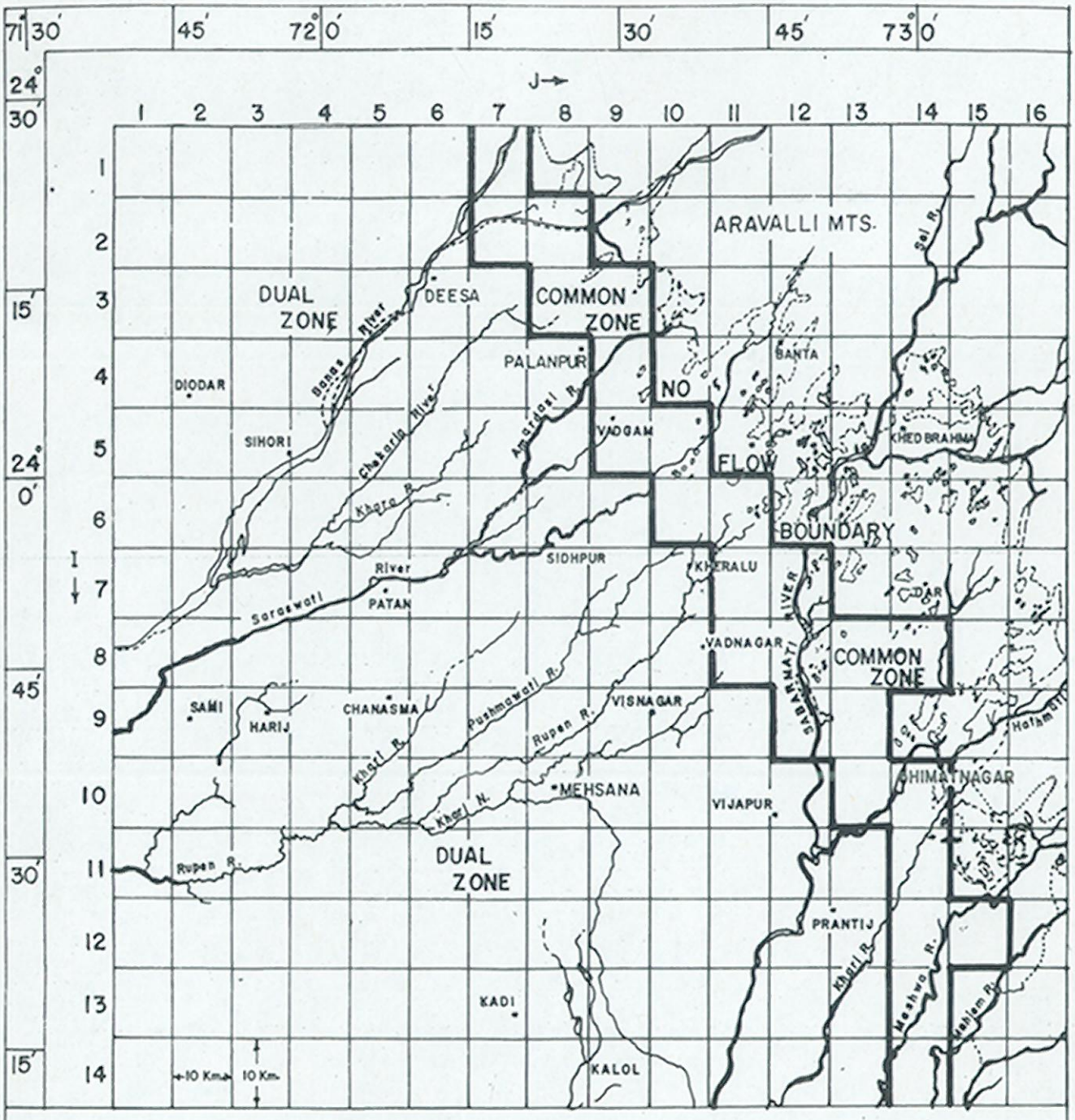
The boundaries of the model were chosen to cover the main portion of the project area and to allow some area between the areas of irrigation development and the model boundaries. This marginal distance was necessary to reduce interference effects from "bounce back" phenomena known to occur if drawdown or mounds reach the physical edge of the model. The north-eastern boundary of the model is the bedrock of the Aravalli mountains. The other boundaries are considered infinite, or open boundaries. In other words, it was assumed that on these boundaries very little water-level changes would be taking place due to hydrologic stresses imposed upon the main pumping and recharge centres.

Figure 68 shows a flow chart of the Gujarat Mathematical Model. As can be seen, the programme is modular, consisting of a main programme and five sub-routines. The source-deck stream can be seen in figure 69.

d. Calibration of model

In mathematical modelling terms, calibration means relating the complex mathematical expressions to the ground-water flow regime as generated by the computer, to the real geologic and hydrologic properties existing in the field. This is usually done by employing the so-called history-

8/ Gujarat Mathematical Model, by Dennis E. Williams, UNDP Consultant, September 1974.



INDIA
GROUNDWATER SURVEYS IN RAJASTHAN & GUJARAT

GUJARAT MATHEMATICAL MODEL
GRID NETWORK
GUJARAT PROJECT AREA

Scale 0 10 20 30 40 Kilometres

Figure 67

SIMPLIFIED FLOW CHART OF THE GUJARAT MATHEMATICAL MODEL

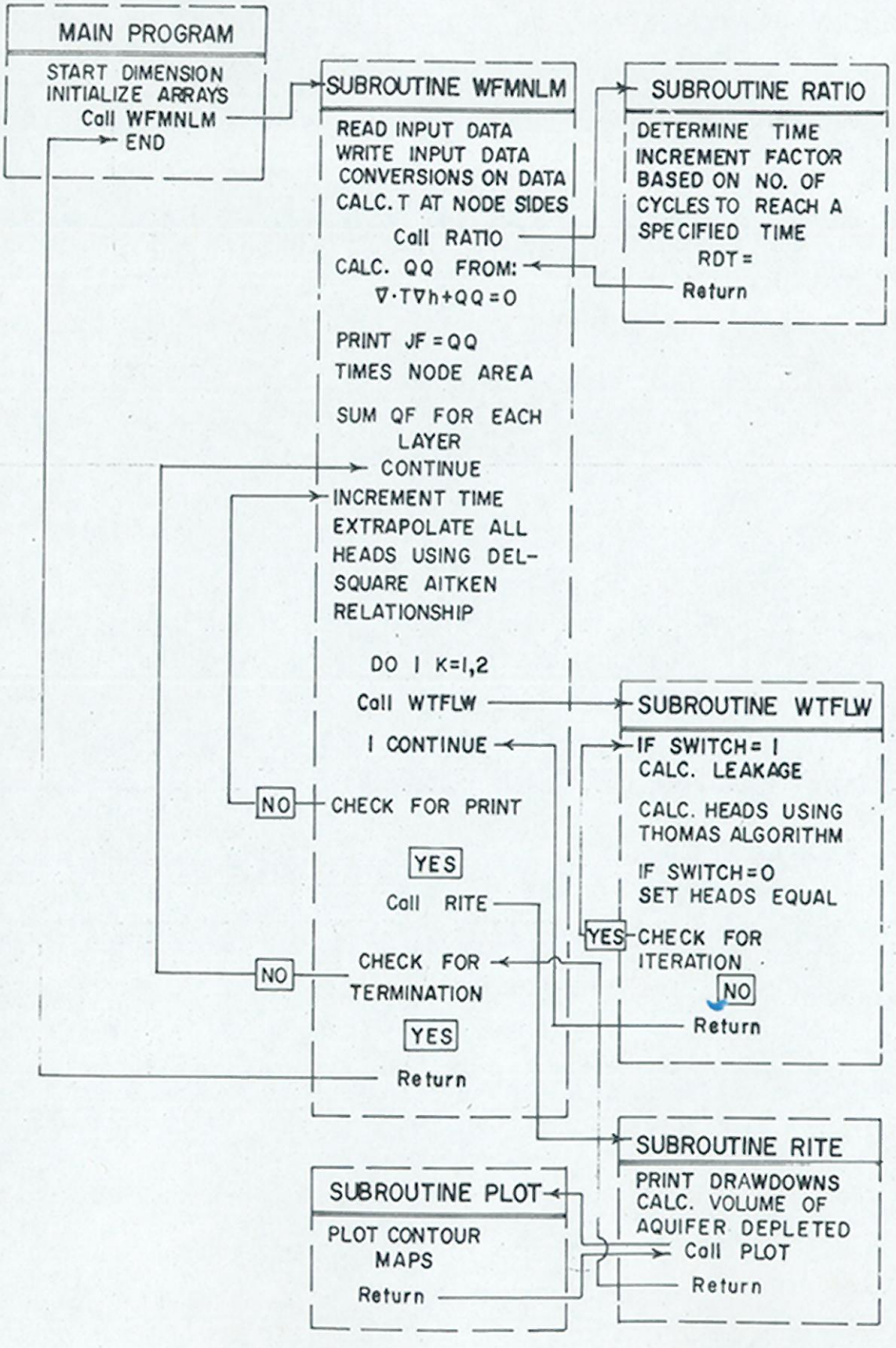
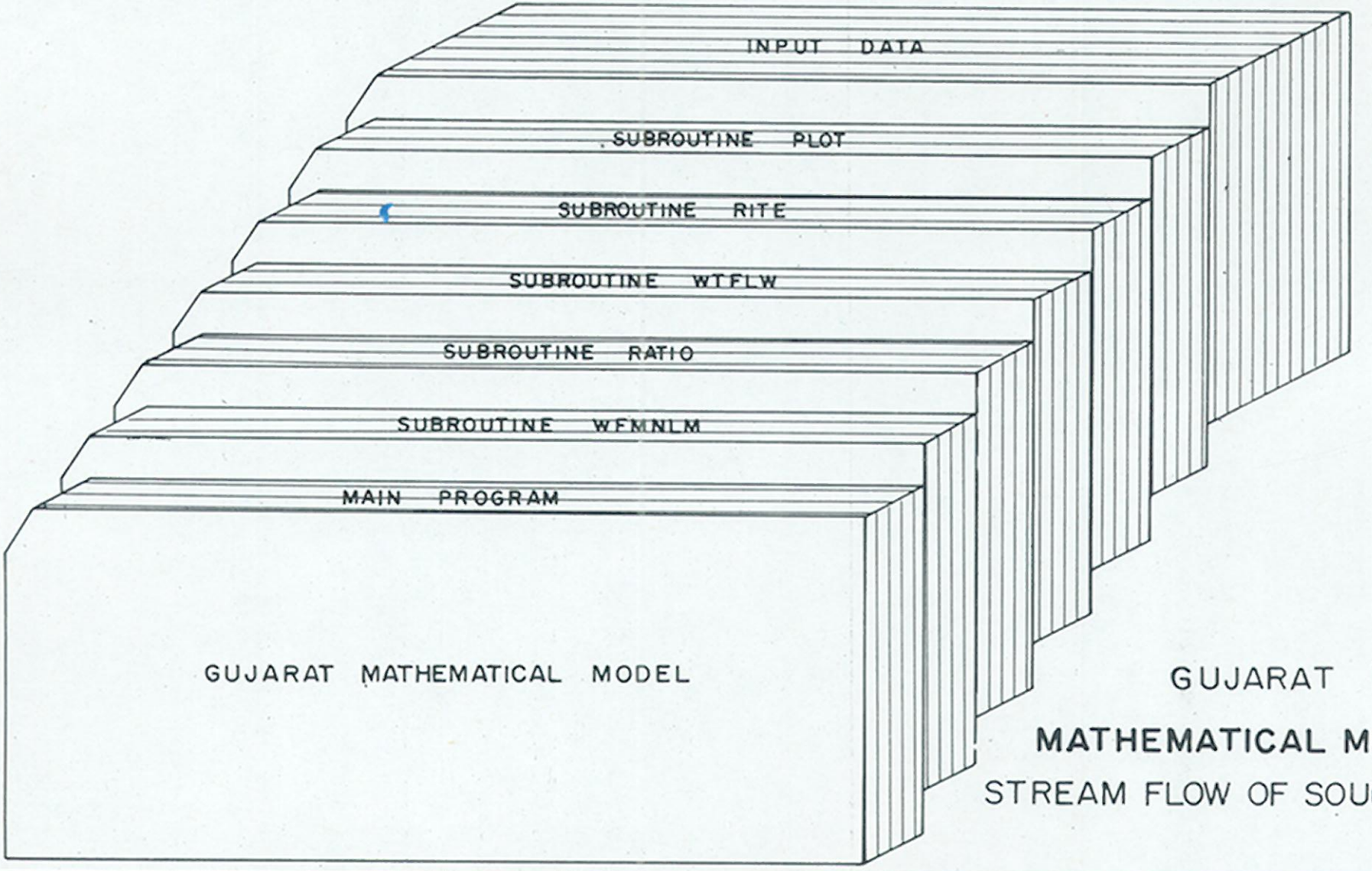


Figure 68



GUJARAT

MATHEMATICAL MODEL

STREAM FLOW OF SOURCE DECK

Figure 69

matching technique. In this technique a representative period of time, known as the calibration period, is chosen and field-measured changes in water levels due to pumping or recharge are mathematically recreated by the computer. Small changes in geohydrologic parameters are made until a reasonable "match" is made between historically measured field values and computer-generated ones. Once the model has been calibrated in this fashion a degree of reliability is established and the model can now be used as a predictive tool for regional ground-water basin management studies.

The period of calibration chosen for the Gujarat area was the 14-year period between 1957 and 1971. Starting water levels were as of 1 March 1957. Pumping values during this time were analysed and extensively refined to obtain "as good as possible" approach to calibration. The pumping input was split into three separate periods:

1. Pre-monsoon pumping (March-June);

2. Monsoon pumping (July-September);

3. Post-monsoon pumping (October-February).

These three pumping periods were coded into the model programme and a switching logic used to provide input for each. (Monsoon pumping was so negligible in most areas that it was assumed to be zero.)

The most recent values of transmissivity, storativity and leakage were coded into each node of the model network. Natural recharge was assumed constant during the calibration period and determined internally from model calculations from the explicit solution of Poisson's equation (III, F, 5, b, equation 2).

Calibration consisted of matching a 14-year computer generated output of water levels and drawdown with those measured in the field during that period of time. Discharges during the calibration period were refined until a reasonable set of values, which could be trusted, were arrived at. Average transmissivities, storativities and leakage coefficient were adjusted until a "match" was forced between the Gujarat field measured water-level data and those data generated by the computer model.

Figures 70 and 71 show computer printouts of the final calibration runs on the Gujarat model. The plates are in the form of regional drawdown contours after 14 years of pumping. Drawdowns start from March 1957 water-level elevations.

e. Ground-water management studies

After completion of its calibration, the ground-water model can be used to investigate a number of problems related to the future exploitation of the aquifers in the Gujarat area:

1. If present pumping in selected areas is reduced, what will be the outcome?

2. Can artificial recharge be employed, and if so, what will be the result on the main pumping centres?

3. Can additional ground water be exploited in high recharge areas (i.e., near the mountain fronts)?

These three major questions are critical to proper management of the Gujarat ground-water basin and operational runs using the calibrated model were made specifically to obtain answers to the questions posed above.

(1) Artificial recharge

During the course of the investigation several operational runs were made with various changes in pumping and recharge patterns. It quickly became apparent that in certain areas (e.g., Mehsana) pumping should be reduced, while in other areas (e.g., near the base of the mountains) more ground water could be exploited. In addition, the effect to be expected from artificial recharge through infiltration ponds in the "common" zone of the aquifer system was tested, under the following assumptions:

1. Surplus water could be made available for regulated and unregulated flow for artificial recharge basins during the post-monsoon months of October-February;

2. These basins would be constructed adjacent to major tributaries in the "common" or recharge zone;

3. An average infiltration rate of 1 metre per day was assumed for estimation purposes. Based on this, the average flow per hectare of recharge area would be:

1 metre/day x 10,000 m^2 ha x 10,001/m
+ 86,400 sec/day = 116 litres/sec/ha.

This value of 116 litres/sec/ha was taken as the artificial recharge unit.

Based on proximity to major tributaries the recharge units were determined as follows:

Grid (I.J.)	Artificial recharge units	Total positive artificial recharge (litres per second)
2,7	2	232
2,8	2	232
3,8	1	116
3,9	1	116
4,9	1	116
5,9	1	116
5,10	2	232
6,10	2	232
6,11	1	116

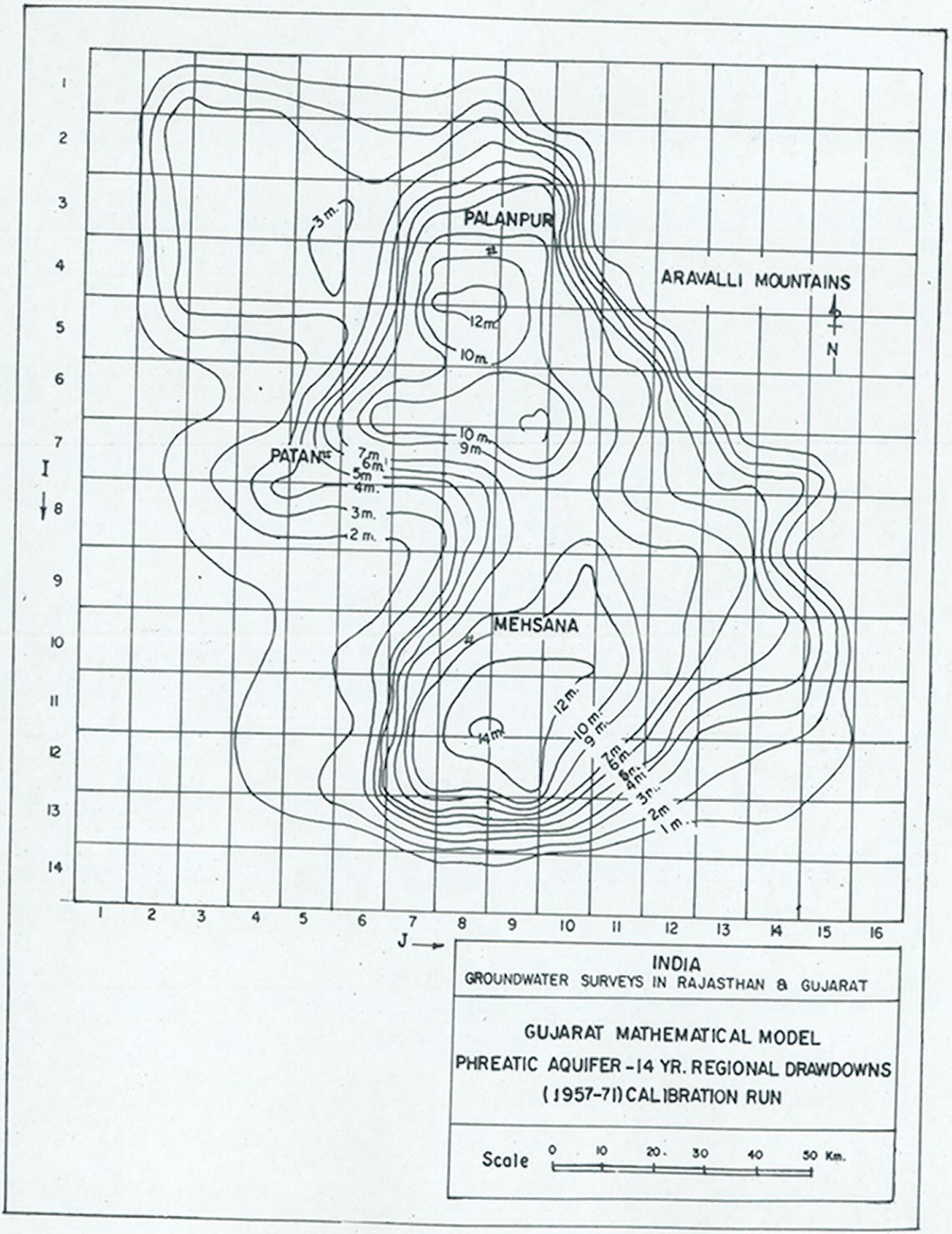

PALANPUR
ARAVALLI MOUNTAINS
N
PATAN
MEHSANA
3m.
12m.
10m.
9m.
7m.
6m.
5m.
4m.
3m.
2m.
14m.
1m.
I
J
INDIA
GROUNDWATER SURVEYS IN RAJASTHAN & GUJARAT
GUJARAT MATHEMATICAL MODEL
PHREATIC AQUIFER - 14 YR. REGIONAL DRAWDOWNS
(1957-71) CALIBRATION RUN
Scale 0 10 20 30 40 50 Km.

Figure 70

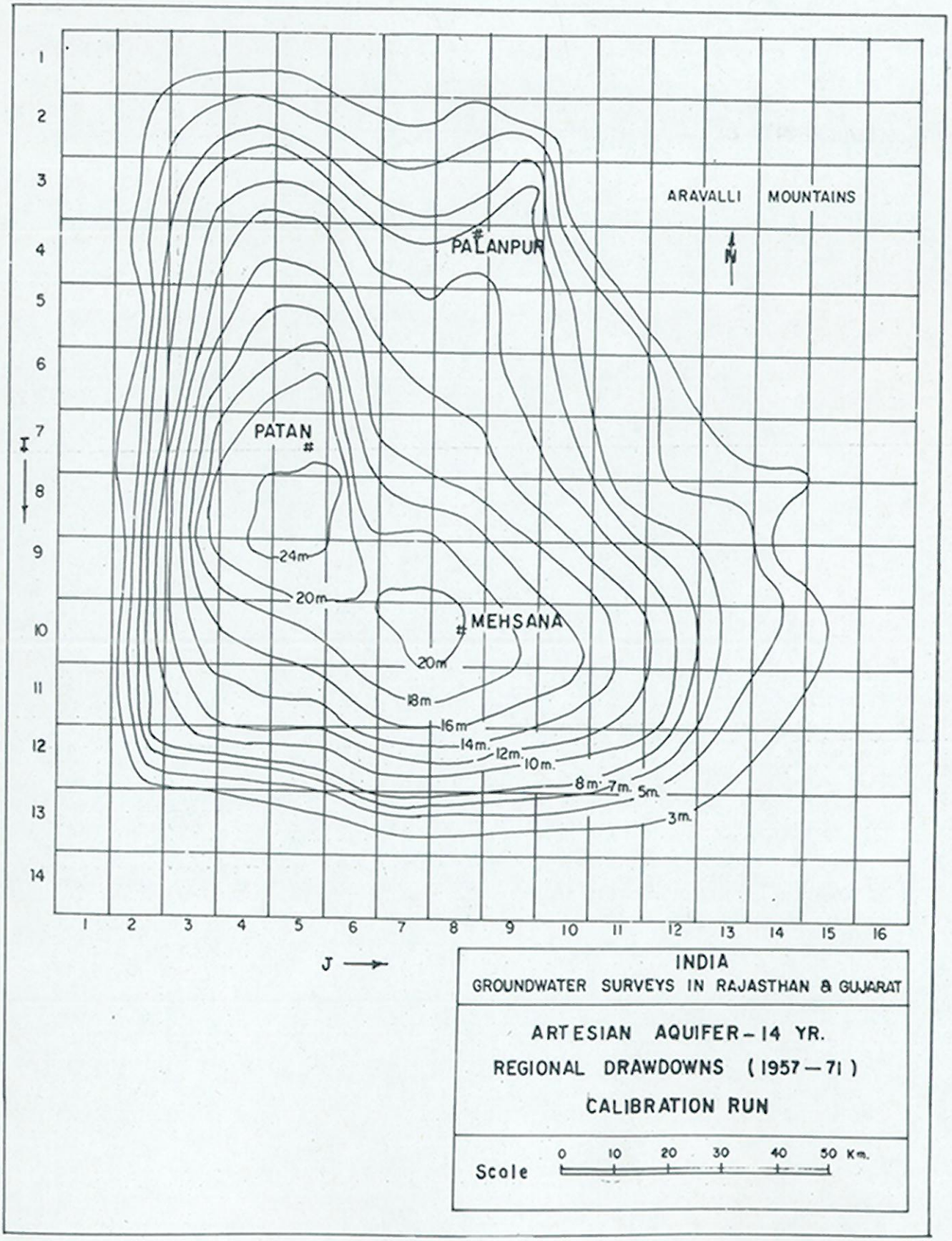

ARAVALLI MOUNTAINS
N
PALANPUR
PATAN
MEHSANA
24m
20m
20m
18m
16m
14m
12m
10m
8m
7m
5m
3m
I
J
1 2 3 4 5 6 7 8 9 10 11 12 13 14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
INDIA
GROUNDWATER SURVEYS IN RAJASTHAN & GUJARAT
ARTESIAN AQUIFER - 14 YR.
REGIONAL DRAWDOWNS (1957 - 71)
CALIBRATION RUN
Scale
0 10 20 30 40 50 Km.

Figure 71

Grid (I.J.) (cont'd)	Artificial recharge units	Total positive artifical recharge (litres per second)
7,11	1	116
7,12	2	232
8,11	1	116
8,12	2	232
9,12	2	232
Total	21	2,436

This recharge amounts to an input of 31.6 MCM during the five-month period.

(2) Additional pumping near the mountains

Owing to the fact that the areas near the base of the mountains have high natural recharge and the aquifer transmissivity is quite high, it was felt that increased production could be affected in this area. Hypothetical well fields therefore were superimposed in three of the nodes and an arbitrary discharge value of 750 litres per second imposed during pre- and post-monsoon pumping seasons.

Grid (I.J.)	Well field discharge (litres per second)
3,8	750.1
6,10	750
8,11	750
Total	2,250.1

This represents an additional well field extraction of 52.5 MCM for the nine-month pumping season.

(3) Reduction in present pumping

Analysis of computer printouts (see figs. 70 and 71) show a need for some reduction in certain areas of the artesian aquifer. It was felt that withdrawal of ground water in the vicinity of Mehsana and Patan should be reduced to prevent further mining of the aquifer.

An arbitrary reduction of 30 per cent in the present artesian pumping was thus imposed on the model in certain areas and the model run for five years starting with November 1973 water-level elevations.

f. Discussion and interpretation results

During the course of the operational runs, many changes in discharge and recharge were tried. Most runs showed excessive drawdown due to imposed pumping patterns with the exception of the operational run entailing the above described reduction of pumpage. These changes (i.e., artificial recharge, decreased pumping near Mehsana and additional well fields near the mountains) proved to be beneficial in the management of the Gujarat ground-water basin. The discussion therefore is limited to explanation and interpretation of the results from that run.

Figures 72 and 73 are contour maps of regional drawdown in the phreatic and artesian aquifers respectively after five years of pumping. It should be noted that maximum drawdown in the phreatic aquifer is only four metres while that of the artesian aquifers has maximum values of 16 metres. It is also interesting to note that the effect of artificial recharge is quite significant in reducing drawdown. This can be noticed by comparison of the contour maps as shown in figures 70 to 73. In figures 72 and 73, the 1-, 2- and 3-metres drawdown contours occur much farther from the base of the mountains owing to the effect of artificial recharge.

Another interesting result from the operational runs is the surprisingly small effect the hypothetical well fields have upon the overall ground-water operation. This of course was suspected from the high natural and artificial recharge near the mountains but was not proved until results from this run were available. Only a slight deflection in the one-metre contour lines in figure 73 suggest that some influence will be noted after five years of exploitation. This last observation opens up many areas for speculation as to the amount of additional pumping which could be affected in the area.

G. Pedology, land and water use

1. Distribution and general characteristics of soils

The soils of the project area fall into five broad groups:

(a) Saline/alkali soils
(b) Calcareous sandy loams
(c) Calcareous sandy soils
(d) Non-calcic brown soils
(e) Non-calcic red-brown soils

The distribution of these soil groups in the area is presented in the soil map (fig. 74);

In general the soils are poor to medium in fertility status and water-retention capacity. Except in the northern part of the project area, vegetation is widespread and cultivable land is planted each year, the main crops being millet, cotton, chili peppers, wheat, castor, barley, pulses and sorghum. About 50 per cent of the irrigation is done on monsoon crops and there is some 50 per cent of double cropping on average. Sheep, goats, draught oxen and camels are numerous. Dairy farming is important mostly in Mehsana district with indigenous cattle and buffaloes.

Most soils have good aeration and porosity and the permeability of the soils is reasonably high, except the alkali soils in the south-western part of the area. Among surface samples, Jadavapura soil has the lowest bulk density of 1.35 and a sample

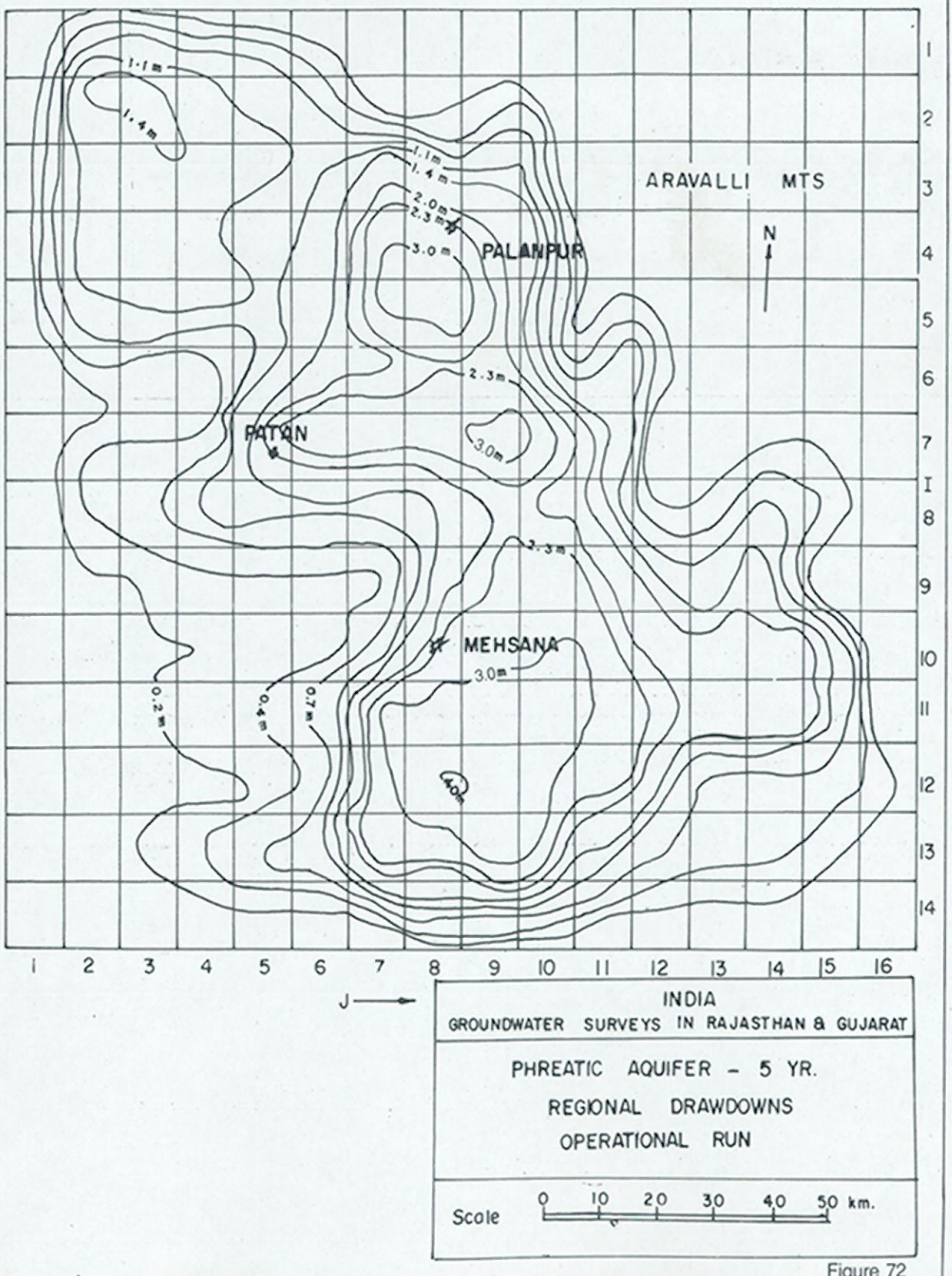

1.1m
1.4m
1.1m
1.4m
2.0m
2.3m
3.0m
ARAVALLI MTS
N
PALANPUR
2.3m
PATAN
3.0m
2.3m
MEHSANA
3.0m
0.2m
0.4m
0.7m
1.0m
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
J
1 2 3 I 4 5 6 7 I 8 9 10 11 12 13 14
INDIA
GROUNDWATER SURVEYS IN RAJASTHAN & GUJARAT
PHREATIC AQUIFER - 5 YR.
REGIONAL DRAWDOWNS
OPERATIONAL RUN
Scale
0 10 20 30 40 50 km.

Figure 72

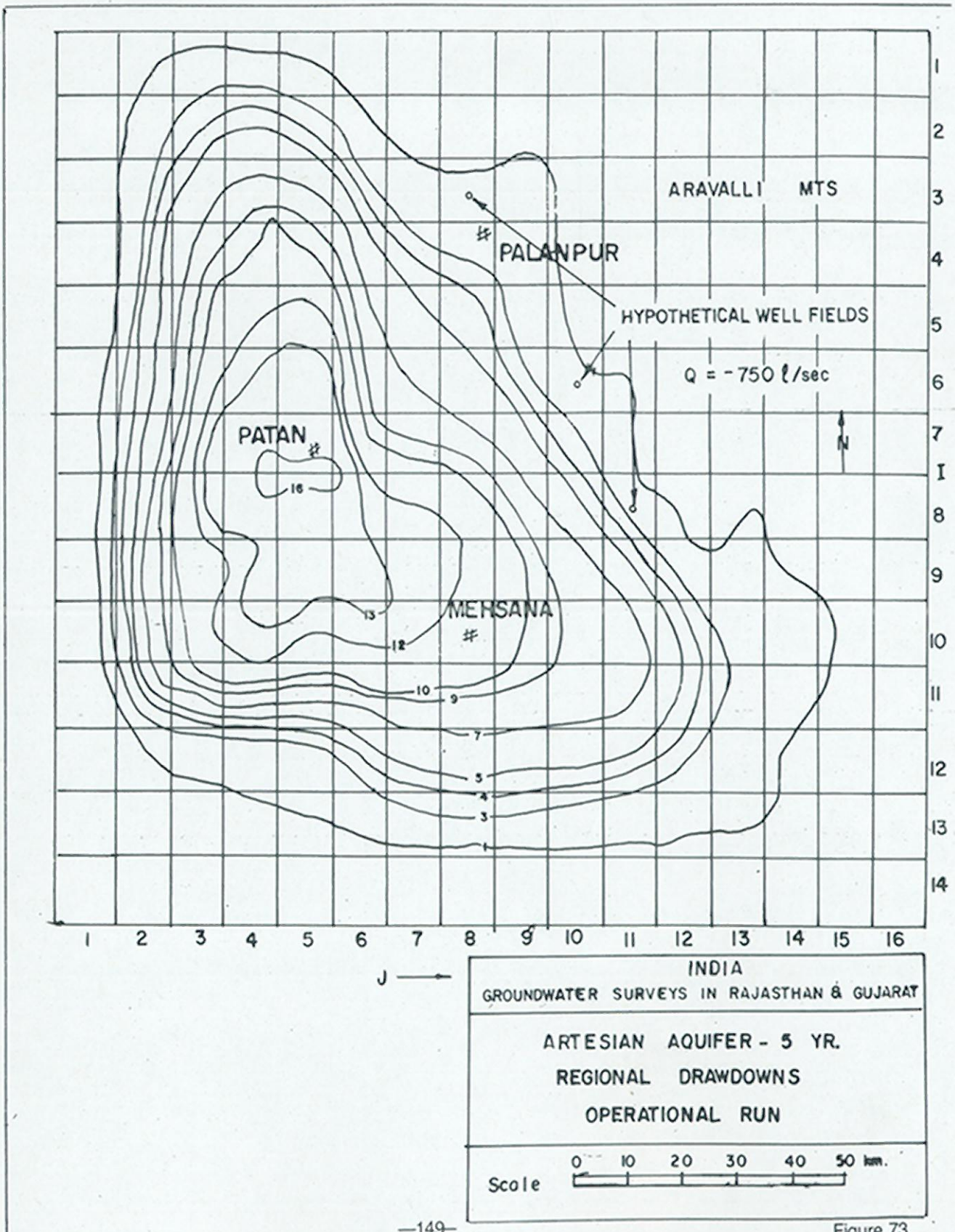
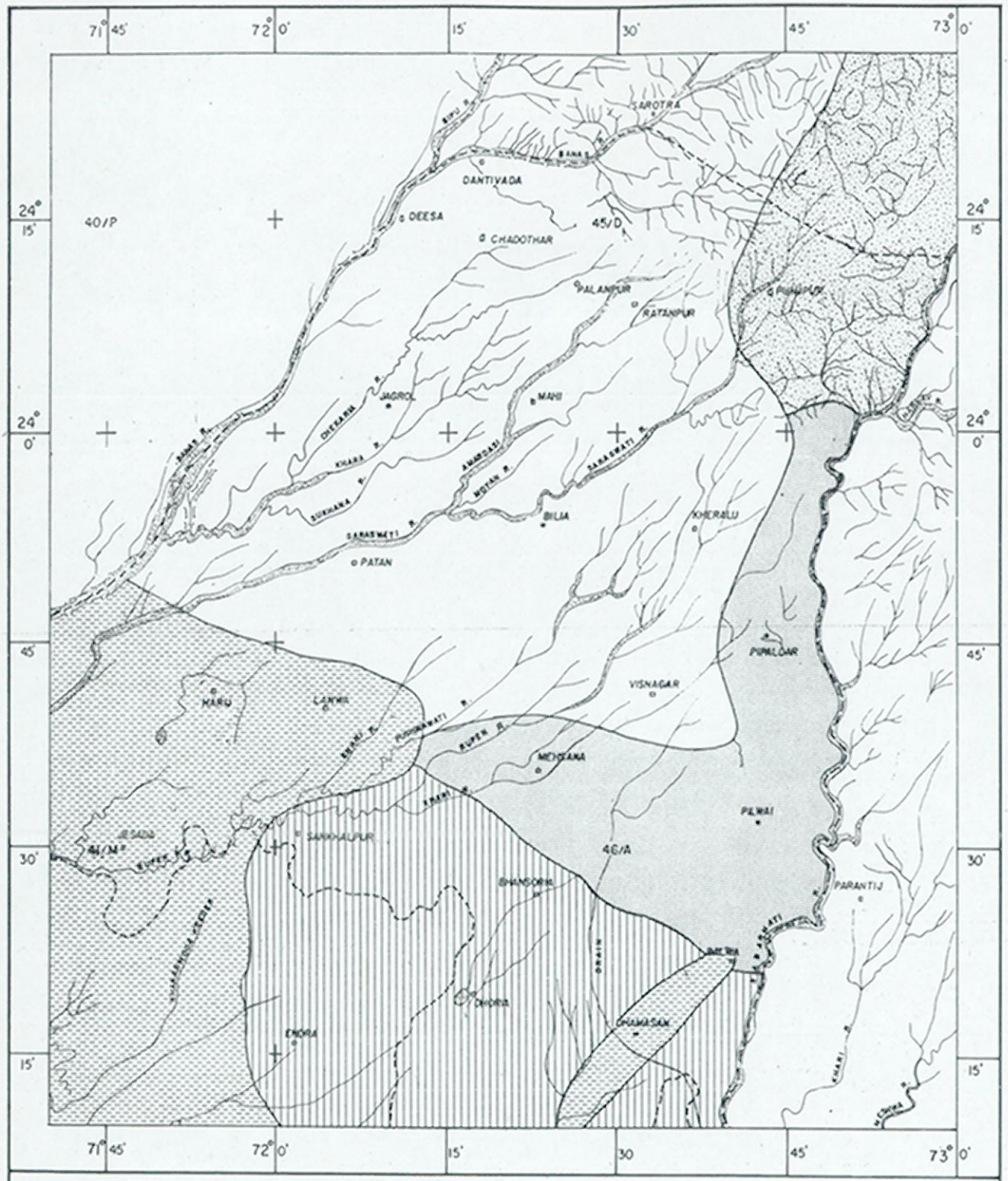

ARAVALLI MTS
PALANPUR
HYPOTHETICAL WELL FIELDS
Q = -750 ℓ/sec
PATAN
MEHSANA
16
13
12
10
9
7
5
4
3
1
N
J
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
I 2 3 4 5 6 7 8 9 10 11 12 13 14
INDIA
GROUNDWATER SURVEYS IN RAJASTHAN & GUJARAT
ARTESIAN AQUIFER - 5 YR.
REGIONAL DRAWDOWNS
OPERATIONAL RUN
Scale
0 10 20 30 40 50 km.

Figure 73



LEGEND

- SALINE & ALKALI SOILS
- CALCAREOUS SANDY LOAMS
- CALCAREOUS SANDY SOILS
- NON-CALCIC BROWN SOILS
- NON-CALCIC RED-BROWN SOILS
- PROJECT BOUNDARY

INDIA
GROUNDWATER SURVEYS IN RAJASTHAN & GUJARAT

GENERALIZED SOIL MAP
GUJARAT PROJECT AREA

Scale 0 2 4 6 8 10 Miles
0 5 10 15 20 25 Kilometres

Figure 74

from Dantiwada has the highest value of 1.63. Usually, the bulk density decreases with the decrease in coarser fraction of the soils. The hydraulic conductivity of the soils ranges from as low as 0 in Jadavapura, Lanwa and Harij samples to more than 7.0 cm/h in Patan and Dantiwada samples. The lowest hydraulic conductivity of the soils collected at the above-mentioned places was due to higher exchangeable sodium percentages (ESP) and increase in the finer fraction of those soils. High levels of exchangeable sodium promote deflocculation and swelling of clay particles in these soils. The hydraulic conductivity of the soils was determined in the laboratory by constant head method using distilled water. Consequently, dispersion and swelling of the clay upon salt removal might have sealed off further movement of water. However, this might change under field conditions where the irrigation water has considerable salt content.

a. Saline and alkali soils

The alkali soils lie in the south-west and south parts of the project area, where the topography is flat to gently sloping. These soils are typically deep, gray calcareous sandy clay loams of extremely low permeability and a high groundwater table. Their AMHC averages 8.5 per cent by volume.

High saline soils occur at Harij, Lanwa and Jadavapura, having an EC range from 7 to 35 mmho/cm^2 in the root zone, while all soils analysed in this group have ESP over 15 and ranging up to 59.

A typical soil profile for this group is described below.

Typical soil profile of a saline-alkaline soil

Harij

Site information

Soil name:	Saline and alkali
Date of examination:	4 November 1973
Location:	Outside the village in cultivated land
Land form:	(i) Physiographic position - on a flat plain (ii) Surrounding land forms - flat (iii) Microtopography - nil
Slope:	Less than 1 per cent
Land use:	Mainly cotton and millet cropping Vegetation acacia

General soil information:

Parent material:	Alluvium
Drainage:	Class 0 to 1, very poorly drained to poorly drained
Moisture condition in profile:	Moist below 36 cm and wet below 130 cm
Presence of salt or alkali:	Strongly affected

Profile description (Munsell soil colour coding):

0- 36 cm	Very dark grayish brown (10 YR 3/2) moist and dark grayish brown (10 YR 4/2); sandy clay loam; plastic and very sticky, strongly calcareous
36- 80 cm	Brown (10 YR 5/3) moist; sandy loam; sticky and slightly plastic, strongly calcareous
80-103 cm	Brown (10 YR 5/3) moist; sandy loam; moderately sticky and plastic; slightly finer textured than above, calcareous
103-132 cm	Dark gray brown; sandy loam; sticky and more plastic than above; friable moist, calcareous

b. Calcareous sandy loams

Calcareous sandy loams are found in the south of the area, being generally deep light grey or brown sandy loams of moderate to good permeability and drainage. Average AMHC is 8 per cent, EC less than 0.5 mmho and ESP less than 15.

Representative profile of a calcareous sandy loam

Dhoria

Site information

Soil name:	Calcareous sandy loams
Date of examination:	8 November 1973
Location:	Outside the village on cultivated land
Land form:	Flat
Slope:	Less than 2 per cent
Land use:	Cotton is the major cash crop Vegetation is sparse; acacia

General soil information

Parent material:	Alluvium

Drainage:	Class 3/4, moderately to well drained
Moisture condition in profile:	Moist below 45 cm.

Profile description:

0- 45 cm	Light brownish grey (10 YR 6/2) moist and light grey (10 YR 7/2) dry; loamy sand; non-sticky and non-plastic; strongly calcareous
45- 90 cm	Brown (10 YR 5/3) moist; sandy loam; slightly calcareous
90-125 cm	Pale brown (10 YR 6/4) moist; loamy sand to sandy loam; slightly calcareous

c. Calcareous sandy soils

The calcareous sandy soils occupy the north-western part of the project area and are mostly pale yellow and brown sands and loamy sands of good depth and good to rapid permeability. They form a zone of gently rolling country with extensive areas of stabilized sand dunes. The zone is well supplied with rivers and drainage channels, except for the flatter alluvial areas west and south of the Chekoria and Saraswati river respectively. The average AMHC found is 4.5 per cent, EC is usually less than 0.5 mmho and ESP values generally are well below 15.

Finer textured soils commonly occupy the inter-dunal areas, particularly where close to the major drainage systems, e.g., the upper reaches of the Banas River.

Representative profile of a calcareous sandy soil

Deesa

Site information

Soil name:	Calcareous sandy soils
Date of examination:	9 November 1973
Location:	Experimental plot near Soil Testing Laboratory
Land form:	Flat
Slope:	Less than 1 per cent

General soil information:

Parent material:	Alluvium
Drainage:	Class 5, somewhat excessively drained
Moisture condition in profile:	Moist below 100 cm

0-110 cm	Yellowish brown (10 YR 5/4) moist and light yellowish brown (10 YR 6/4) dry; loamy sand; non-sticky and non-plastic; diffuse boundaries; slightly calcareous
110-130 cm	Yellowish brown (10 YR 5/4) moist, sand; strongly calcareous

d. Non-calcic brown soils

The non-calcic brown soils occupy a very flat alluvial plain in the east central section of the area and are characteristically pale brown to brown deep loamy sands and sandy loams of adequate to good permeability.

Surface drainage is poor in this region and the absence of $CaCO_3$ in the root zone is probably due to high illuviation of these profiles. AMHC capacity ranges from 2.1 to 9.8 per cent with an average of 4.1 per cent. A typical soil profile of this group is given below.

Typical profile of a non-calcic brown soil

Pilwai

Site information

Soil name:	Non-calcic brown
Date of examination:	18 October 1973
Location:	Outside the village near project drilling site
Land form:	(i) Physiographic position - on flat land near clay pits (ii) Surrounding land forms - flat (iii) Microtopography - nil
Slope:	Less than 1 per cent
Land use:	Virgin land. Uncultivated grass land with sparse trees. Surrounding land cultivated.

General soil information:

Parent material:	Mainly alluvial deposits
Drainage:	Class 4 to 5, i.e., well to excessive
Moisture condition in profile:	Slightly moist below 50 cm
Surface factors:	Top 5 cm compacted by human and animal traffic

Profile description:

0-50 cm	Dark brown (10 YR 4/3) moist and light yellowish brown (10 YR 6/4) dry, loamy sand; structureless massive; slightly sticky, very slightly plastic, roots present; diffuse boundary; slight compaction up to 15 cm
50-80 cm	Dark brown (10 YR 3/3) moist and brown to dark brown (10 YR 4/3) dry; sandy loam; slightly sticky and plastic, slightly angular; roots present
80-120 cm	Very pale brown (7.5 YR 7/3) moist and pink (7.5 YR 7/4) dry; sandy loam; slightly sticky and plastic; slightly sub-angular blocky
120-170 cm	Dark brown (7.5 YR 4/4) moist and strong brown (7.5 YR 5/6) dry; sandy loam; roots present

General:

Illuviation of calcium carbonate below root zone.

e. Non-calcic red-brown soils

The occurrence of non-calcic red-brown soils is confined to the hilly areas in the north-east part of the project area, where they form wide flat valleys. They are of mixed colluvial and alluvial derivation from rocks of the Aravalli System. They are mostly deep loamy sands to sandy loams with adequate to good hydraulic conductivity. Their AMHC is about 6 per cent, EC less than 1.9 mmho and ESP very low.

Representative profile of a non-calcic red-brown soil

Punjapura

Site information:

Soil name:	Non-calcic red-brown soils
Date of examination:	11 November 1973
Location:	4 km from Danta on Palanpur road in farm field
Land form:	(i) Physiographic position - in a wide flat valley between rocky hills (ii) Surrounding land forms - flat (iii) Microtopography - nil
Slope:	Less than 2 per cent
Land use:	Chief crops are millet and wheat

Gene ral soil information:

Parent material:	Colluvial/alluvial deposits
Drainage:	Well drained
Moisture condition in profile:	Moist below 50 cm

Profile description:

0-60 cm	Dark brown (7.5 YR 4/4) moist and brown (7.5 YR 5/4) dry; loamy sand; non-sticky and non-plastic; very friable consistency when moist
60-90 cm	Dark reddish brown (5 YR 3/4) moist; sandy loam; slightly sticky and slightly plastic

2. Physical characteristics of the soils

Soils in the northern part of the project area are predominantly sandy in texture, and sand content being as high as 90 per cent in the soil sample collected at Dantiwada. In general, clay and silt increase from the northern to the southern part of the project area. It is not unusual to see well stabilized sand dunes even in the southern part of the project area, where soil texture is mainly sandy (e.g., Bhansoria). The intensity of cultivation and the density of vegetation, including larger trees, increases from the northern to the southern parts of the project area except in salt-affected parts. This is probably due to the increase in clay and silt fractions. Cation exchange capacity increases with clay content (fig. 75).

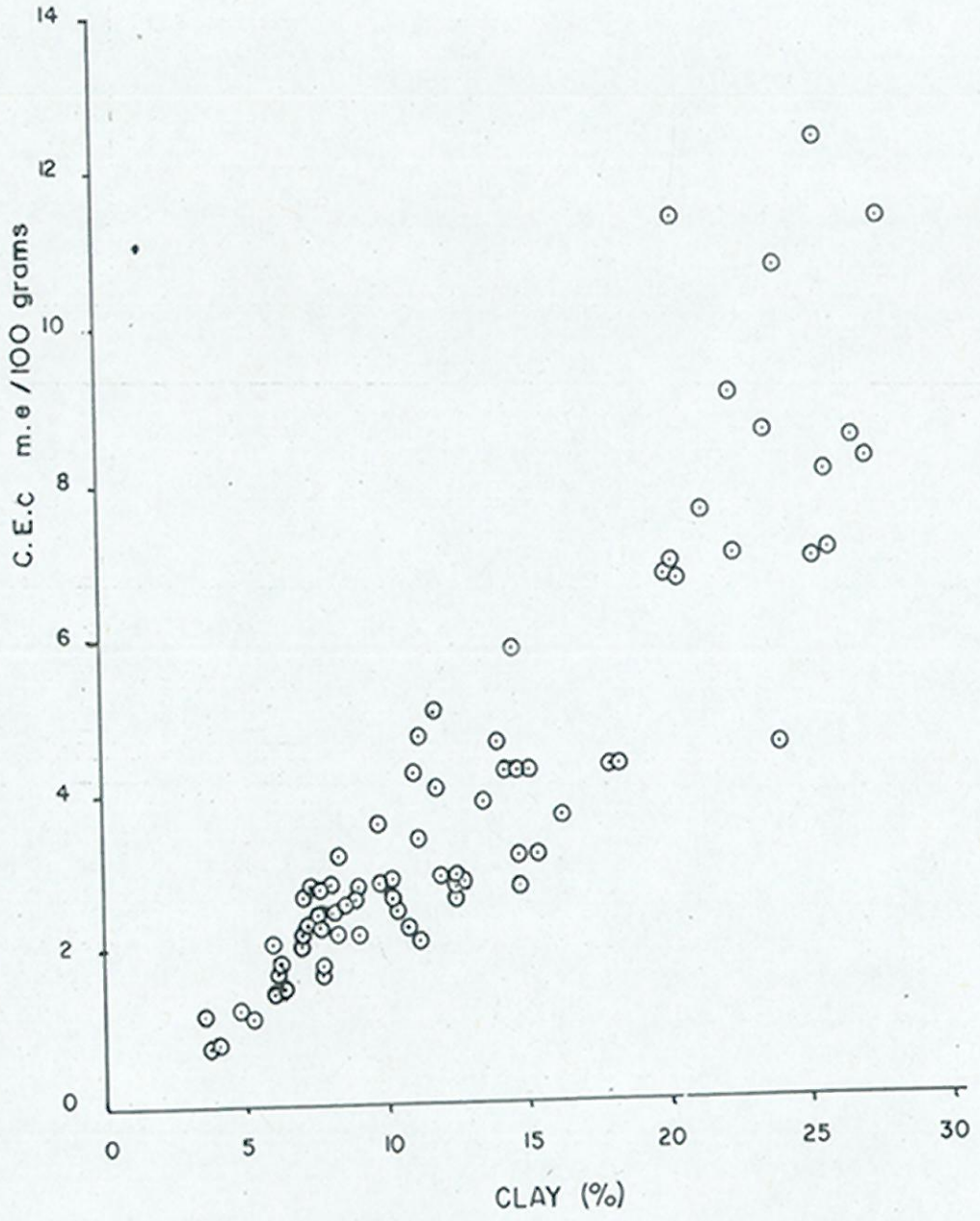
Physical characteristics of soil samples from the Gujarat project area are presented in annex 23.

3. Soil moisture

Moisture percentage in the soils at 0.3 atmospheres and 15.0 atmospheres increases with clay percentage. The available moisture percentage, i.e., the difference between the moisture percentage at 0.3 and 15.0 atmospheres suction, also increases with the fineness of the texture. Available moisture holding capacity of the surface soil collected at Mahi was found to be lowest among the samples collected (0.37 per cent), whereas the soil samples of lower horizons collected at Sarodra and Sankaipur gave values of more than 9.0 per cent. The general trend is for an increase in moisture retention capacity of soils from the northern part to the southern part of the project area.

4. Chemical characteristics

The results of the chemical analysis of the soils are given in annex 24. The pH of the soils is generally above 7.0 and a maximum pH of 9.0 or more, was observed in the sub-soils samples for



RELATIONSHIP BETWEEN CLAY AND CATION EXCHANGE CAPACITY (C.E.C) OF SOILS IN GUJARAT PROJECT AREA.

Figure 75

Jadavapura, Yesada and Patan. Generally, the pH increases with the depth in soils and this can be due to the increase in lime($CaCO_3$) content or ESP of the soils. The EC of the soils is rather low and most of the soils except in the south-western part of the project area are non-saline.

The heavy monsoon rains of 1973 may have washed down salts in sandy soils because of their high permeability. Soils with low or zero permeability, like those represented by the profiles from Jadavapura, Lanwa and Harij were not leached even by these rains.

Most of the soils are calcareous, the $CaCO_3$ ranging from 0.1 per cent to as much as 10.28 per cent (in the lower horizon of Jadavapura soil profile). The soils at Parantiz, Balwa, Pipaldar, Punjapura and Mehsana are non-calcareous. In somes cases, the surface soils are non-calcareous whereas in deeper layers considerable amounts of lime are present. The accumulation of organic matter in these soils is very low because of the high summer temperatures which cause its rapid oxidation.

The cation exchange capacity of the soils is low in most cases because of their coarse texture. Values for CEC were found to increase with the increase in the clay content. Values for SAR of saturation extract are low as compared to the ESP of the soils. However, a fairly good relationship could be observed for SAR-ESP values (fig. 76) although there was considerable deviation from similar data published elsewhere (U.S. Salinity Laboratory Staff, 1954). This might be either due to the breaking down of the equilibrium between the soil solution and the exchange complex of the soils, due to heavy monsoon rains (1973) or the dominant clay mineral in the soils might be different in each case. In addition, the presence of lime also has some effect on the ESP of the soils. Earlier studies elsewhere show that at the same SAR of saturation extract the ESP was higher for calcareous soils as compared to soils with no lime.

5. Irrigability of soils

From the examination of physical and chemical characteristics, it is ascertained that soils, except in the southern part of the project area are not saline although pH is in most cases more than 7.5. Generally the soils are alluvial and are internally well drained. Depending on the finer fraction percentage, the available moisture capacities are low to medium. The topography in the northern part of the project area is undulating, comprising sand dunes mixed with aeolian sands, whereas in the southern part the land is more nearly level and the soils are darker with a higher fine fraction.

According to the irrigability classes suggested by the All India Soil and Land Use Survey Organization, I.A.R.I., New Delhi, most of the soils in the project area are in classes C, D and E with a few soils falling into class B (tables 65-68). Soils of class B have moderate limitations for sustained use under irrigation while class C and D soils have severe or very severe limitations, respectively.

Soils of class C and D are common in the northern part of the project area where the main limitations for irrigation are undulating topography, coarse texture, and low moisture holding capacity. In the south-western part of the project area, the soils are highly saline or alkaline with very low permeability and belong to classes D and E. In the rest of the area, the soils are mostly of classes B and C, according to texture, topography and available moisture holding capacity.

Although class E soils are defined as non-irrigable, they may be irrigated for production of selected crops and varieties, by following suitable soil-water management practices and improving drainage conditions.

6. Suitability of ground water for irrigation

Chemical analysis of tubewell water show that the EC of more than 40 out of 70 water samples analysed exceeds 2,250 mmho/cm and 8 samples show more than EC 5,000 mmho/cm. Among dug-well water samples, 37 out of 75 have a conductivity of more than 2,250 mmho/cm and 13 samples have EC more than 5,000 mmho/cm. According to U.S. Soil Laboratory classification of irrigation waters, water having EC between 2,250 and 5,000 mmho/cm is termed not suitable for irrigation under ordinary conditions. But where the clay content is less than 30 per cent, such water can be used for irrigation. Water having EC values higher than 5,000 mmho/cm can also be used in the project area, except in its south-western part.

Out of 70 tubewell water samples analysed, 23 samples have SAR values higher than 18.0 and 26 samples have RSC values higher than 2.5 meq/litre. In dug-well water samples, out of 75 samples analysed only 13 have SAR values higher than 18.0 and 19 have RSC values higher than 2.5 meq/litre. As the soils in the project area are mainly light textured with less than 30 per cent clay, the waters with EC values up to about 8,000 mmho/cm could be used for irrigation purposes with reasonable soil-water management practices. In all cases, drainage characteristics of the soils, together with the selection of crops, should be taken into consideration in assessing the suitability of well-water for irrigation purposes.

The soils in the south-western region of the project area are problematic because of their very low permeability and high ESP. Moreover these soils are highly saline and the drainage appears to be unsatisfactory. Under these conditions, the ground water table level may be important for assessing the soils for irrigation. The map showing the water-level depths indicates that the ground-water level is about 5 to 15 metres from

Table 65. Irrigability classes* of saline and alkaline soils

Soil Characteristics	Jadavpura	Lanwa	Harij	Jesada	Radhanpur	Damasar
Depth	A	A	A	A	A	A
Texture of surface to 30 cm	A	A	A	B	A	A
Permeability (of least permeable layer)	D	D	D	D	A	A
Available M.H.C. to 90 cm	C	C	C	C	D	C
Coarse fragments (75 mm)	A	A	A	A	A	A
Kankar (25-75 mm)	B	A	B	B	A	A
Rock outcrops (distance apart in m)	A	A	A	A	A	A
Salinity (mmho)	C	B	E	A	A	A
Salt affected (% area)	B	C	C	C	B	B
Severity of alkali problem (ESP)	D	D	D	D	C	D
Sub-strata drainage	C	C	C	C	B	B
Soil irrigability class	D	D	E	D	D	D

* Classification of All India Soil and Land Use Survey Organization, I.A.R.I. New Delhi India

Table 66. Irrigability classes* of calcareous sandy loams

Soil characteristics	Endra	Sankaipura	Dhoria	Bhansoria
Depth	A	A	A	A
Texture of surface	A	B	B	B
Permeability	A	A	A	A
A.M.H.C.	B	A	C	D
Coarse Fragments	A	A	A	A
Kankar	A	A	A	A
Rock outcrops	A	A	A	A
Salinity	A	A	A	A
Salt affected	A	A	A	A
Alkali problem	A	A	B or C	A
Drainage	A	A	A	A
Soil Irrigability Class	B	B	C	D

* See note table 65.

Table 67. Irrigability classes* of non-calcic soils

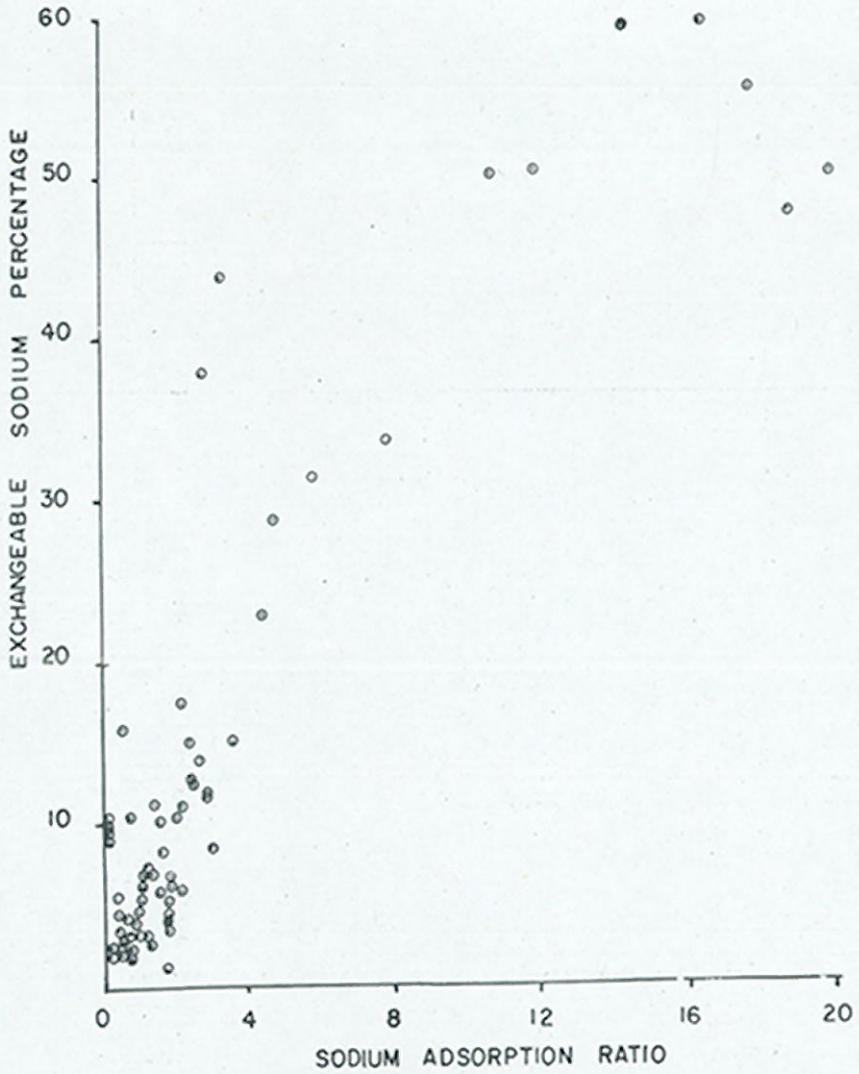
Soil characteristics	Pilwai	Parantiz	Mehsana	Punjapur
Depth	A	A	A	A
Texture	B	C	A	B
Permeability	A	A	A	A
A.M.H.C.	D	D	C	C
Coarse fragments	A	A	A	A
Kankar	A	A	A	A
Rock outcrops	A	A	A	A
Salinity	A	A	A	A
Salt affected	A	A	A	A
Alkali Problems	A	A	A	A
Drainage	A	A	A	A
Soil irrigability Class	D	D	C	C

* See note table 65

Table 68. Irrigability classes* of calcareous sandy soils

Soil characteristics	Sarodra (Interdunal)	Dantawada	Paton	Bilia	Mahi	Deesa	Chadothar
Depth	A	A	A	A	A	A	A
Texture	A	C	C	C	B	C	C
Permeability	A	B	B	B	A	A	A
A.M.H.C.	B	D	D	C	E	D	D
Coarse fragments	A	A	A	A	A	A	A
Kankar	A	A	A	A	A	A	A
Rock outcrops	A	A	A	A	A	A	A
Salinity	A	A	A	A	A	A	A
Salt affected	A	A	A	A	A	A	A
Alkali problems	A	A	B	A	A	A	A
Drainage	B	A	A	A	A	A	A
Soil irrigability Class	B	D	D	C	E	D	D

* See note table 65



RELATIONSHIP BETWEEN SODIUM ADSORPTION RATIO (S.A.R) OF SATURATION EXTRACT AND EXCHANGEABLE SODIUM PERCENTAGE (E.S.P) OF SOILS IN GUJARAT PROJECT AREA.

Figure 76

surface in summer (June 1972). It is to be expected therefore that in the rainy season, the water level will be higher and in summer, evaporation may cause salts to accumulate on the soil surface. In that region, white saline patches were observed everywhere and crop growth was not satisfactory. So this region cannot be considered for irrigation without first improving the drainage condition.

Regarding the rest of the area, available water, although saline, could be used with suitable management practices even in the southern part of the project area where clay content is higher. If the ESP of the soils rises due to unsatisfactory SAR factor and RSC values of the well water, this should not be a major limiting factor for irrigation, because higher ESP does not impair the physical condition of mainly light textured soils.

Boron content of the water from tubewells is within permissible limits and only one sample out of 30 analysed has a boron concentration above 2.0 ppm.

The presence of potassium and nitrate ions in the well water is a favourable factor for plant nutrition and might mitigate the harmful effect of salinity on plant growth by creating a better and balanced ionic environment in the root zone. Nitrate and potassium are present in significant amounts. They are readily absorbed by the plants for their physiological functions and metabolic activities and thus would add to the fertilizer economy of the region to some extent.

Generally, no clay or other hard pans were observed in the soils profiles and the soils are reasonably to highly permeable resulting in good internal drainage except in the south-western part of the project area. Even saline water, with EC values of more than 11,000 mmho/cm could in some cases be used for irrigation purposes. But it might be useful to put some land in fallow once in two or three years, depending on the amount of salt accumulated every season and the amount leached out of the root zone by the monsoon rains. However, it is necessary to have better knowledge the salt balance of the soils and leaching requirement in relation to the crops to be grown. The quality of the water can in some places be improved by adding gypsum, so that the SAR would be lowered to a safer level. The addition of organic matter to these soils will promote better structure and physical conditions and moderate the effects of saline irrigation waters on soil properties such as pH and ESP. It is advisable to choose crops and varieties, which are salt-resistant and have low leaching requirements. The adverse effect of salinity can be alleviated to some extent by planting on slopes. For maximum irrigation efficiency, frequency and amount of irrigation, soil permeability and drainage conditions, and salt tolerance of the crop should be carefully considered.

7. Irrigation and cropping practices

Higher figures for irrigation intensities are due to the growing of longer duration crops such as chili peppers, cotton and August-sown fodder sorghum.

Rain-fed crops, e.g., peas, millet, bidi tobacco, castor, tur (pigeon tea) and sorghum are not usually given any supplementary irrigation, the monsoon rainfall being considered adequate throughout the project area (61 cm at Mehsana). The soils have higher available moisture holding capacity than those of the Rajasthan project area and the potential evapotranspiration figures (Penman formula) for the months June to September inclusive average between 5/8 and 3/4 of those for the Rajasthan arid zone through the same period.

In the northern and central parts of the area most monsoon crops are grown on plateau and marginal lands on the interfluves. As slopes can increase up to the order of 4 per cent, the present system of ploughing and planting in the direction of the main slopes is undesirable. Soil conservation measures are therefore indicated and where properly carried out should obviate the need for supplementary irrigation in an average season. These measures, designed to minimize runoff, include contour bunding, planting, harrowing, and sowing inter-culture along the contour. This is particularly necessary in the case of wider-spaced line-sown crops such as tobacco, tur (pigeon tea) and castor.

In the case of late-sown monsoon and post-monsoon crops such as fodder sorghum, rough tillage (i.e., moldboard ploughing to at least 15 cm) is preferable to the conventional harrowing as a moisture conservation measure.

To control evaporation from the soil, crop spacing should not be as wide as currently used.

There is scope for increasing the use of fertilizers to favour better root development and hence water utilization from deeper horizons, the resultant increase in crop canopy reducing water wastage by evaporation.

Earlier winter sowing especially on the lighter-textured soils is preferable to make use of residual soil moisture. The use of dwarf varieties will tend to reduce transpiration per unit area.

Good crops have been reported from loamy sand and drained loamy soils under irrigation with water containing up to 3,000 ppm TDS, and under good management practices even up to 4,000 ppm TDS. Irrigation with water containing more than 5,000 ppm TDS, salt accumulation in the soil over 7 years has been estimated to have reduced bajra (millet) yields by about one half.

Cotton grown on "black cotton soil" of the south-western parts of the area has maintained satisfactory yields under irrigation with water up to 4,000 ppm TDS; leaching of salts by the monsoon rains in this area prevents massive salt accumulation in the soil.

Where tobacco and winter vegetables are irrigated with water of high salinity, beneficial results were obtained if the water contained also high amounts of potassium and nitrates.

Fast-growing cotton (e.g., 125-day strains) sown in August will produce similar yields as June or July sown 8- or 9-month cotton. This will allow farmers to grow short-duration pulse crops like cowpea or green manure during heavy rainfall periods (when cotton makes only slow growth) thus improving soil fertility and subsequent returns. There is scope for increasing cropping irrigation intensities particularly on deep sandy loams in the 600 to 850-mm rainfall belt including Mehsana and Banaskantha by the introduction of improved wheat and bajra varieties. Common two-year crop rotations in the area are bajra cotton, bajra-castor, tobacco-bajra. It is possible to fit in extra crops within this period of time by adopting such rotations as: hybrid millet - mexican wheat - vegetable - cotton.

However, irrigation intensity can only be raised through the adoption of more appropriate methods of irrigation on these soils and by the elimination of water waste through deep percolation and seepage.

The establishment of grass land (e.g., Genchrus cilliaris) has been recommended for slopes too steep for annual crops. However, as in Rajasthan project area, many farms are too small to make a viable unit or to fit a grass-resting break into the rotation to provide stock feed and soil fertility without reducing the food available for people living near subsistence level. The problem is to produce enough food for the average family, fodder for their livestock kept for milk and draught purposes, manure and crop residue for soil amelioration and plus some marketable cash crop. The present quality and productivity of most of the livestock make it quite uneconomic to attempt to grow feed for them.

Long-duration grass fallows have been found in this climate to deplete soil moisture and reduce the yield of the following crop. Their effect on soil structure is only shortlived and their main value is probably to recover nutrients, especially nitrogen from the sub-soil. As soil N status is very low, a grass/legume mixture would be preferable. Such a grass fallow is probably only of real value as a structure builder in soils containing not less than 25 per cent clay. As an alternative to perennial grasses the sowing of quick maturing, shallow rooted annuals (e.g., Eragrostis spp.) may be of value for hay or by protecting the soil against drying winds, thus conserving moisture below the root zone.

REFERENCES

Annual Administrative Report of the Office of the Project Director, Agriculture Department, Bikaner for the year 1971-1972

Auden, J.B. (1933) Geological Survey of India (GSI) Memo., LXII, 244.

Auden, J.B. (1934) Geology of the Krol Belt, Record 67 (4)

Baweja, B.K. (1969) Geology and Ground Water Conditions in the Mehsana, Visnagar Kheralu, Chanasma and Patan Talukas, Mehsana, Gujarat. Bull. Geol. Surv. India.

Bergstrom and Forsman (1973) "Development of a Conceptual Deterministic Rainfall-Runoff Model" Nordic Hydrology Vol. 4, No. 3, Copenhagen

Blanford, V.T. (1877) GSI Record, X, 18.

Boulton, N.S. (1954) Unsteady Radial Flow to a Pumped Well Allowing for Delayed Yield from Storage. Int. Assoc. Sci. Hydr. Gen. Assem. Rome, V. 2, Publ. 37.

Chandra, P.K. and Choudhary, L.R. (1969) Stratigraphy of the Cambay Basin O.N.G.C. Bull. Vol. 6, No. 2.

Chatterjee, P.C. (1968) Geology and Chemistry of Surface Water in the Arid Zone of Rajasthan, 21st Int. Geogra. Cong., India.

Coulter, J.D. (1973) "Prediction of Evapotranspiration from Climatological Data" Soil and Plant Water Symposium, DSIR Information Series 96:38-45, Wellington, N.Z.

Geological Survey of India, Western Region, Jodhpur (1973) Seminar on Recent Advances in the Geology of Rajasthan and Gujarat, Oct. 21-23, 1973.

Ground-water Surveys in Rajasthan (1973), U.N. Tech. Report 1, pp. 17-26.

Halevy, E. and A. Nir (1963) Determination of Aquifer Characteristics with the Aid of Radioactive Tracers, J. Geoph. Res. 67, 2403.

Halevy, E., A. Nir, Y. Harpaz and S. Mandel (1958) Use of Radio-isotopes in Studies of Groundwater Flow; Part 1, Proc. 2nd UN Int. Conf. PVAE 20, 158.

Heron, A.M. (1922) GSI Record, LIV, 346.

Heron, A.M. (1932) GSI Record, LXVI, 43, 132.

Heron, A.M. (1935) Syno. Pre-Vindhian Geology of Rajasthan Trans. Nat. Inst. Sci. 1 (2).

Khatri et al. (1964) Gravity Survey in Cambay Basin, Intern. Geol. Congress, 22nd Session, N. Delhi, India, Part II, see pp. 224-235.

Kidwai, A.L., Mishra, P.S. (1968) Ground-water Exploration by Drilling and Testing in a Part of Nagaur Dist. Rajasthan, Geological Survey of India, Open Report No. 3.

Krishnan, M.S.(1960), Geology of India and Burma, Higginbothams, Pvt. Ltd. Madras.

Krishnan and Kushwaha (1970) "Evaluation of Evapotranspiration Models for Prediction of Soil Moisture Storage ..." Plant Response to Climatic Factors. Symposium Uppsala, Sweden.

Knutsson, G. and H.G. Forsberg (1966) Laboratory Evaluation of ^{51}Cr-EDTA as a Tracer for Groundwater Flow; Isotopes in Hydrology. (Proc. Symp. Vienna, 1966) IAEA, Vienna (1967)

La Tobche, T.D. (1902) GSI Memo XXXV, 20.

Mathur, L.P., Rao K.L.N. and Chambe A.N. (1956) Tectonic Framework of Cambay Basin, India.

Mathur, L.P. and Evans, P. (1964) Oil in India, Geol. Congress, 22nd Session, New Delhi, India, pp. 55-62.

Mithal, R.S. (1969) Ground-water Studies in Arid to Semi-Arid Region, Sym. Proc. p. 495.

Oza, M.M. (1967) Geology and Ground-water Resources of District Mehsana, Gujarat. Geol. Surv. India.

Pascoe, E.H. (1959, 1964, 1973) Manual of Geology of India and Burma, Vol. I, II, III.

Raju, A.T.R. (1969) Geological Evaluation of the Assama and Cambay Tertiary Basins of India, Selected Lectures on Petroleum Exploration, Vol. I, pp. 145-169.

Rao, K.L.N. and Sahadeva Rao V (1970) Some Aspects of Petroleum Hydrogeology of Cambay basin ONGC Bull. No. 7, Vol. 1.

Rao, et al (1971) "Evaporation over India" Indian J. Geophys. 22.

Roy, B.C. (1959) GSI Mem., Vol. 86, pp. 110-117.

Sastry et al. (1964) Seismic Exploration in Cambay basin, India Int. Geol. Congress, 22nd Session, New Delhi, India, Part II, pp. 292-306.

Taylor, G.C. (1952) Occurrence of Ground Water in Rocks of Western Rajasthan, India, Nat. Inst. of Sci., Bull. No. 1.

Thornthwaite, C.W. (1943) "An approach to a Rational Classification of Climate" Geophy. Rev., Vol. 38.

Wellen, C.G. (1966) "Global Solar Radiation and Potential Evapotranspiration in Sweden" Contrib. Series B, No. 24, Swedish Met. and Hydrol. Inst., Stockholm.

World Meteorological Organization (1966) "Measurement and Estimation of Evaporation and Evapotranspiration" Technical Note No. 83, Geneva.

Annex 1

Data from representative existing tubewells, Rajasthan area

Location	Depth drilled (m)	Well depth (m)	Water level depth (m)	Screened section (m)	Aquifer thickness (m)	Discharge (m^3/h)	Drawdown (m)	Specific capacity ($m^3/h/m$)	Nature of aquifer
				Sikar basin					
Bursu	82	68	46.30	49- 54 61- 67	33	15.90	16.76	0.95	Quaternary aeolian sand
Churu	99	89	30.75	55- 87	60	44.30	5.73	7.73	- do -
Daulatpura	65	46	26.50	36- 44	7	1.80	7.01	0.26	- do -
Jaesinghsar	87	64	38.30	32- 39 43- 46 50- 63	51	22.70	2.15	10.55	- do -
Jusri	90	89	47.55	47- 53 57- 60 61- 86	47	12.70	10.67	1.19	- do -
Kerap	64	58	31.30	40- 46 52- 56	40	90.20	6.00	15.04	- do -
Khunkhuna	88	64	36.20	37- 48 52- 62	25	74.60	6.64	11.20	- do -
Kuchaman	78	60	12.80	14- 25 32- 58	-	153.00	6.86	32.20	- do -
Loa	79	58	30.10	23- 36 40- 57	29	22.30	6.35	3.51	- do -
Parihara	59	55	25.30	23- 41 47- 54	15	31.10	4.20	7.40	- do -
Sadalpur	44	42	30.95	31- 42	13	14.30	5.71	2.50	- do -
Sankhu	101	99	33.10	35- 41 47- 57 76- 98	50	46.50	7.99	5.81	- do -
Sardarshahr	96	73	37.90	52- 62 67- 73	35	46.60	4.20	11.09	- do -
Taranagar	42	41	16.55	29- 41	28	12.30	10.28	1.19	- do -

Annex I (continued)

Location	Depth drilled (m)	Well depth (m)	Water level depth (m)	Screened section (m)	Aquifer thickness (m)	Discharge (m^3/h)	Drawdown (m)	Specific capacity ($m^3/h/m$)	Nature of aquifer
					Bikaner basin				
Bikaner Cantt	182	138	83.15	109-137	>60	59.90	6.29	9.51	Palana sandstone
Bikaner medical college	150	110	77.25	93-109	>60	21.40	7.11	3.08	- do -
Deatra	227	182	94.00	134-181	64	81.60	7.31	11.10	- do -
Kolayat	273	150	67.15	98-104 112-148	105	13.70	0.82	16.70	- do -
Kolasar	139	133	68.55	99-131	-	12.30	1.52	8.10	- do -
Koramdesar	228	168	73.50	74- 85	-	9.00	12.19	0.74	- do -
Ladnun	116	113	34.65	40-113	>81	84.10	6.35	13.20	Nagaur sandstone
Lunkaransar	199	113	61.70	68- 80 87-103 106-110	92	12.00	2.67	4.50	Palana sandstone
Napasar	204	99	73.60	79- 90 91- 97	-	27.50	4.94	5.57	- do -
Nokha	132	130	81.65	99-130	>50	11.40	10.40	1.09	Nagaur sandstone
Palana	249	133	103.00	113-124 127-132	>20	22.70	0.7	32.5	Palana sandstone
Sandwa	105	105	-	63- 79 88-103	>46	13.60	8.48	1.60	Nagaur limestone
Sheobari	202	149	62.00	83-146	-	33.00	4.72	6.98	Palana sandstone
Sujandesar	206	142	47.35	59- 72 82-141	73	18.20	2.72	6.70	- do -
Surpura	238	232	87.70	115-132 137-143 156-164 163-208 211-218 221-229	49	10.80	1.24	8.71	- do -

Annex 1 (continued)

Location	Depth drilled (m)	Well depth (m)	Water level depth (m)	Screened section (m)	Aquifer thickness (m)	Discharge (m^3/h)	Drawdown (m)	Specific capacity ($m^3/h/m$)	Nature of aquifer
					Luni basin				
Butati	187	162	31.65	47- 50 58- 66 72- 87 99-103 106-109 132-160	Qat:63 Pal.s:50	7.70	12.77	0.61	Quaternary alluvium, Palana and Nagaur sandstones
Dangawas	143	139	39.75	41- 47 60-100 106-112 124-134	>102	99.80	2.16	46.20	Quaternary sand and gravel
Kashnau	245	201	26.80	75- 92 98-113 134-148 167-184 190-199	P:130 N: 77	119.00	3.30	36.10	Palana and Nagaur sand-stones
Kuchera	210	171	34.50	42- 48 54- 57 69-120 132-169	Qat:6 P:114 N:>27	141.00	1.79	78.90	Quaternary sand and gravel, Palana and Nagaur sandstones
Merta City-Pushkar Road	202	184	39.60	42- 56 61-115 124-144 167-182	Qat:>30 N: 40	30.00	4.57	6.55	Quaternary alluvium Nagaur sandstone

Annex 2

Interpretation of pumping tests in Sikar Basin
by Boulton method *

SITE	Match point	rB_U	$\frac{1}{A}$	$\frac{1}{UY}$	W/UA	W/UY	"S"	"t" in days	Transmissivity KD m2/d	Average m2/d	USGPD/ft	S_A x10^{-4}	S_Y x10^{-2}	days^{-1}	twt in days	y	Distance from Test well in m	Pumping rate m3/day
Anandpura I	A	0.1					1.65	0.001	105									
	B	0.1	10	10	1	1	1.71	0.34	101	103	8,293	1.8	5.9	0.078	38	329	15.24	2,180.2
Anandpura II	A						1.40	0.015	124									
	B	0.4	10	10	1	1	1.34	1.56	130	127	10,226	8.5	9.2	0.26	13	109	29.6	2,180.2
Anandpura III	A						1.71	0.36	101									
	B	0.5	10	10	1	1	1.65	6.11	105	103	8,293	4.0	7.1	0.103	33	176	60.0	2,180.2
Average										111	8,938	4.7	7.4					
Dadhia	A						0.58	0.031	314									
	B	0.6	10	10	1	1	0.70	3.75	260	287	23,109	6.8	7.6	0.216	16.6	112	75.6	2,289.2
Fatehpur	A						0.49	0.015	354									
	B	0.7	10	10	1	1	0.58	4.86	299	327	26,330	5.5	15.0	0.25	15.2	274	62.2	2,180
Jhunjhunu	A						0.62	0.025	175									
	B	1.25	10	10	1	1	0.79	5.56	137	156	12,561	5.8	10.0	0.7	7.3	173	54.9	1,362.0
Mukandgarh	A						0.49	0.035	266									
	B	0.8	10	10	1	1	0.53	4.86	246	256	20,613	10.3	13.3	0.33	12	130	60	1,635.1

* After Boulton, N.S. 1954, which see for definition of column-head elements.

Annex 2 (continued)

SITE	Match point	rB_U	$\frac{1}{A}$	$\frac{1}{UY}$	W/UA	W/UY	"S" in m	"t" in days	Transmissivity KD Average m2/d	m2/d	USGPD/ft	S_A x10^{-4}	S_Y x10^{-2}	days^{-1}	twt in days	%	Distance from Test well in m	Pumping rate m3/day
Setolao I	A						0.88	0.004	345									
	B	0.1	10	10	1	1	0.98	0.104	323	334	26,737	8.2	5.4	0.41	8.3	67	60.7	3,816
Setolao III	A						0.94	0.028	281									
	B	0.6	10	10	1	1	1.16	3.47	228	254	20,452	8.5	8.5	0.26	14	101	61	3,319.2
Setolao IV	A						0.82	0.049	322									
	B	0.6	10	10	1	1	1.04	6.6	254	288	23,190	6.8	7.3	0.14	26	108	96	3,319.2
Setolao V	A						0.88	0.0097	300									
	B	0.3	10	10	1	1	1.07	1.7	247	274	22,062	2.2	3.2	0.187	17	146	72.5	3,319.2
Average										288	23,190	6.4	6.1					
Talab ki Dhani	A						0.5	0.014	217									
	B	0.7	10	10	1	1	0.7	4.17	155	186	14,977	6.1	12.9	0.29	13.1	212	44.5	1,362.6

Annex 3

Results of boreholes drilled by Project in Rajasthan

Location	Depth drilled (m)	Zone tested (m)	Screened sections	Thickness tapped (m)	Thickness of aquifer (m)	Depth to water level (m)	Discharge m3/hr	Draw-down (m)	Quality TDS ppm	Quality Cl ppm	Remarks
A. SIKAR BASIN - (aquifer in Quaternary aeolian sands)											
a) Test wells											
Anandpura	64.60	-	36.60 - 44.50 47.44 - 56.45	16.80	43.00	13.10	90.80	10.20	1,020	270	3 OH**
Dadhia	128.65	-	73.00 - 80.60 86.60 - 92.75 98.85 - 103.40 106.50 - 112.55	24.35	78.00	42.70	95.40	7.30	270	30	2 OH
Fatehpur	82.90	-	53.05 - 65.25 72.55 - 76.80	16.45	48.00	35.05	90.80	5.50	1,826	288	1 OH
Jhunjhunu	78.35	-	47.55 - 57.90 64.00 - 73.75	20.10	40.00	33.50	56.80	7.80	1,250	225	1 OH
Makundgarh	107.60	-	63.40 - 73.15 75.60 - 79.55 86.90 - 92.65 94.20 - 100.30	25.55	60.00	38.40	68.10	11.60	786	195	2 OH
Setolao	115.80	-	68.35 - 75.65 78.90 - 84.75 89.30 - 97.45	21.30	72.00	43.30	138.30	9.45	540	80	5 OH
Talab-ki-Dhani	73.45	-	48.75 - 56.35 62.45 - 67.30	12.45	34.00	34.15	56.80	6.00	2,316	390	1 OH

Annex 8 (i)

Chemical analyses of water samples from dug wells,
Rajasthan area, samples collected May 1973

Well No.	pH	Conductivity (in micromhos/cm)	TDS in ppm at 180°C	SiO_2 ppm	Constituents in meq/l										B ppm	Total hardness (Ca, Mg) as $CaCO_3$	SAR	U.S. Salinity Lab. Classification	RSC
					Ca^{3+}	Mg^{2+}	Na^{2+}	K^{+}	CO_3^{2-}	HCO_3^{2-}	Cl^{-}	SO_4^{2-}	NO_3	F					
45I/1A-1	7.60	830	414	18	2.00	1.00	4.61	0.11	Nil	4.60	1.97	1.20	0.14	-	0.60	150	3.76	C_3 S_1	1.6
45I/1B-2	7.20	2,032	1,256	20	4.20	3.60	12.83	0.15	Nil	4.80	11.56	1.40	3.47	-	1.12	390	6.49	C_3 S_1	-3.0
45I/1B-3	7.20	1,255	880	57	6.20	3.20	4.18	0.36	Nil	5.40	2.96	1.00	4.03	-	0.70	470	1.93	C_3 S_1	-4.0
45I/1-C-1	7.30	2,908	2,054	19	6.60	8.70	17.27	0.25	Nil	6.00	20.16	4.10	1.47	-	0.95	765	6.22	C_4 S_1	-9.3
45I/1D-14	7.50	1,604	1,026	22	1.30	1.70	15.33	0.05	Nil	9.80	5.64	1.20	0.94	-	1.05	150	12.52	C_3 S_2	8.8
45I/1D-9	7.50	1,604	1,086	21	1.50	1.70	15.53	0.05	Nil	13.00	4.86	0.70	0.42	-	0.99	160	12.28	C_3 S_2	9.8
45I/2D-3	8.10	2,286	1,554	18	2.00	3.90	18.14	0.07	Nil	10.80	6.13	1.50	6.25	0.22	1.52	295	10.55	C_4 S_2	4.90
45I/2-D-5	7.55	2,783	1,926	23	4.00	6.50	19.88	0.37	Nil	11.60	8.53	2.10	7.58	0.03	1.86	525	8.68	C_4 S_1	1.1
45I/2D-16	8.05	2,668	1,630	19	2.10	1.70	23.05	0.12	Nil	12.00	11.77	1.40	2.16	0.23	1.35	190	16.72	C_4 S_1	8.2
45I/2D-20	7.70	1,102	784	26	3.00	4.40	4.96	0.04	Nil	6.20	2.40	0.90	3.55	0.03	0.88	370	2.58	C_3 S_1	-1.2
45I/1B-7	7.60	1,757	1,156	35	4.90	4.70	10.61	0.18	Nil	9.40	6.20	2.20	2.54	0.09	0.93	480	4.84	C_3 S_1	-0.2
45I/4D-11	7.80	1,355	832	27	2.20	2.80	9.44	0.34	Nil	9.40	3.52	2.40	0.86	-	1.07	250	5.97	C_3 S_1	3.4
45I/3D-12	7.60	1,567	1,150	23	3.60	4.80	9.22	0.06	Nil	6.60	5.78	2.60	3.47	0.13	0.97	420	4.50	C_3 S_1	-1.8
45I/3D-15	0.05	3,097	2,048	21	4.10	5.50	23.05	0.11	Nil	10.60	16.79	3.80	2.08	0.11	1.22	480	10.52	C_4 S_2	1.0
45I/4D-1	8.25	1,357	886	45	2.30	3.10	10.65	1.0	0.60	0.50	3.58	1.00	1.52	0.13	0.78	270	6.40	C_3 S_1	4.7
45I/3C-13	7.85	1,840	1,340	22	2.00	3.40	15.96	0.12	Nil	7.10	8.25	2.10	4.84	0.03	1.44	260	9.71	C_3 S_1	1.7
45I/2D-23	7.80	2,433	1,730	21	2.80	4.10	19.88	0.07	Nil	11.30	10.43	1.30	3.74	0.01	1.60	345	1.70	C_3 S_2	4.4
45I/4B-6	7.80	1,130	658	26	3.60	4.80	6.79	0.11	Nil	8.60	2.61	3.80	0.67	0.03	0.60	420	3.20	C_3 S_4	0.2

Annex 7 (continued)

Location	Type of well*	Toposheet No.	Date of collection	Aquifer**	pH Lab.	Conductivity***	TDS (mg/l)	Constituents in meq/litre Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4	Hardness****	SAR	RSC
(a) Eastern part																	
								Luni basin									
Badauli	TW	45J/3A	16.11.71	Q	7.8	2,465	1,362	1.8	1.4	20.35	-	Nil	6.6	14.95	2.0	160	16.1	3.4
Aniala	SH	45J/2A	7. 7.71	Q	7.3	4,930	2,850	1.2	2.4	45.31	0.28	Nil	19.6	27.49	2.6	190	33.0	16.0
Antroli	SH	45J/1B	- 10.71	Q	8.2	1,099	680	1.0	1.4	7.99	-	Nil	5.2	4.79	0.4	120	9.5	2.8
Bagot	SH	45J/1C	4. 8.71	Q	7.4	2,165	1,346	0.8	0.6	20.36	-	Nil	8.8	11.56	1.4	70	24.8	7.4
Bamra	SH	45J/1A	15. 7.71	Q	7.6	4,775	3,026	4.8	7.4	36.39	0.54	Nil	8.4	33.13	7.6	610	14.7	- 3.8
Barnil	SH	45J/1E	-.10.71	Q	7.8	1,520	918	0.6	0.8	12.41	-	Nil	11.6	1.41	0.8	70	14.8	10.2
Bhainsra	SH	45J/2A	-. 5.71	Q	7.3	4,204	2,600	1.8	3.2	36.53	0.25	Nil	9.2	25.98	7.2	250	23.1	4.2
Chondian	SH	45J/2A	22. 6.71	Q	7.6	3,486	2,156	1.2	3.0	30.28	0.20	Nil	9.4	22.28	3.00	210	20.8	5.2
Dangawas	SH	45J/2A	22. 8.73	Q	7.5	940	520	0.4	0.2	8.5	-	Nil	4.6	3.1	1.4	30	15.5	4.0
Dhaneri	SH	45J/3A	14. 4.73	Q	7.6	3,221	2,204	2.2	3.0	27.32	-	Nil	9.4	23.12	-	260	16.8	4.2
Kekind	SH	45J/3A	8. 4.72	Q	8.2	1,554	866	0.8	0.8	13.69	-	Nil	9.2	4.09	2.0	80	15.4	7.6
						lower aquifer												
Kitalsar	SH	45J/1B	29. 7.71	Q	7.90	2,647	1,678	0.8	0.6	25.19	0.28	Nil	13.2	9.87	3.8	70	30.3	11.8
Luniawas	SH	45J/1B	20. 7.71	Q	7.7	680	426	1.6	1.4	3.8	0.2	Nil	4.6	2.4	tr.	150	3.1	1.6
Tamroli	SH	45J/1B	20. 7.71	Q	8.4	10,210	7,576	2.0	6.8	110.06	0.46	2.0	11.6	73.32	32.4	440	52.5	4.8
(b) Western part																		
Lai	SH	45F/2D	22. 5.71	NS	7.3	10,210	7,112	4.2	25.4	84.78	0.47	Nil	4.0	94.45	16.4	1,480	22.0	-25.6
Merta City	SH	45J/2A	4. 7.71	NL	7.6	28,496	18,180	32.0	21.0	233.45	0.95	Nil	3.2	248.2	36.0	2,650	45.0	-49.8
Oladan	SH	45F/1D	23. 6.71	PHS	7.2	1,554	826	1.4	2.0	11.65	0.30	Nil	7.0	7.75	0.6	170	8.7	3.6
Kashnau	Existing TW	45I/4A	1970	PHS	7.45	7,143	4,720	6.0	13.5	52.4	-	Nil	9.2	52.0	10.7	980	16.8	-10.3

Annex 8 (continued)

Well No.	pH	Conductivity (in micromhos/cm)	TDS in ppm at 180°C	SiO_2 ppm	Constituents in Meq/l										B ppm	Total hardness (Ca, Mg) as $CaCO_3$	SAR	U.S.Salinity Lab. Classification	RSC
					Ca^{3+}	Mg^{2+}	Na^{2+}	K^{+}	CO_3^{2-}	HCO_3^{2-}	Cl^{-}	SO_4^{2-}	NO_3	F					
45J/1C-10	7.60	895	632	28	2.00	1.90	8.70	1.80	Nil	7.50	2.03	1.40	1.03	0.03	0.57	195	6.21	C_3 S_1	3.60
45J/1B-5	7.55	4,532	2,986	26	4.80	6.00	41.32	0.08	Nil	13.80	33.72	2.20	3.55	0.12	1.68	540	17.78	C_4 S_2	3.00
45J/1D- (Gachipura-3)	7.50	5,708	3,642	24	6.30	7.30	46.11	0.08	Nil	7.90	50.07	0.60	2.01	0.06	1.50	680	17.67	C_4 S_2	-5.70
45J/1C-6(a)	7.45	1,771	1,148	23	3.20	1.60	14.35	0.16	Nil	7.90	6.26	2.00	3.47	-	1.88	240	9.26	C_3 S_1	3.10
44L/4C-2	7.70	2,056	1,372	20	1.20	1.20	19.00	0.07	Nil	8.20	11.42	2.00	0.74	0.05	0.93	120	17.34	C_3 S_2	5.80
44L/3C-9	7.40	2,431	1,528	25	2.80	5.80	16.40	0.23	Nil	6.20	16.22	2.10	0.84	0.03	0.55	430	7.90	C_4 S_1	-2.40
44L/2B-4	7.25	1,674	1,126	30	4.60	2.80	9.44	0.13	Nil	3.60	9.59	1.40	2.13	-	0.80	370	4.91	C_3 S_1	-3.80
44L/4A-8	7.30	1,012	710	23	3.20	2.30	4.61	0.11	Nil	3.90	2.68	0.70	2.98	-	0.68	275	2.71	C_3 S_1	-1.60
44L/4B-8	7.30	1,995	1,276	20	4.20	2.70	13.90	0.14	Nil	5.80	11.42	2.80	1.37	-	0.57	345	7.50	C_3 S_1	-1.10
44L/3B-12	7.35	675	390	24	2.50	1.70	3.52	0.13	Nil	5.30	1.55	0.90	0.27	-	0.45	210	2.42	C_2 S_1	1.10
44L/3B-2	7.20	1,450	942	22	2.00	2.60	11.48	0.21	Nil	7.60	3.81	2.20	3.81	-	0.62	230	7.57	C_3 S_1	3.00
44L/4D-5	7.20	1,777	1,334	21	3.50	3.50	11.92	0.15	Nil	5.50	4.09	1.90	7.74	-	1.29	350	6.37	C_3 S_1	-1.5
44L/3D-11	7.30	2,248	1,430	17	2.70	2.80	18.14	0.08	Nil	5.80	12.27	5.40	1.31	-	0.45	275	10.90	C_3 S_2	0.30
44P/4B-2	7.40	519	360	35	4.00	1.80	1.35	0.12	Nil	5.10	0.56	0.70	0.92	-	0.25	290	0.79	C_2 S_1	0.70
44P/4B-19	7.30	1,823	1,230	20	2.60	2.60	15.53	0.06	Nil	12.70	4.85	1.40	2.25	-	0.63	260	9.63	C_3 S_1	7.50
44P/4A-11	7.19	1,194	708	22	2.50	4.70	6.78	6.06	Nil	8.40	4.14	1.20	0.57	0.12	0.55	360	3.57	C_3 S_1	1.20
44P/4B-8	7.35	2,932	1,818	23	3.20	2.80	25.53	0.08	Nil	10.60	18.19	1.90	0.64	-	1.66	300	14.74	C_4 S_2	4.60
45M/2A-11	8.40	644	340	28	1.30	1.60	2.96	0.09	1.00	3.00	0.90	0.20	0.61	-	0.19	145	2.46	C_2 S_1	1.10
45M/3A-1	7.60	844	610	26	1.90	1.30	6.09	0.04	Nil	6.60	2.40	0.40	0.44	-	0.30	160	4.80	C_3 S_1	3.40

Annex 8 (continued)

Well No.	pH	Conductivity (in micromhos/cm)	TDS in ppm at 180°C	SiO_2 ppm	Constituents in meq/l										B ppm	Total hardness (Ca, Mg) as $CaCO_3$	SAR	U.S. Salinity Lab. Classification	RSC
					Ca^{3+}	Mg^{2+}	Na^{2+}	K^{+}	CO_3^{2-}	HCO_3^{2-}	Cl^{-}	SO_4^{2-}	NO_3	F					
45I/4A-4	7.45	848	496	23	3.00	2.40	4.70	0.12	Nil	7.10	0.49	2.20	0.57	0.006	0.20	270	2.86	C_3 S_1	1.7
45I/2A-4	7.90	1,042	702	26	3.40	3.60	4.91	0.44	Nil	4.10	4.57	1.60	2.24	-	0.55	350	3.62	C_3 S_1	-2.9
45J/1C-6	7.50	1,676	1,060	24	2.60	1.10	14.35	0.13	Nil	7.70	8.60	1.50	1.13	0.03	0.68	185	10.60	C_3 S_2	4.0
45J/1B-10	8.00	2,364	1,670	24	2.40	1.80	21.75	0.09	Nil	11.50	7.47	2.20	5.2	0.02	1.59	210	15.00	C_4 S_2	7.20
45J/1B-9	7.50	2,648	1,786	29	2.20	2.80	25.53	0.09	Nil	13.40	13.45	3.00	1.06	0.09	0.73	250	16.15	C_4 S_2	10.80
45J/1B-9	7.50	2,499	1,860	22	1.80	1.60	28.14	0.05	Nil	14.20	14.10	2.30	0.83	0.18	1.14	170	21.58	C_4 S_3	10.80
45J/2A-8	7.50	2,136	1,444	34	4.80	4.80	13.49	0.32	Nil	8.80	6.32	2.40	4.87	0.04	1.39	480	6.20	C_3 S_1	-0.8
45J/2B-9	8.05	3,069	2,044	31	1.70	2.40	29.14	0.10	Nil	5.60	22.56	3.10	1.99	0.21	0.93	205	20.00	C_4 S_3	1.5
45J/2A-14	7.90	1,151	740	28	2.00	3.40	7.44	0.11	Nil	7.90	3.67	1.00	0.66	-	0.45	270	4.53	C_3 S_1	2.50
45J/2B-10	7.60	883	638	25	1.50	2.30	6.92	0.13	Nil	9.00	1.55	0.60	0.24	0.05	0.28	190	5.02	C_3 S_1	5.20
45J/1A-6	8.40	1,482	1,152	26	2.50	4.70	10.09	0.12	1.60	6.60	2.68	1.40	4.75	0.15	1.22	360	5.32	C_3 S_1	1.00
45J/3A-12	8.30	1,591	1.034	28	3.00	2.60	13.47	0.12	0.80	8.80	6.40	1.20	1.33	0.58	0.62	280	8.05	C_3 S_1	4.00
45J/3A-3	7.40	1,047	724	27	4.4	1.70	6.09	0.15	Nil	4.80	4.00	1.10	2.01	0.01	0.63	305	3.47	C_3 S_1	-1.3
45J/3A-18	7.30	998	618	26	2.60	1.30	7.39	0.05	Nil	7.40	3.31	1.00	0.29	0.03	0.29	195	5.28	C_3 S_1	3.50
45J/1B-6	8.10	2,088	1,452	22	0.70	2.00	21.75	0.03	Nil	12.80	7.61	0.90	2.13	0.32	1.14	135	18.70	C_3 S_3	10.10
45J/1C-1	7.80	5,140	3,402	28	2.50	5.60	47.20	0.06	Nil	19.30	28.82	3.20	4.87	0.34	2.55	405	23.50	C_4 S_3	11.20
45J/1C-2	8.90	2,305	1,586	25	0.90	1.00	23.18	0.03	3.60	10.50	5.98	0.20	3.91	0.30	1.54	925	23.80	C_4 S_3	12.20
45J/1C-3	7.95	1,831	1,170	31	1.60	1.10	17.70	0.08	Nil	15.80	3.38	0.60	0.96	0.07	0.84	135	15.20	C_3 S_3	13.10
45J/1B-4	7.45	6,420	4,450	39	4.70	7.10	58.72	0.18	Nil	14.00	40.11	6.20	10.40	0.45	2.52	590	24.17	C_4 S_3	2.20
45J/1B-19	7.35	2,568	1,650	38	8.60	5.10	11.52	1.0	Nil	6.00	18.76	2.30	0.35	-	0.42	685	4.40	C_4 S_1	-7.70

Annex 8 (continued)

Well No.	pH	Conductivity (in micromhos/cm)	TDS in ppm at 180°C	SiO_2 ppm	Constituents in meq/l										B ppm	Total hardness (Ca, Mg) as $CaCO_3$	SAR	U.S. Salinity Lab. Classification	RSC
					Ca^{3+}	Mg^{2+}	Na^{2+}	K^{+}	CO_3^{2-}	HCO_3^{2-}	Cl^{-}	SO_4^{2-}	NO_3	F					
45E/2D-1	7.40	1,714	1,414	26	6.90	3.70	13.48	0.56	Nil	7.00	11.34	3.90	2.50	0.01	0.42	530	5.85	C_4 S_1	-3.60
45E/2D-11	7.80	2,570	1,832	18	1.10	0.70	23.6	0.07	Nil	7.40	5.08	1.90	11.09	0.17	1.84	90	24.83	C_4 S_3	5.60
45E/2A-4	7.20	3,107	1,924	35	7.30	4.10	19.42	0.17	Nil	5.60	22.00	4.80	0.11	0.01	0.25	570	7.95	C_3 S_1	-5.80
45E/2C-2	7.20	1,806	982	21	3.80	1.70	13.49	0.18	Nil	5.40	9.02	2.70	2.58	-	0.22	275	8.12	C_3 S_1	-0.10
45E/1B-12	7.30	2,905	1,932	21	5.50	5.00	18.55	0.08	Nil	7.00	15.57	1.10	5.64	0.05	0.98	525	8.10	C_4 S_1	-3.50
45E/1A-12	7.30	902	562	21	3.80	2.50	3.15	0.12	Nil	5.60	2.40	0.10	0.37	0.02	0.25	315	1.71	C_3 S_1	-0.70
45E/2A-13	7.20	1,674	1,042	28	2.80	1.80	11.51	0.1	Nil	6.20	7.55	2.30	0.12	0.02	0.32	230	7.59	C_3 S_1	1.60
45E/1D-2	7.20	846	526	22	2.20	1.70	4.35	0.14	Nil	3.40	2.40	0.80	1.35	-	0.14	195	3.10	C_3 S_1	-0.50
45E/1D-7	7.30	759	558	23	3.20	1.10	2.70	0.20	Nil	3.60	1.69	0.70	1.37	-	0.19	215	1.84	C_3 S_1	-0.70
45E/2D-5	7.60	1,132	920	21	3.40	1.30	6.17	0.13	Nil	4.10	2.03	0.20	4.64	-	0.41	235	4.02	C_3 S_1	-0.60

Annex 8 (continued)

Well No.	pH	Conductivity (in micromhos/cm)	TDS in ppm at 180°C	SiO_2 ppm	Constituents in Meq/l										B ppm	Total hardness (Ca, Mg) as $CaCO_3$	SAR	U.S. Salinity Lab. Classification	RSC
					Ca^{3+}	Mg^{2+}	Na^{2+}	K^{+}	CO_3^{2-}	HCO_3^{2-}	Cl^{-}	SO_4^{2-}	NO_3	F					
45M/3A-3	7.40	642	434	29	2.80	1.70	2.57	0.11	Nil	5.00	0.85	0.30	1.03	-	0.18	225	1.71	C_2 S_1	0.50
45M/1A-2	7.70	1,730	1,100	18	1.20	1.50	16.48	0.03	Nil	11.20	6.49	1.30	0.89	0.07	0.55	135	14.20	C_3 S_2	8.50
45M/1A-16	7.60	2,094	1,390	17	1.70	0.50	19.70	0.08	Nil	13.00	6.40	1.30	1.77	0.11	0.54	110	18.78	C_3 S_2	10.80
45M/1D-6	7.75	1,238	722	17	0.80	0.20	11.96	0.06	Nil	10.40	2.11	0.20	0.62	0.10	0.26	50	16.91	C_3 S_2	9.40
45M/1A-18	8.80	896	560	21	1.10	0.50	7.61	0.04	Nil	6.40	2.40	0.30	0.64	0.21	0.34	80	8.51	C_3 S_1	4.80
45M/3A-17	7.80	1,024	602	42	2.90	2.90	6.09	0.07	Nil	7.80	1.55	1.00	1.49	-	0.92	290	3.51	C_3 S_1	2.00
45M/4A-2	7.80	592	326	26	2.80	1.60	2.61	0.11	Nil	5.20	0.85	0.80	0.52	-	0.02	220	1.75	C_2 S_1	0.80
44H/4C-1	8.40	1,944	1,132	26	1.20	2.00	11.83	0.16	0.8	5.40	9.59	3.10	1.59	0.01	0.99	160	13.30	C_3 S_2	3.0
44H/3C-10	7.40	2,127	1,526	21	2.40	2.40	16.10	0.15	Nil	7.00	6.40	3.00	6.13	0.07	0.38	240	10.91	C_3 S_2	2.20
44H/4C-5	7.20	2,890	2,640	19	4.80	6.40	26.10	0.17	Nil	4.00	18.75	3.80	10.08	-	1.12	560	11.03	C_4 S_2	-7.20
44H/4C-8	7.60	821	468	21	1.00	0.90	6.92	0.07	Nil	5.70	1.75	1.10	0.28	0.05	0.16	95	7.10	C_3 S_1	3.80
44H/4A-7	7.40	2,014	1,384	24	2.70	6.60	16.83	0.27	Nil	7.70	8.52	7.50	2.20	0.11	0.54	465	7.80	C_3 S_1	-1.68
45A/1D-5	7.50	2,108	1,280	18	3.40	2.20	14.96	0.07	Nil	6.00	12.60	3.20	0.08	0.11	0.32	280	8.90	C_3 S_1	0.40
45F/2D-9	7.30	642	390	33	3.80	0.80	2.70	0.17	Nil	4.80	1.89	0.40	0.23	-	Trace	230	1.78	C_2 S_1	0.20
45F/3D-8	7.40	613	314	26	2.40	1.20	3.26	0.12	Nil	4.40	1.75	0.80	0.19	0.14	0.16	180	2.69	C_2 S_1	0.80
45F/3D-6	7.95	642	450	22	3.00	0.80	3.09	0.21	Nil	4.80	1.27	0.50	0.45	0.02	0.18	190	2.42	C_2 S_1	1.00
45F/1D-6	7.80	665	414	35	3.60	2.60	2.39	0.08	Nil	5.90	1.61	1.00	0.49	0.05	0.30	310	1.35	C_2 S_1	-0.30
45F/2D-3	7.60	941	600	20	5.80	2.80	2.91	0.13	Nil	9.10	2.26	0.50	0.18	0.02	0.34	430	1.40	C_3 S_1	0.50
45E/1C-5	8.30	902	644	27	3.60	0.80	5.39	0.77	0.80	5.00	2.54	0.60	1.33	0.06	0.36	220	3.64	C_3 S_1	1.40
45F/1C-12	8.35	786	412	17	1.30	0.30	7.09	0.15	1.00	4.60	2.45	0.80	0.30	0.02	0.09	80	7.93	C_3 S_1	4.00

Annex 9 (continued)

Tehsil	Area	Dug wells (mote)				Wells with oil engine				Wells with elec. pump				Total draft for irrigation	Domestic consumption	Total present Draft
		No.	Discharge	Pumping time	Draft	No.	Discharge	Pumping time	Draft	No.	Discharge	Pumping time	Draft			
	(km^2)		m^3/h	h/yr	MCM/yr		m^3/h	h/yr	MCM/yr		m^3/h	h/yr	MCM/yr	MCM/yr	MCM/yr	MCM/yr
SIKAR DISTRICT																
Fatehpur	1,069.8	958	6	600	3.45	7	13	800	0.07	64	15	800	0.77	4.29	2.07	6.36
Lachhman-garh	1,219.2	407	6	600	1.47	15	13	800	0.16	213	15	800	2.56	4.19	2.26	6.45
*Sikar	*1,251	926	6	600	3.33	42	13	800	0.44	619	15	800	7.43	11.20	3.42	14.62
*Danta Ram-garh	* 457.0	1,236	3	600	2.22	68	13	800	0.71	96	15	800	1.15	4.08	0.82	4.90
Total	3,997	5,120			10.47	132			1.38	992			11.91	23.76	8.57	32.33
NAGAUR DISTRICT																
Ladnun	38,1	3	6	600	0.01	--	--	--	--	15	17	400	0.10	0.11	0.17	0.28
Didwana	1,004.5	450	6	600	1.62	29	13	800	0.30	340	15	800	4.08	6.00	1.75	7.75
Parbat-sar	351.4	554	10	960	5.32	18	15	800	0.22	12	15	800	0.14	5.68	0.72	6.4
Nawa	548.7	1,819	6	600	6.55	137	18	800	1.97	190	15	1,120	3.19	11.71	1.22	12.93
Total	1,942.7	2,954			13.5	188			2.49	559			7.51	23.5	3.86	27.36
Grand total	14,464	9,747			28.13	351			4.19	2,307			27.03	59.35	23.66	83.01

* Area of Sikar and Danta Ramgarh includes basement - 59.2 and 65.8 km^2 respectively.

Annex 9

Present ground-water draft in Sikar basin

Tehsil	Area	Dug wells (mote)				Wells with oil engine				Wells with elec. pump				Total draft for irrigation	Domestic consumption	Total present Draft
		No.	Discharge	Pumping time	Draft	No.	Discharge	Pumping time	Draft	No.	Discharge	Pumping time	Draft			
	(km^2)		m^3/h	h/yr	MCM/yr		m^3/h	h/yr	MCM/yr		m^3/h	h/yr	MCM/yr	MCM/yr	MCM/yr	MCM/yr
CHURU DISTRICT																
Taranagar	934.9	--	--	--	--	--	--	--	--	--	--	--	--	--	0.69	0.69
Rajgarh	517.2	--	--	--	--	--	--	--	--	--	--	--	--	--	0.35	0.35
Churu	1,588.1	24	3	960	0.07	--	--	--	--	69	15	800	0.83	0.90	2.15	3.05
Sardar-Shahar	1,371.0	6	6	600	0.02	--	--	--	--	9	15	800	0.11	0.13	0.82	0.95
Ratangarh	1,583.1	122	6	600	0.44	--	--	--	--	57	15	800	0.68	1.12	1.77	2.89
Sujangarh	678.4	56	6	600	0.20	--	--	--	--	13	15	400	0.08	0.28	0.86	1.14
Total	6,672.6	208			0.73					148			1.70	2.43	6.64	9.07
JHUNJHUNU DISTRICT																
Jhunjhunu	1,321.2	1,278	3	600	2.30	22	10	400	0.18	234	15	400	1.40	3.88	3.04	6.92
Udaipurvati (Nawalgarh)	530.4	315	6	600	1.13	13	13	800	0.14	376	15	800	4.51	5.78	1.55	7.33
Total	1,851.6	1,593			3.43	35			0.32	610			5.91	9.66	4.59	14.25

Annex 10

Present ground-water draft in Bikaner and Luni basins **

Tehsil	Area	Wells with mote				Wells with oil engine				Wells with elec. pump				Total draft for irrigation	Domestic consumption	Total draft
		No.	Discharge	Pumping time	Draft	No.	Discharge	Pumping time	Draft	No.	Discharge	Pumping time	Draft			
	km2		m^3/h	h/yr	MCM/yr		m^3/h	h/yr	MCM/yr		m^3/h	h/yr	MCM/yr	MCM/yr	MCM/yr	MCM/yr
BIKANER DISTRICT																
Lunkaransar	2,286	0			0	0			0	0			0	0	0.61	0.61
Kolayat	1,201	0			0	0			0	0			0	0	2.15	2.15
Bikaner	2,596	0			0	0			0	4	12	800	0.04	0.04	4.71	4.75
Nokha	2,441	0			0	0			0	4	12	300	0.01	0.01	0.15	0.16
Total	8,524	0			0	0			0	8			0.05	0.05	7.62	7.67
CHURU DISTRICT																
Sardarshahr *	1,702	7	6	600	0.03	1	15	800	0.01	11	15	800	0.13	0.17	1.06	1.23
Dungargarh	2,966	2	6	600	0.01	0			0	22	12	400	0.10	0.11	1.53	1.64
Ratangarh *	112	8	6	600	0.03	0			0		15	800	0.04	0.07	0.11	0.18
Sujangarh *	1,977	151	6	600	0.54	9	13	800	0.07	35	13	400	0.21	0.82	1.72	2.54
Total	6,757	168			0.61	10			0.08	71			0.48	1.17	4.42	5.59

* One part in Sikar basin.

** including basement areas.

Annex 10

Present ground-water draft in Bikaner and Luni Basins

Annex 11

Summary of ground-water resources in the Rajasthan Project area, by district

District	Area	Present draft for			Present Available Resources					Expected domestic consumption til 1994		Expected water resources in 1994		
		Irrigation	Domestic consumption	Total	TDS <3,000 ppm		3,000 TDS -5,000 ppm		Total (with TDS <5,000 ppm)			TDS<3,000 ppm	3,000 TDS 5,000 ppm	Total (TDS <5,000 ppm)
	km^2	MCM	MCM	MCM	km^2	MCM	Km^2	MCM	km^2	MCM	MCM	MCM	MCM	
Bikaner	8,524.0	0.05	7.62	7.67	6,274.0	69.64	1,027.0	13,49	1,301,0	83.13	9.53	60.11	13.49	13.6
Churu	13,429.6	3.60	11.06	14.66	8,942.0	142.12	1,887,8	48.92	16,860.2	195.04	13.96	132.16	48.92	181.1
Jhunjhunu	1,851.6	9.66	4.59	14.25	1,525.0	36.07	251.9	8.31	1,776.9	45.08	5.78	30.99	8.31	39.3
Nagaur	13,059.7	37.57	14.74	52.31	9,974.0	155.55	1,965.8	33.59	11,939.8	189.14	18.50	137.05	33.59	170.6
Sikar	3,997.0	23.76	8.57	32.33	3,701.3	89.81	160.8	5.30	3,862.1	95.11	10.81	79.00	5.30	84.3
Total	40,862	74.6	46.6	121.2	30,416.3	497.2	5,293.3	109.6	35,740.0	607.5	58.6	439.3	109.6	548.9

Annex 10 (continued)

Tehsil	Area	Wells with(mote)				Wells with oil engine				Wells with elec. pump				Total draft for irrigation	Domestic consumption	Total draft
		No.	Discharge	Pumping time	Draft	No.	Discharge	Pumping time	Draft	No.	Discharge	Pumping time	Draft			
	km^2		m^3/h	h/yr	MCM/yr		m^3/h	h/yr	MCM/yr		m^3/yr	h/yr	MCM/yr	MCM/yr	MCM/yr	MCM/yr
NAGAUR DISTRICT																
Nagaur	2,444	16	6	600	0.06	5	15	800	0.06	20	15	500	0.15	0.27	2.16	2.43
Jael	2,070	24	6	600	0.09	15	15	800	0.18	66	15	800	0.79	1.06	1.76	2.82
Ladnun	1,218	26	6	600	0.09	4	18	800	0.06	139	15	400	0.83	0.98	1.61	2.59
Didwana*	665	50	6	600	0.18	3	13	800	0.03	38	15	800	0.46	0.67	0.25	0.92
Parbatsar *	1,242	256	10	960	2.46	8	15	800	0.10	4	15	800	0.06	2.62	1.10	3.72
Merta	1,980	111	6	600	0.40	75	12	800	0.72	416	12	800	4.00	5.12	1.85	6.97
Degana	1,498	610	6	600	2.20	38	12	800	0.36	83	12	800	0.79	3.35	2.15	5.50
Total	11,117	1,093			5.48	138			1.51	766			7.08	14.07	10.88	24.95
Grand total	26,398	1,261			6.09	148			1.59	845			7.61	15.29	22.92	38.21

* One part in Sikar Basin.

Annex 12 (continued)

Location Fine, coarse	Depth range (cm)	Mechanical analysis (%)				Hydraulic conductivity cm/h	Maximum water holding capacity (%)	Bulk density	Moisture (%)		Available moisture (%)
		Clay	Silt	Fine sand	Coarse sand				at 0.3 atm	at 15.0 atm	
Lunkaransar	0- 10	6.7	7.2	85.2	1.5	6.7	21.0	1.68	3.13	1.95	1.18
-do-	10- 60	7.5	9.8	76.5	2.5	4.6	29.4	1.55	8.21	6.83	1.38
-do-	60- 73	10.3	9.6	74.2	2.0	2.8	31.3	1.47	10.70	4.36	6.34
-do-	below 73	9.3	9.0	70.5	1.5	2.1	30.5	1.46	10.53	4.62	5.91
Raneri	0- 65	9.5	9.3	74.1	4.5	2.9	23.6	1.61	7.02	4.01	3.01
-do-	65-132	10.1	12.0	70.8	3.5	1.6	30.8	1.46	11.49	5.67	5.82
Bigga	0- 53	7.0	8.2	81.5	2.5	8.7	24.3	1.60	2.00	0.31	1.69
-do-	53-130	4.8	8.8	83.0	2.7	9.6	22.9	1.60	1.84	0.96	0.88
Buchas	0- 45	6.0	6.2	85.2	2.3	5.7	29.4	1.55	4.68	2.73	1.95
-do-	45-130	10.2	6.9	80.0	3.0	4.6	31.8	1.49	5.50	3.13	2.37
Churu	0- 25	1.2	2.3	50.5	46.0	8.4	23.9	1.57	2.75	1.72	1.03
-do-	25-115	4.0	6.4	51.5	37.5	6.0	28.9	1.51	6.20	2.30	3.90
-do-	115-265	4.5	7.8	55.7	32.0	7.3	29.2	1.53	5.52	2.80	2.72
Jhunjhunu	0- 25	4.3	10.2	46.2	39.0	2.7	26.9	1.53	3.86	2.34	1.52
-do-	25-135	4.8	7.7	46.0	21.5	6.5	29.1	1.49	5.15	2.47	2.68
Ratangarh	0-120	12.8	17.8	29.0	24.0	0.9	39.3	1.41	9.39	4.25	3.16
-do-	120-190	8.4	16.6	29.5	36.0	0.5	31.2	1.46	8.37	4.10	4.27
Salasar	0- 20	7.6	10.3	59.0	19.0	0.1	34.5	1.40	11.03	6.35	4.68
-do-	20- 40	11.3	14.7	44.7	24.8	0.1	41.1	1.41	16.06	8.70	7.36
-do-	40-130	17.2	12.9	51.0	10.5	0.2	39.3	1.34	36.25	14.06	12.19
Nawalgarh	0-115	4.5	9.2	42.5	43.5	6.5	27.5	1.51	4.07	2.25	1.82
-do-	115-132	3.8	8.4	45.0	41.4	8.0	30.8	1.51	4.83	2.27	1.56

Annex 12

Physical properties of Soils in Project Area, Rajasthan
(Analysed by UNDP Project Soil Laboratory, Central Ground Water Board, Jodhpur)

Location Fine, coarse	Depth range (cm)	Mechanical analysis (%)				Hydraulic conductivity cm/h	Maximum water holding capacity (%)	Bulk density	Moisture (%)		Available moisture (%)
		Clay	Silt	Fine sand	Coarse sand				at 0.3 atm	at 15.0 atm	
Sital	0-140	5.4	6.8	81-7	2.8	8.8	20.4	1.64	3.92	1.79	1.64
-do-	140-200	6.8	8.1	76.0	3.6	7.4	21.8	1.61	3.68	1.61	2.07
-do-	below 200	4.2	2.8	80.6	5.9	7.8	21.0	1.63	6.07	2.22	3.85
Palana	0- 90	11.2	13.3	71.4	2.0	4.1	28.6	1.54	9.71	4.49	5.22
-do-	90-120	7.5	10.7	75.4	3.0	3.9	27.8	1.56	7.33	3.63	3.70
-do-	120-140	8.1	9.0	72.0	1.7	4.0	28.0	1.55	7.61	3.92	3.79
Nokha	0- 80	6.2	3.8	87.7	2.2	10.9	20.3	1.65	1.51	0.39	1.13
-do-	80-130	6.8	7.7	82.8	1.5	8.7	23.0	1.59	3.76	2.09	1.67
-do-	below 130	8.1	6.4	79.0	1.8	6.5	22.6	1.57	4.07	1.93	2.14
Massuri	0-130	3.1	5.3	90.1	1.5	13.6	21.8	1.64	2.12	0.71	1.41
Lakhasar	0- 70	5.9	13.8	76.7	1.5	4.5	22.4	1.62	3.03	1.07	1.96
-do-	70- 90	8.4	8.7	77.8	1.8	3.8	23.5	1.60	5.57	2.54	3.03
-do-	90-130	9.1	8.9	73.4	1.5	2.9	24.0	1.60	7.08	2.26	4.82
Sandwa	0-130	4.5	3.5	90.5	1.5	11.2	20.8	1.63	2.63	1.45	1.18
Sardarshahr	0- 40	6.3	8.0	83.4	1.0	8.0	20.1	1.68	2.74	1.42	1.32
-do-	40- 80	11.6	12.4	71.0	1.5	4.3	23.5	1.60	6.27	3.72	2.55
-do-	80-120	10.8	10.2	65.0	1.5	2.9	34.8	1.35	20.85	12.53	8.32
-do-	120-190	11.3	10.0	60.5	1.9	1.9	38.1	1.31	26.47	17.83	8.64

Annex 7

Chemical analyses of water from project boreholes, Rajasthan area

Location	Type of well*	Toposheet No.	Date of collection	Aquifer**	pH Lab.	Conductivity***	TDS (mg/l)	Constituents in meq/litre Ca^{2+}	Mg^{2+}	$Na^{2-}+K^{+}$	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4	Hardness****	SAR	RSC
Sikar Basin																	
Anandpura	TW	45I/4D	9. 2.72	Q	7.7	2,151	1,270	2.4	6.0	13.87	0.19	Nil	10.6	8.46	3.2	410	5.8	2.2
Dadhia	TW	45M/2A	-	Q	7.7	529	268	0.8	0.6	2.64	-	Nil	3.2	0.846	Tr.	70	3.1	1.8
Fatehpur	TW	45I/1D	1. 4.73	Q	7.7	2,732	1,826	1.3	2.7	27.21	-	Nil	19.5	8.11	3.6	200	19.0	15.5
Jhunjhunu	TW	44P/4B	- 2.73	Q	7.75	2,006	1,250	1.2	3.2	17.51	-	Nil	13.8	6.31	1.8	220	12.8	9.4
Makundgarh	TW	45M/1A	2.12.72	Q	8.2	1,227	786	1.2	0.9	10.08	-	Nil	7.4	5.5	Tr.	105	10.5	5.3
Setolao	TW	45M/2A	25. 2.74	Q	7.75	715	380	2.0	1.10	5.83	0.07	Nil	4.6	2.18	0.3	155	4.7	1.5
Talab-ki-Dhani	TW	45I/2D	25. 2.73	Q	7.3	3,445	2,316	2.4	5.9	18.00	-	Nil	12.9	10.99	2.4	415	13.8	4.8
Biramsar	SH		10. 1.73	Q	7.5	3,644	2,408	1.6	5.7	30.00	0.23	Nil	12.1	15.79	8.1	365	15.6	5.8
Chhapribari	SH	45I/3C	19. 8.71	Q	7.3	1,458	836	0.6	0.4	12.59	-	Nil	8.0	4.79	0.8	50	17.8	7.0
Kolasar	SH	45I/1C	6.12.73	Q	8.2	10,847	7,256	2.8	8.2	80.93	-	Nil	10.4	67.63	13.90	550	35.0	- 0.6
Losal	SH	45I/3D	20.12.71	Q	8.0	1,588	1,060	1.2	3.8	10.33	0.18	Nil	8.4	4.51	2.6	250	6.5	3.4
Ranasar	SH	45I/4D	27. 8.71	Q	7.6	1,934	1,004	2.0	3.6	11.98	-	Nil	7.8	8.18	1.6	280	7.2	2.2
Ratangarh	SH	44L/4C	7. 9.73	Q	7.8	2,347	1,686	1.6	1.6	23.40	0.25	Nil	5.2	16.35	2.8	160	18.4	2.0
Bikaner Basin																	
Bandnau	TW	44L/2B	15. 6.74	P	7.4	907	516	2.0	0.9	7.60	0.01	Nil	5.0	2.70	0.7	145	6.5	2.1
Bhamatsar	TW	45E/2B	13. 2.73	NS	8.0	1,662	1,050	0.8	1.2	15.00	0.13	Nil	2.8	8.32	6.0	100	15.0	0.8
Gadhwala I	TW	45E/1B	28. 8.73	NS	7.6	2,107	1,320	4.4	2.4	15.00	0.15	Nil	3.0	14.52	14.2	340	8.1	- 3.8
Gadhwala II	TW	45E/1B	23.11.73	P	7.5	800	464	0.9	0.9	11.74	-	Nil	4.3	3.24	1.4	90	11.1	2.5
Jasrasar	TW	45E/2D	7. 7.74	P	7.35	2,527	1,466	4.8	2.4	16.52	0.02	Nil	4.0	11.68	2.0	260	8.2	- 3.2
Karmisar	TW	44H/4B	24. 3.73	P	7.9	2,698	1,656	1.2	1.2	24.00	0.19	Nil	7.6	15.37	4.2	120	22.0	5.2
Mudh	TW	45A/1D	-	NS	8.0	4,087	2,707	8.2	7.4	28.4	0.40	Nil	2.6	30.74	9.0	780	10.0	-13.0
Pharrod	TW	45I/4A	4. 5.74	NS	7.0	26,622	22,704	40.0	47.5	299.0	0.77	Nil	4.8	309.86	7.5	4,375	45.5	-82.7
Raneri	TW	45A/2D	23. 6.74	P	7.45	2,301	1,298	5.0	3.1	15.87	0.01	Nil	5.3	13.37	3.2	405	7.9	- 2.8
Sital	TW	44H/1C	19. 4.74	NS	7.35	2,210		4.5	3.5	15.0	0.16	Nil	2.8	14.8	4.8	400	7.5	- 5.2
Dhanipura	SH	44L/2B	25.11.73	NS	8.5	5,598	3,882	4.5	6.0	48.71	-	Nil	4.9	51.61	2.3	505	21.6	5.2
Jodhyasi	SH	45E/3D	- 4.74	NS	7.4	46,032	29,110	55.0	12.5	407.61	4.82	Nil	10.7	292.25	22.5	3,375	70.0	-56.8
Manasir	SH	45E/4C	-	NL (top)	7.5	19,620	14,204	38.0	21.6	160.0	0.41	Nil	4.2	155.1	56.0	2,980	29.5	-55.4
Manasir	id.		-	NL (bottom)	-	10,490	8,740	30.0	10.4	90.0	0.56	Nil	2.2	52.17	67.6	2,020	36.8	-38.2

* TW - Tubewell
SH - Slim hole

** Aquifer : Q - Quaternary Sand
P - Palana Sandstone
NS - Nagaur Sandstone
NL - Nagaur Limestone

*** Electric conductivity in micromhos at 25°C.

**** Total hardness (Ca, Mg) as $CaCO_3$ expressed in mg/litre.

Annex 6 (continued)

Location	Ca/Mg	Cl/HCO_3	Ca/Na	Na/Cl	$\frac{Na\ (ppm)}{TDS\ (ppm)}$
		Luni Basin			
Butati	1.10	0.44	0.08	3.83	0.32
Chandarun	0.75	0.29	0.13	4.08	0.32
Dangawas	0.50	1.38	0.04	1.86	0.35
Dangawas-4	3.80	0.73	0.25	2.00	0.30
Degana	0.67	2.24	0.04	1.49	0.40
Gachhipura-1	0.66	2.34	0.09	1.34	0.34
Gachhipura-2	0.57	1.47	0.08	1.56	0.34
Gachhipura-3	1.09	3.50	0.15	1.08	0.37
Gachhipura-4	1.51	2.42	0.14	1.23	0.32
Kitaisar	0.80	0.81	0.05	2.33	0.36
Kod	0.67	2.24	0.04	1.49	0.40
Kuchera	4.20	0.15	3.23	1.83	0.08
Marwar-Chapri	1.46	2.07	0.20	1.24	0.29

Annex 6

Ratios of various constituents of water from existing tubewells, samples collected May 1973

Location	Ca/Mg	Cl/HCO_3	Ca/Na	Na/Cl	$\frac{Na(ppm)}{TDS(ppm)}$
		Sikar basin			
Baklia	2.40	0.38	1.23	1.51	0.17
Churu-1	0.67	1.33	0.08	2.10	0.31
Churu-2	0.45	1.72	0.06	2.03	0.35
Daulatpura	0.45	0.94	0.04	2.24	0.34
Kerap	0.81	3.49	0.10	1.19	0.31
Kuchamam City	1.00	0.29	0.18	3.92	0.36
Nimbod	0.82	0.39	0.17	3.10	0.36
Nimbi Bari	1.30	0.81	0.23	1.80	0.28
Ratangarh	0.74	3.07	0.14	1.16	0.29
Ratan Nagar	0.47	1.73	0.10	1.70	0.27
Sikar	2.40	0.31	1.10	1.98	0.16
		Bikaner basin			
Bikaner	1.40	2.68	0.24	1.26	0.29
Chenar	1.67	3.17	0.22	1.36	0.25
Dungargarh	0.88	1.57	0.16	1.47	0.29
Karmisar	1.64	1.44	0.28	1.62	0.28
Kukni	1.62	1.98	0.30	1.33	0.26
Marwar-Mundwa	0.63	0.40	0.06	3.91	0.41
Megasar	1.37	0.57	0.33	2.09	0.30
Mukandgarh	1.63	2.55	0.23	1.29	0.31
Nagaur D.C.B.	2.27	3.36	0.21	1.44	0.26
Nokha	0.58	2.46	0.14	1.05	0.30
Sandwa	2.00	0.51	1.03	1.76	0.15
Sardarshahr	0.78	1.05	0.09	2.02	0.34
Sarupdesar	2.66	0.54	0.32	2.14	0.26
Sheo Bari	1.00	2.82	0.20	1.28	0.28
Sujandesar	0.73	0.54	0.25	2.27	0.24
Surpura	1.36	4.80	0.52	0.77	0.19

Annex 5

Chemical analyses of water from existing tubewells, samples collected in May 1973

Location	Topo sheet No.	Aquifer (1)	pH Lab.	Conductivity(2)	TDS mg/l	SiO_2 mg/l	meq/litre Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	pH	Total iron mg/l	B mg/l	Hardness (3)	SAR Lab.	U.S. Salinity Classification	RSC (meq/l)
Sikar basin																						
Baklia	45-I/2B	Q	7.00	1,056	632	23	5.80	2.40	4.70	0.0	Nil	8.20	3.10	0.80	0.51	Nil	Nil	0.70	410	2.32	C_3S_1	0.00
Churu-I	44-L/2D	Q	8.00	2,694	1,854	23	2.00	3.00	24.58	0.1	Nil	8.80	11.70	7.10	1.02	Nil	Nil	1.08	250	15.15	C_4S_3	3.80
Churu-2	44-L/3D	Q	8.10	3,272	2,270	20	2.00	4.40	34.36	0.1	Nil	9.80	16.92	11.60	1.15	0.02	Nil	1.08	320	19.21	C_4S_3	3.40
Daulatpura	45-I/3C	Q	7.35	4,958	3,416	24	2.10	4.70	50.02	0.1	Nil	23.70	22.35	4.10	5.94	0.28	Nil	3.04	340	27.13	C_4S_4	16.90
Kerap	45-I/3B	Q	7.20	5,122	3,100	26	4.40	5.40	42.41	0.0	Nil	10.20	35.67	4.30	2.50	Nil	Nil	3.68	490	19.16	C_4S_3	0.40
Kuchaman City	45-I/4D	Q	7.50	1,056	562	28	1.60	1.60	8.87	0.06	Nil	7.60	2.26	1.10	0.38	0.05	Nil	0.67	160	7.01	C_3S_2	4.40
Nimbod	45-I/4D	Q	7.55	920	676	24	1.80	2.20	10.44	0.06	Nil	8.60	3.38	1.40	1.31	Nil	Nil	0.84	200	7.38	C_3S_2	4.60
Nimbi Bari	45-I/3C	Q	7.60	1,516	916	22	2.60	2.00	11.18	0.09	Nil	7.60	6.20	1.60	1.09	0.05	0.06	0.53	230	7.37	C_3S_2	3.00
Ratangarh	44-L/4C	Q	8.05	3,179	1,896	20	3.40	4.60	23.58	0.12	Nil	6.60	20.30	3.60	1.49	Nil	Nil	1.24	400	11.79	C_3S_2	-1.40
Ratan Nagar	44-L/4D	Q	7.65	3,927	2,744	23	3.20	6.80	32.20	0.20	Nil	10.90	18.89	10.20	1.45	Nil	Nil	0.31	500	15.67	C_4S_3	0.90
Sikar	45-I/2A	Q	7.50	689	454	53	3.40	1.40	3.09	0.05	Nil	5.00	1.55	0.30	0.87	Nil	Nil	0.65	240	1.99	C_2S_1	0.20
Bikaner basin																						
Bikaner	44-H/2B	P	7.50	1,924	1,144	19	3.50	2.50	14.24	0.10	Nil	4.20	11.28	3.60	0.38	0.06	Nil	0.59	300	8.25	C_3S_1	-1.80
Chenar	45-E/4C	NS	7.40	5,820	4,028	30	9.50	5.70	43.06	0.15	Nil	9.90	31.44	10.60	7.41	0.23	Nil	2.96	760	15.62	C_4S_3	-5.30
Dungargarh	44-L/4A	P	7.70	1,213	720	22	1.50	1.70	9.22	0.09	Nil	4.00	6.27	1.50	0.66	Nil	Nil	0.76	160	7.29	C_3S_2	0.80
Karmisar	45-E/1B-I	P	7.40	1,653	1,066	24	3.60	2.20	12.83	0.18	Nil	5.40	7.90	4.30	1.31	0.09	Nil	0.63	290	7.54	C_3S_2	-0.40
Kulni	45-E/2C	P	7.50	1,478	1,040	20	3.40	2.10	11.66	0.25	Nil	4.40	8.74	2.10	1.51	0.03	Nil	0.20	275	7.03	C_3S_2	-1.10
Marwar Mundwa	45-E/4D	NS	7.90	1,813	1,124	29	1.20	1.90	19.89	0.04	Nil	12.80	5.08	3.80	0.31	0.37	Nil	1.06	155	15.35	C_3S_2	9.70
Megasar	45-E/1A-1	P	7.70	1,006	602	18	2.60	1.90	7.83	0.11	Nil	6.60	3.74	1.50	0.11	0.11	Nil	0.76	225	5.22	C_3S_2	2.10
Mukandgarh	44-H/4B	P	7.50	2,132	1,242	18	3.60	2.20	15.83	0.11	Nil	4.80	12.27	4.50	0.24	0.07	Nil	0.65	290	9.25	C_3S_2	-1.00
Nagaur D.C.B.	45-E/4C	NS	7.40	5,504	4,090	35	10.00	4.40	47.07	0.15	Nil	9.70	32.66	10.10	7.74	0.32	0.06	2.20	720	17.55	C_4S_3	-4.70
Nokha	45-E/2B	NS	7.90	1,807	1,032	26	1.90	3.30	13.49	0.16	Nil	5.20	12.83	1.60	0.23	Nil	Nil	0.19	260	8.37	C_3S_2	0.00
Sandwa	45-I/1A	NL	7.45	1,014	672	21	4.60	2.30	4.46	0.12	Nil	5.00	2.54	1.30	2.22	Nil	Nil	0.64	345	7.60	C_3S_2	-1.90
Sardarshahr	44-L/3B	P	7.50	2,148	1,348	26	1.80	2.30	20.08	0.09	Nil	9.50	9.94	4.40	1.97	Nil	Nil	1.52	205	14.55	C_3S_2	5.40
Sarupdesar	45-E/1A-10	P	7.30	977	660	29	2.40	0.90	7.55	0.09	Nil	6.50	3.52	0.40	0.14	0.03	Nil	0.40	165	5.87	C_3S_2	3.20
Sheo Bari	44-H/4B	P	7.70	1,741	1,070	20	2.60	2.60	13.04	0.12	Nil	3.60	10.15	3.40	0.53	0.12	Nil	0.55	260	8.09	C_3S_2	-1.60
Sujandesar	45-E/1B-2	P	7.70	860	620	22	1.60	2.20	6.39	0.15	Nil	5.20	2.82	0.80	0.66	0.09	Nil	0.64	190	4.64	C_3S_1	1.40
Surpura	45-E/2B	P	7.60	2,827	2,136	19	8.20	6.00	15.83	0.34	Nil	4.20	20.16	3.40	2.16	0.03	0.06	0.32	710	5.94	C_3S_1	-10.00
Luni basin																						
Butati	45-F/1D	Q	7.60	2,803	1,968	59	2.20	2.00	27.06	0.02	Nil	16.10	7.05	4.00	5.16	0.15	Nil	2.78	210	18.67	C_4S_3	11.9
Chandarun	45-J/1B	Q	8.00	1,085	666	21	1.20	1.60	9.22	0.03	Nil	7.60	2.26	1.40	1.51	0.17	Nil	0.52	140	7.83	C_3S_2	4.1
Dangawas	45-J/2A	Q	8.45	2,578	1,712	34	1.00	2.00	25.75	0.04	1.20	10.00	13.82	2.50	0.66	0.26	Nil	1.26	150	21.00	C_4S_3	8.1
Dangawas-4	45-J/2A	Q	7.30	1,835	1,124	39	3.80	1.00	14.66	0.02	Nil	10.00	7.33	1.20	1.13	0.14	Nil	0.84	240	9.46	C_3S_2	5.1
Degana-1	45-J/1B	Q	7.55	5,708	3,512	21	2.20	3.30	61.76	0.04	Nil	18.40	41.23	5.70	0.56	0.63	Nil	3.65	275	37.20	C_4S_4	12.9
Gachhipura-1	45-J/1B	Q	7.70	3,905	2,472	21	3.10	4.70	36.10	0.07	Nil	11.50	26.93	1.50	2.42	0.13	0.06	1.86	390	18.28	C_4S_3	3.1
Gachhipura-2	45-J/1B	Q	7.20	3,210	1,992	28	2.50	4.40	29.57	0.03	Nil	12.80	18.89	2.90	1.91	0.20	Nil	1.44	345	15.85	C_4S_3	5.9
Gachhipura-3	45-J/1B	Q	7.10	4,815	3,026	28	6.10	5.60	40.45	0.09	Nil	10.70	37.38	1.30	2.24	0.07	Nil	2.20	585	14.45	C_4S_3	-1.1
Gachhipura-4	45-J/1B	Q	7.20	4,403	2,788	30	5.30	3.50	38.93	0.08	Nil	13.00	31.45	1.20	1.93	0.07	Nil	1.56	440	13.56	C_4S_3	4.0
Kitalsar-1	45-J/2B	Q	7.90	2,963	1,896	31	1.50	1.90	29.71	0.03	Nil	15.80	12.75	3.80	0.93	0.57	Nil	1.45	170	22.80	C_4S_3	12.4
Kod	45-J/2B	Q	7.55	586	372	22	2.80	2.80	1.39	0.05	Nil	4.90	1.13	0.20	0.60	0.05	0.17	1.66	200	0.83	C_2S_1	-0.70
Kuchera	45-F/1D	Q	7.50	542	380	20	4.20	1.00	1.30	0.18	Nil	4.60	0.71	0.60	0.51	Nil	Nil	0.34	260	0.81	C_2S_1	-0.60
Marwar Chapri	45-F/1D	Q	7.20	3,350	2,112	42	5.40	3.70	27.06	0.04	Nil	10.50	21.72	3.50	0.66	0.06	Nil	1.04	455	40.09	C_4S_4	1.40

(1) Aquifer Q.- Quaternary deposits; P - Palana Sandstone; NS - Nagaur Sandstone; NL - Nagaur Limestone
(2) Electrical Conductivity in micromhos/cm at 25°C
(3) Total hardness (Ca, Mg) as $CaCO_3$ expressed in mg/l

Annex 4

World Health Organization International standard for drinking water

Constituents	Desirable (ppm)	Max. permissible (ppm)
Total solids	500	1,500
Chloride	200	600
Calcium	75	200
Magnesium	50	150
Sulfate	200	400
Nitrate (NO_3)	10	
Fluoride	-	Less than 0.5 and more than 1.5. harmful
Iron	0.3	1.0

Annex 3 (continued)

Location	Depth drilled (m)	Zone tested	Screened section (depth zone) (m)	Thickness tapped (m)	Thickness of aquifer: Quat./ Palana series (m)	Nagaur series (m)	Total (m)	Water level depth (m)	Discharge (m^3/hr)	Drawdown (m)	Quality: TDS	Quality: Cl	Remarks
b. Western part: (Quaternary and Tertiary aquifers) - slim holes)													
Lai	395.00	67.10 - 91.40 Q*	-	-	34+67	171	272	42.20	-	-	2,122	860	-
		134.20 -164.60 P*						43.95			3,562	1,670	
		146.90 -253.00 NS*						46.35			7,112	3,350	
Merta City	420.90	32.25 -122.00 Q*	-	-	30+86	>99	>215	32.25	-	-	3,100	1,280	-
		161.50 -323.00 NS*	-	-				40.80			6,226	2,900	
		317.00 -323.00 NS*						-			19,226	10,000	
		378.00 -384.00 NL*						42.80			18,180	8,800	
Oladan	327.35	76.20 -201.20 NS*	-	-	19	120+ >33	>172	63.30	-	-	1,100	300	
		261.00 -274.30 NL*						65.20			3,248	1,470	

* Q - Quaternary alluvium

P - Palana Sandstone

N - Nagaur sandstone

NL - Nagaur Limestone

XX OH = Observation well

Annex 3 (continued)

Location	Depth drilled (m)	Zones tested (m)	Screened sections (m)	Thickness tapped (m)	Thickness of aquifer (m)	Water level depth (m)	Discharge (m^3/hr)	Draw-down (m)	Quality TDS ppm	Quality Cl ppm	Remarks
C. LUNI BASIN											
a. Eastern part (Quaternary aquifer only)											
a) Test wells											
Badauli	65.55	-	37.80 - 43.90	12-45	12+20	14.00	45.46	11.06	1,362	530	Three observation wells, OH_1, $2OH_2$, tapping the lower aquifer and OH_3 tapping the upper.
Padukalan	72.25	-	49.10 - 63.40	14.30	15+12	27.30	11.40	15.55	1,278	260	-do-
b) Slim holes											
Aniala	82.60	16.75-61.00	-	-	50	16.75	-	-	2,850	975	-
Antroli	82.00	30-50-48.80	-	-	35	25.60	-	-	750	170	-
Bagot	32.00	28.65-32.00	-	-	3	28.65	-	-	1,346	410	-
Bamma	67.65	45.10-67.00	-	-	7	45.10	-	-	3,026	1,075	-
Barnil	85.95	42.85-60.95	-	-	41	42.85	-	-	918	50	-
Bhainsra	84.10	18.75-32.90 35.35-50.00	-	-	56	18.75 18.70	-	-	2,860 2,582	960 960	-
Chondian	208.50	47.20-70.10 73.15-143.25	-	-	$\geqslant$ 116	47.20 46.95	-	-	1,808 2,156	510 790	-
Dhaneri	88.70	18.60-27.40 53.65-60.95	-	-	40	18.60 22.05	-	-	1,462	430	-
Kekind	60.05	6.65-15.25 34.75-49.75	-	-	28	7.65 14.50	-	-	1,222 866	320 145	-
Kitalsar	74.10	51.80-73.75	-	-	34	35.65	-	-	1,678	350	-
Luniawas	96.00	28.00-96.00	-	-	43	28.00	-	-	426	95	-
Tamroli	71.65	33.90-39.00 33.90-70.10	-	-	33	33.90	-	-	7,578	2,600	-

Annex 3 (continued)

	Location	Depth drilled (m)	Zones tested (m)	Screened sections (m)	Thickness stapped (m)	Thickness of aquifer			Water level depth (m)	Discharge m^3/hr	Draw-down (m)	Quality		Remarks
						Quat. Palana Sand-stones (m)	Nagaur sand-stone (m)	Total (m)				TDS ppm	Cl ppm	
	Pharrod	234.50	-	48.30 - 63.20	14.90	-	33*	33	28.65	2.60	15.00	22,704	11,000	-
	Raneri	564.00	-	124.00 - 178.00	54.00	95*	274	369	100.00	50.00	1.77	1,298	475	OH
	Sital	522.00	-	310.60 - 375.20	64.60	15	58 +64*	137	77.10	13.20	50.30	670	96	
b)	Slim holes													
	Bhanipura	295.70	-	170.00 - 182.00	-	62*	94	156	55.50	-	-	3,882	1,830	-
	Jodhyasi	275.25	-	- -	-	-	7*	7	18.00	-	-	29,110	10,375	-
	Karmisar	509.90	-	- -	-	72	117*	189	-	-	-	-	-	Test could not be conducted (Drilling rods get stuck up)
	Kitasar	372.50	-	- -	-	-	44 +55	99	-	-	-	-	-	-
	Lakhasar	556.30	-	88.00 - 100.00	-	166*	91	257	37.00	-	-	2,444	285	-
	Manasir	398.00	-	179.80 - 196.90	-	-	2*	-	24.40	-	-	14,204	5,500	)Limestone
				249.00 - 260.00	-	-	-	-	30.00			8,740	1,850	)evaporite
				354.80 - 385.30	-								2,100	)sequence) (227 m)) Jodhpur sand stone (92 m)

* Aquifer tapped.

Annex 3 (continued)

Location	Depth drilled (m)	Zones tested (m)	Screened sections (m)	Thickness tapped (m)	Thickness of aquifer			Water level depth (m)	Discharge m^3/hr	Draw-down (m)	Quality		Remarks
					Quat. Palana Sand-stones (m)	Nagaur sand-stone (m)	Total (m)				TDS ppm	Cl ppm	
Gadhwala I	530.00	-	274.35 - 277.20 280.50 - 286.30 291.10 - 302 40 306.60 - 310.70 313.40 - 316.50 328.30 - 332.50 340.30 - 350.70 364.40 - 375.00 393.50 - 401.50	60.35	60	121*	181	69.50	45.40	37.50	1,320	515	
Gadhwala II	418.20	-	101.90 - 111.30 118.50 - 122.80 127.90 - 137.90 141.90 - 149.00 152.80 - 158.60 161.60 - 169.20 174.50 - 183.90	53.60	60*	-	60	74.65	56.80	14.50	465	115	1 OH
Jasrasar	438.00	-	91.00 - 95.00	4.00	12*	129	141	79.00	20.40	12.65	1,466	450	
Karmisar	139.60	-	109.10 - 114.65 118.60 - 124.10	11.05	72*	-	72	91.15	-	-	1,656	535	Could not be tested (Heavy mud losses, then clogged)
Mudh	613.00	-	335.00 - 350.00 352.00 - 368.00 371.00 - 391.00	51.00	97	160 +152*	409	109.70	28.40	29.00	2,760	1,090	1 OH

Annex 3 (continued)

Location	Depth drilled (m)	Zone tested (m)	Screened sections	Thickness tapped (m)	Thickness of aquifer (m)	Depth to water level (m)	Discharge m^3/hr	Draw-down (m)	Quality TDS ppm	Quality Cl ppm	Remarks
b) Slim holes											
Biramsar	96.60	34.15 - 88.40	-	-	54.00	34.15	-	-	2,300	500	-
Chapribari	74.20	30.80 - 73.15	-	-	42.00	30.80	-	-	836	170	-
Dhankoli	82.60	-	-	-	-	-	-	-	-	-	No zone test owing to caving
Kolasar	43.00	28.00 - 42.40	-	-	Nil	28.00	-	-	7,256	2,400	-
Losal	92.35	33.55 - 79.30	-	-	46.00	33.50	-	-	1,060	160	-
Ranasar	67.05	28.35 - 76.85	-	-	39.00	28.35	-	-	1,005	290	-
Ratangarh	76.25	35.00 - 76.25	-	-	20.50	35.00	-	-	1,686	225	-

* Drawdown after 24 hours of pumping.

** OH - Observation well.

Location	Depth drilled (m)	Zones tested (m)	Screened sections (m)	Thickness tapped (m)	Thickness of aquifer: Quat. Palana Sand-stones (m)	Thickness of aquifer: Nagaur sand-stone (m)	Thickness of aquifer: Total (m)	Water level depth (m)	Discharge m^3/hr	Draw-down (m)	Quality TDS ppm	Quality Cl ppm	Remarks
B. BIKANER BASIN													
a) Test wells													
Bandnau	472.40	-	103.00 - 114.00 123.00 - 161.00	49.00	76*	38	114	77.65	28.40	0.76	516	95	1 OH
Bhamatsar	322	-	236.20 - 251.15 254.20 - 266.40 286.50 - 299.90 303.90 - 308.15	44.80	84	136*	220	89.00	-	-	1,050	295	Could not be tested owing to poor discharge

Annex 12 (continued)

Location Fine, coarse	Depth range (cm)	Mechanical analysis (%)				Hydraulic conductivity (cm/h)	Maximum water holding capacity (%)	Bulk density	Moisture (%)		Available moisture (%)
		Clay	Silt	Fine sand	Course sand				at 0.3 atm	at 15.0 atm	
Fatehpur	0- 35	6.4	16.8	41.6	30.6	0.5	39.4	1.59	9.10	4.00	5.10
-do-	35-140	5.4	14.4	49.0	48.5	0.9	38.0	1.54	6.81	3.23	3.58
Sikar	0-130	3.2	4.4	60.5	32.0	6.9	24.5	1.58	2.58	1.52	1.06
Ramgarh	0-100	6.8	9.2	49.3	34.0	4.1	25.5	1.49	4.40	2.72	1.68
-do-	100-130	7.5	11.2	46.5	34.5	3.7	32.5	1.52	6.03	3.61	2.42
Kuchaman	0-130	6.2	6.4	81.5	5.7	6.7	21.4	1.58	3.98	2.13	1.85
Didwana	0- 75	4.2	7.9	82.0	3.5	3.5	23.2	1.65	2.75	1.31	1.44
-do-	75-100	7.8	7.5	79.1	1.8	4.4	24.7	1.61	4.91	2.45	2.46
-do-	100-125	7.8	8.4	76.5	3.1	3.0	25.6	1.64	5.12	2.22	2.90
-do-	125-132	6.3	7.6	73.3	3.5	2.8	27.2	1.63	5.75	1.93	3.82
Degana	0-100	5.2	13.4	78.0	2.8	4.2	25.4	1.59	7.52	4.48	3.04
-do-	100-130	8.3	12.2	75.3	4.2	4.6	34.5	1.39	8.00	4.40	3.60
Luniawas	0- 95	9.8	17.4	70.5	1.5	3.9	25.9	1.56	6.55	3.09	3.46
-do-	95-130	11.3	17.2	68.3	3.2	3.9	32.4	1.40	9.22	3.87	5.35
Merta City	0- 30	4.8	7.2	80.0	5.2	5.7	23.1	1.60	4.64	3.21	1.43
-do-	30-115	15.1	15.4	50.0	16.5	5.8	35.7	1.35	10.97	7.30	3.64
-do-	115-130	13.3	22.7	54.0	9.5	2.7	33.4	1.37	10.67	7.54	3.13
Samidalao	0- 40	17.3	16.2	49.0	14.6	1.8	34.6	1.38	11.88	7.33	4.55
-do-	40- 65	9.7	14.1	54.7	16.3	2.4	34.0	1.34	6.39	3.45	2.94

Annex 12 (continued)

Location Fine, coarse	Depth range (cm)	Mechanical analysis (%)				Hydraulic conductivity (cm/h)	Maximum water holding capacity (%)	Bulk density	Moisture (%)		Available moisture (%)
		Clay	Silt	Fine sand	Coarse sand				at 0.3 atm	at 15.0 atm	
Manasir	0- 30	7.8	10.4	63.1	18.7	3.0	27.5	1.56	6.18	3.76	2.42
-do-	30- 60	12.4	10.5	66.5	10.3	2.1	32.8	1.37	11.05	6.85	4.20
-do-	60-105	14.8	16.1	60.4	8.1	1.3	30.9	1.41	17.15	13.11	4.04
-do-	105-130	8.0	11.8	62.2	15.6	2.5	37.0	1.32	9.89	7.02	2.87
Chenar	0- 13	13.8	17.9	60.0	7.5	2.6	34.0	1.35	11.59	6.95	4.64
-do-	13- 40	14.8	11.0	55.7	8.7	2.9	32.7	1.44	11.73	6.56	4.17
-do-	40-130	11.0	13.8	62.3	3.5	1.0	35.2	1.17	11.81	8.42	3.39
Katothi	0- 30	8.6	10.7	75.4	6.2	3.1	29.8	1.51	8.19	4.01	4.18
-do-	30- 70	10.9	11.0	76.0	2.0	1.4	31.7	1.50	8.66	4.03	4.63
-do-	70-100	16.6	17.1	58.5	7.8	0.0	38.4	1.46	23.96	13.13	10.83

Annex 13

Chemical Analyses of Soils in Project Area in Rajasthan
(Analysed by UNDP Project Soil Laboratory, Central Ground Water, Jodhpur)

Location	Depth Range (cm)	pH	EC in mhos/cm at 25°	* Analysis of saturation extract				SAR	CEC meq/100 g	Exchangeable cations (meq/100 g)				ESP	Organic carbon (%)	Lime content (%)
				Ca	Mg	K	Na			Ca	Mg	K	Na			
				meq/litre												
Sital	0-140	7.9	357	1.22	0.25	0.34	0.14	0.82	1.46	1.41	0.22	0.55	0.28	11.3	0.018	3.1
-do-	140-200	8.2	130	0.85	0.25	0.56	1.65	2.21	1.44	0.26	0.19	0.65	0.34	23.6	0.006	5.2
-do-	below 200	8.2	1,629	8.80	2.47	2.00	2.49	1.05	1.43	0.28	0.20	0.69	0.26	18.1	0.006	7.4
Palana	0- 90	8.1	1,057	4.40	2.95	2.85	1.60	0.83	4.25	2.91	0.46	0.35	0.46	10.8	0.030	2.2
-do-	90-120	8.0	1,414	3.70	7.57	1.50	1.40	0.59	2.46	1.86	0.21	0.13	0.26	10.3	0.054	4.1
-do-	120-140	8.0	745	3.95	2.28	0.71	0.94	0.56	3.04	2.27	0.31	0.14	0.32	10.5	0.012	9.2
Nokha	0- 80	8.0	295	2.01	0.21	0.15	0.30	0.90	2.18	1.54	0.11	0.18	0.35	15.1	0.06	0.0
-do-	80-130	8.1	232	1.50	0.46	0.1	0.30	0.96	4.17	3.58	0.24	0.16	0.19	4.5	0.06	1.2
-do-	below 130	8.0	388	1.70	0.82	0.55	2.00	5.60	1.75	1.09	0.37	0.18	0.16	19.14	0.01	4.3
Massuri	0-130	7.9	269	2.10	2.84	0.20	0.30	0.77	1.44	0.77	0.28	0.16	0.12	8.33	0.024	0.0
Lakhasar	0- 70	8.1	437	2.45	1.64	0.80	0.90	0.47	1.37	0.78	0.18	0.24	0.17	12.4	0.07	2.1
-do-	70- 90	8.5	576	2.43	1.68	0.70	0.90	0.63	1.43	0.82	0.20	0.24	0.17	11.8	0.03	3.3
-do-	90-130	8.4	422	0.84	2.56	0.80	0.85	0.66	1.52	0.69	0.45	0.19	0.19	11.2	0.04	6.8
Sandwa	0-130	8.1	213	1.71	1.49	0.31	0.11	0.06	1.52	0.91	0.35	0.14	0.12	7.98	0.006	0.0
Sardarshahr	0- 40	8.0	301	2.11	0.51	0.51	0.61	0.52	2.46	1.37	0.57	0.36	0.12	4.87	0.006	1.2
-do-	40- 80	8.2	304	1.72	0.80	0.32	0.45	0.40	2.46	1.58	0.45	0.26	0.17	6.91	0.01	2.0
-do-	80-120	8.2	304	1.71	0.95	0.20	0.65	0.56	2.66	1.27	0.91	0.20	0.22	8.46	0.26	12.6
-do-	120-190	8.0	375	1.32	2.04	0.21	0.75	0.41	4.64	2.51	1.61	0.24	0.28	6.03	0.21	16.5

Annex 13 (continued)

Location	Depth Range (cm)	pH	EC in mhos/cm at 25°	Analysis of saturation extract (meq/litre)				SAR	CEC meq/100 g	Exchangeable cations (/100 g)				ESP	Organic carbon (%)	Lime content (%)
				Ca	Mg	K	Na			Ca	Mg	K	Na			
Lunkaransar	0- 10	8.1	532	2.55	1.65	0.42	0.65	0.51	1.66	1.01	0.21	0.19	2.25	15.06	0.06	1.1
-do-	10- 60	8.3	387	1.76	1.02	0.15	1.40	1.18	3.04	2.20	0.34	0.16	0.34	11.18	0.036	2.3
-do-	60- 73	8.9	899	2.64	2.40	1.71	3.4	2.12	3.90	2.39	0.38	0.16	0.97	24.87	0.071	3.9
-do-	below 73	8.3	3,993	4.26	1.62	3.11	30.00	12.38	3.32	1.46	0.55	0.15	1.16	34.90	0.071	10.2
Baneri	0- 65	8.2	532	2.52	1.52	0.25	1.01	0.70	3.76	2.74	0.34	0.44	0.26	6.91	0.13	1.5
-do-	65-132	8.2	1,228	4.25	3.73	1.10	2.30	1.16	4.05	3.14	0.36	0.21	0.25	6.17	0.12	4.2
Bigga	0- 53	8.2	351	2.1	0.26	3.01	4.49	4.14	2.74	2.05	0.45	0.12	0.12	4.37	0.49	0.0
-do-	53-130	8.2	360	1.4	0.84	0.43	1.20	1.3	1.58	1.04	0.36	0.07	0.11	6.96	0.03	1.8
Bhuchas	0- 45	8.0	378	1.72	1.22	0.61	0.99	1.01	1.95	1.25	0.35	0.21	0.14	7.17	0.018	0.0
-do-	45-130	8.0	289	1.79	0.81	0.38	0.51	0.32	1.90	0.14	0.46	0.16	0.14	7.37	0.005	0.2
Churu	0- 25	7.8	352	0.25	0.15	0.15	3.02	6.8	4.30	2.65	0.65	0.18	0.82	19.1	0.01	0.15
-do-	25-115	8.1	458	0.29	0.17	0.11	3.23	6.9	5.00	3.85	0.20	0.17	0.78	15.6	0.12	0.01
-do-	115-265	8.2	542	0.32	0.14	0.14	4.64	9.9	5.87	3.65	0.50	0.43	1.20	20.4	0.06	0.02
Jhunjhunu	0- 25	8.1	341	0.47	0.22	0.19	2.69	4.6	3.89	2.75	0.40	0.19	0.51	13.1	0.10	0.0
-do-	25-135	7.9	225	0.24	0.16	0.21	0.80	4.2	4.72	3.65	0.34	0.12	0.65	13.8	0.15	0.0
Ratangarh	0-120	8.2	341	1.21	0.19	0.20	2.90	6.5	8.04	5.45	0.97	0.44	1.28	15.9	0.23	6.39
-do-	120-190	8.4	631	0.23	0.17	0.12	4.86	10.9	4.59	2.90	0.80	0.11	0.78	17.0	0.11	9.41
Salasar	0- 20	8.3	460	0.13	0.10	0.09	3.74	11.0	6.38	3.29	1.75	0.44	1.97	29.3	0.65	3.12
-do-	20- 90	8.8	514	0.21	0.11	0.16	4.47	11.2	9.74	4.95	1.95	0.39	2.45	29.31	0.31	4.45
-do-	90-130	8.8	614	0.18	0.12	0.11	5.00	12.9	9.17	6.90	0.52	0.13	1.62	17.7	0.22	8.65

Annex 13 (continued)

Location	Depth Range (cm)	pH	EC in mhos/cm at 25°	Analysis of saturation extract (meq/litre)				SAR	CEC meq/100 g	Exchangeable cations (Meq/100 g)				ESP	Organic carbon (%)	Lime content (%)
				Ca	Mg	K	Na			Ca	Mg	K	Na			
Nawalgarh	0-115	6.5	240	0.22	0.10	0.09	1.47	3.7	3.48	2.02	0.96	0.10	0.40	11.5	0.03	0.10
-do-	115-132	8.4	221	0.19	0.08	0.08	1.59	4.3	3.48	2.65	0.43	0.05	0.35	10.1	0.04	1.25
Fatehpur	0- 35	8.2	1,414	0.82	0.38	0.22	12.56	16.2	5.78	3.70	0.67	0.22	1.19	22.6	0.21	4.36
-do-	35-140	7.8	1,504	1.08	0.32	0.24	13.75	16.4	4.37	3.05	0.27	0.16	0.09	20.4	0.09	0.27
Sikar	0-130	8.0	296	1.08	0.32	0.24	13.75	3.7	1.74	1.40	0.10	0.08	0.16	9.2	0.12	0.01
Ramgarh	0-100	7.7	200	0.30	0.14	0.11	0.94	2.0	2.39	1.85	0.22	0.15	0.17	7.1	0.17	0.00
-do-	100-130	7.9	169	0.25	0.10	0.10	0.80	1.8	3.26	2.05	0.67	0.21	0.33	10.1	0.10	0.00
Kuchaman	0-130	8.4	337	0.84	0.64	0.40	2.20	1.81	1.74	0.89	0.45	0.15	0.29	16.76	0.03	0.00
Didwana	0- 75	8.5	164	1.06	0.42	0.40	0.33	0.38	1.74	1.08	0.41	0.17	0.17	9.76	0.17	2.3
-do-	75-100	8.6	196	1.50	0.39	0.30	0.45	0.46	3.04	2.26	0.39	0.19	0.20	6.49	0.08	3.6
-do-	100-125	8.2	312	1.72	1.01	0.31	0.50	0.54	2.60	1.76	0.51	0.14	0.19	7.31	0.07	4.3
-do-	125-132	8.3	380	1.71	1.02	0.45	0.70	0.75	2.48	0.67	0.49	0.13	0.19	7.66	0.04	7.8
Degana	0-100	8.0	305	1.50	0.39	0.2	0.33	0.34	4.14	3.24	0.58	0.17	0.15	3.62	0.054	0.0
-do-	100-130	7.9	216	1.1	0.79	0.15	0.31	0.32	4.07	3.28	0.46	0.16	0.17	4.17	0.054	0.0
Luniawas	0- 95	7.7	299	0.8	0.46	0.10	0.80	1.01	3.90	3.16	0.35	0.12	0.18	4.62	0.027	0.0
-do-	95-130	7.8	333	1.6	0.51	0.59	1.20	1.17	4.61	3.83	0.45	0.15	0.18	0.91	0.053	0.0
Merta City	0- 30	7.8	636	3.62	0.79	0.80	1.20	0.82	3.48	2.05	1.02	0.23	0.18	5.17	0.066	2.8
-do-	30-115	7.8	242	1.68	0.42	0.30	0.40	0.38	4.79	3.74	0.45	0.36	0.24	5.10	0.079	1.9
-do-	115-130	7.5	185	1.20	0.48	0.30	0.40	0.44	5.00	3.96	0.46	0.30	0.27	5.40	0.053	0.4
Samidalan	0- 40	7.7	445	2.60	0.60	0.60	0.90	0.71	7.90	5.88	1.12	0.46	0.34	4.31	0.053	3.1
-do-	40- 65	8.0	252	1.68	0.43	0.30	0.60	0.68	8.23	6.74	0.78	0.26	0.45	5.47	0.066	4.8
Manasir	0- 30	7.5	364	2.70	0.73	0.19	0.40	0.30	4.09	2.37	0.68	0.69	0.35	8.55	0.78	0.4

Annex 13 (continued)

Location	Depth Range (cm)	pH	EC in mhos/cm at 25°	Analysis of saturation extract (meq/litre)				SAR	CEC meq/100 g	Exchangeable cations (Meq/100 g)				ESP	Organic carbon (%)	Lime content (%)
				Ca	Mg	K	Na			Ca	Mg	K	Na			
Manasir	30-60	8.0	473	1.40	0.56	0.90	1.90	1.92	3.94	2.74	0.22	0.36	0.62	15.75	0.088	0.4
-do-	60-105	8.4	378	0.80	0.15	0.93	3.00	4.31	5.04	3.19	0.23	0.27	1.35	37.25	0.076	0.5
-do-	105-130	8.4	241	1.20	0.27	0.13	0.80	0.92	4.05	2.31	0.90	0.28	0.56	13.81	0.088	2.8
Chenar	0- 13	7.9	603	2.02	0.42	0.13	4.00	3.62	5.40	4.15	0.65	0.33	0.27	5.00	0.077	0.8
-do-	13- 40	7.8	651	2.04	0.49	0.80	3.85	3.42	5.78	3.88	0.22	0.42	0.26	4.50	0.051	1.2
-do-	40-130	8.1	765	1.22	1.23	1.55	3.22	3.79	7.15	4.35	1.35	0.56	0.88	12.30	0.181	8.6
Katothi	0- 30	8.1	440	2.85	0.85	0.15	0.61	0.45	4.21	2.95	0.69	0.34	0.23	5.40	0.026	0.2
-do-	30- 70	8.0	505	2.85	1.14	0.10	0.19	0.81	5.22	3.47	0.68	0.23	0.84	16.15	0.101	0.0
-do-	70-100	8.7	728	2.28	1.71	0.30	4.5	3.18	9.30	4.31	0.24	0.35	4.40	47.31	0.076	0.8

Annex 14

Description of soil profiles in Rajasthan area

1. Sital

Location: Near the Panchayat office building. Typical desert sandy area with bushes characteristic of the area. The area is fairly flat.

0-140 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 5/4, yellowish brown
Sand, no roots, $CaCO_3$ concretions (kankar) increase with depth. Non-plastic, non-sticky

140-200 cm : Dry colour, 10 YR 6/4, light yellowish brown
Wet colour, 10 YR 6/4, light yellowish brown
Sand texture, loose structure, more cohesive than above horizon, more kankar nodules which are slightly bigger than in the above horizon

below 200 cm: Dry colour, 10 YR 7/3, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Sand texture, more calcareous

General observations

The profile is structureless, non-plastic, non-sticky, no skins, no illuviation, calcareous throughout.

2. Palana

Location: Outside the village on virgin land.

0-90 cm : Dry, 10 YR 7/3, very pale brown
Wet, 10 YR 6/3, pale brown
Sandy loam, calcareous, no concretions, when dry slightly hard, non-sticky and non-plastic

90-120 cm : Dry, 10 YR 7/3, very pale brown
Wet, 10 YR 7/4, very pale brown
Loamy sand, calcareous concretions and present constitute 10 per cent of the soil material (with less than about 2.0 mm diameter).

120-240 cm : C horizon, calcareous, concretions bigger than 2.0 mm size also present

General observations

The profile is calcareous, land slightly undulating, microrelief is gently sloping. Bigger trees are very sparse, with Acacia Spp. Usual desert weeds are also found.

3. Nokha

Location: Two kilometres outside the town in a farmer's field where bajra is the standing crop. The growth of the crop was not good.

0-80 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Sand, non-calcareous, non-plastic, non-sticky, loose structure

80-130 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Sand, calcareous, non-plastic, non-sticky, loose structure

below 130 cm: C horizon, calcareous with limestone concretions of larger than 2.0 mm diameter

General observations

Undulating area, desert profile with poor structure, slightly stabilized sand dunes in the area. Usual desert weeds and Acacia trees are present. Microrelief is slightly sloping with numerous hummocks.

4. Massuri

Location: Outside the village in a farmer's field where bajra, melon and green gram are the standing crops.

0-130 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellow with brown
Sand texture, structureless, non-sticky, non-plastic, non-calcareous

General observations

The topography is undulating, with a high percentage of sand dunes. Trees are sparse but there is a good cover of desert plants and weeds.

5. Lakhasar

Location: Outside the village in a farm field. The standing crops were bajra and green gram. The stand of the crops is sparse. The location is between two moderately stabilized sand dunes.

0-70 cm : Dry colour, 10 YR 8/4, very pale brown
Wet colour, 10 YR 7/4, very pale brown
Loamy sand, calcareous, effervescence is moderate with dilute HCl, non-plastic, non-sticky

70-90 cm : Dry colour, 10 YR 8/3, very pale brown
Wet colour, 10 YR 7/2, light gray
Loamy sand, calcareous, effervescence more than above.

90-130 cm : Dry colour, 10 YR 8/2, white
C horizon, highly calcareous

below 130 cm: No change in colour, hard consistence

General observations

This is a dune area. There are few trees. Topography is very undulating. Microrelief is slightly sloping.

6. Sandwa

Location: Six kilometres from the village in cultivated land; bajra crop harvested

0-130 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Sand, non-sticky, non-plastic, non-calcareous

General observations

Topography highly undulating with sand dunes, microrelief is sloping.

7. Sardarshahr

Location: Outside the town near the railway crossing, virgin land.

0-40 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Sand, texture, non-sticky; non-plastic, calcareous

40-80 cm : Dry colour, 10 YR 6/3, pale brown
Wet colour, 10 YR 5/3 brown
Sand loam texture, calcareous, non-sticky, non-plastic

80-120 cm : Dry colour, 10 YR 7/2, light gray
Wet colour, 10 YR 6/2, light brownish gray
Loamy sand. The soil is mixed with parent material and contains $CaCO_3$ concretions. It is highly calcareous, CaCO3 nodules comprise 40 per cent of the soil.

120-90 cm : C horizon, white, calcareous material

General observations

Many dunes, microrelief slightly sloping. Root development up to C horizon is seen showing good permeability, pore space and aeration. Acacia trees are seen in the area.

8. Lunkaransar

Location: Two kilometres from the town on the way to Bikaner in cultivated land. Previous crops bajra and cluster beans harvested.

0-10 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Sand texture, non-plastic, non-sticky, calcareous

10-60 cm : Dry colour, 10 YR 7/6, yellow
Wet colour, 10 YR 6/4, yellowish brown
Loamy sand, non-sticky, calcareous

60-73 cm : Dry colour, 10 YR 6/4, light yellowish brown
Wet colour, 10 YR 5/4, yellowish brown
Loamy sand, calcareous, white mottlings are seen

below 73 cm : Dry colour, 10 YR 7/6, yellow
Mixture of kankar nodules and soil, highly calcareous

General observations

Area is fairly flat, slope less than 2 per cent, thorny bushes are seen but no bigger trees nearby.

9. Raneri

Location: Outside the village by the side of the road. Virgin land with scattered weeds and bushes.

0-65 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Texture, loamy sand, non-sticky, non-calcareous.
Hard surface, gravelly

65-130 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Sand loam texture as above but calcareous concretions are seen which have about 1.0 cm size. Non-plastic, non-sticky.
Gravelly consistence, hard.

General observations

Topography is undulating, microrelief fairly flat. Agriculture is not developed in the area because of the gravelly surface. Bigger trees are very scanty in the region.

10. Bigga

Location: Outside the village in a farm field with gram crop of about one month old.

0-45 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Loamy sand texture, non-calcareous, loose structure

45-130 cm : Wet colour, 10 YR 5/4, yellowish brown
Sand, slightly calcareous. Effervescence with dilute HCl increases with depth

General observations

Fairly flat area, with scattered sandy hummocks. Desert weeds are seen. Only Acacia trees are seen around.

11. Churu

Location: Six kilometres from Churu town on Bhalori Road. Virgin land by the side of a stabilized sand dune. Topography is sloping (slope more than 4 per cent).

0-25 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Texture sand, non-plastic, non-sticky, non-calcareous. Dry consistency is weak.

25-115 cm : Dry colour, 10 YR 6/3, pale brown
Wet colour, 10 YR 5/3 brown
Texture sand, slightly heavier than above, non-plastic, non-sticky, non-calcareous, dry consistency is weak.

115-265 cm : Dry colour, 10 YR 6/3, pale brown
Wet colour, 10 YR 5/3, brown
Sand to loamy sand texture, non-plastic, non-sticky, slightly calcareous

General observations

The area is undulating with fairly well stabilized sand dunes. The main crop around the location is bajra. Acacia trees are sparsely distributed and weeds are seen.

12. Jhunjhunu

Location: About 6 kilometres outside the town on the road to Churu, farmer's field after harvested bajra crop. Topography comparatively flat in a dune area.

0-25 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Loamy sand texture, non-sticky, non-plastic. Dry consistency weak, non-calcareous

25-130 cm : Dry colour, 10 YR 6/4, light yellowish brown
Wet colour, 10 YR 6/4, yellowish brown
Loamy sand to sand loam texture, but a bit finer than above and non-calcareous

General observations

Main crop in the area is bajra; many Acacia trees are seen in this area. Usual arid-land weeds are found.

13. Ratangarh

Location: About 4 kilometres from town on Sujangarh road; near a sand dune which is fairly well stabilized. Samples taken in a cultivated field. Topography, undulating, microrelief; sloping more than 2 per cent.

0-120 cm : Dry colour, 10 YR 6/3, pale brown
Wet colour, 10 YR 5/3, brown
Texture is sand loam slightly plastic, non-sticky; dry consistency slightly hard, calcareous

120-190 cm : Dry colour, 10 YR 6/4, light yellowish brown
Wet colour, 10 YR 5/4, yellowish brown
Texture is sand loam; slightly plastic, non-sticky; dry consistency is harder than above horizon; more calcareous

General observations

Lime concretions larger than 2 cm diameter scattered are throughout the profile. Weeds and thorny bushes (e.g., Zizyphus nummularia) are found. Crops predominating in this locality are bajra and cluster beans.

14. Salasar

Location: About five kilometres from the town on the road to Sikar. Virgin land. Topography fairly flat with less than 2 per cent slope.

0-20 cm : Dry colour, 10 YR 6/3, pale brown
Wet colour, 10 YR 5/3, brown
Loamy sand texture, dry consistency soft; non-sticky, non-plastic, calcareous

20-40 cm : Dry colour, 10 YR 5/3, brown
Wet colour, 10 YR 4/3, brown to dark brown
Sandy loam, dry consistency soft to slightly hard calcareous

40-130 cm : Dry colour, 10 YR 4/2, dark gray brown
Wet colour, 10 YR 3/2, very dark gray brown
Sandyloam texture, dry consistency very hard, calcareous white lime mottlings, plastic and sticky

General observations

There are not many sand dunes in the area. The vegetation consists of numerous well-grown Acacia trees and shrubs.

15. Navalgarh

Location: Outside the village in a farmer's field. After harvested bajra crop. Topography sloping microrelief hummocky. Average slope less than 2 per cent.

0-115 cm : Dry colour, 10 YR 7/4, very pale brown

Wet colour, 10 YR 6/4, light yellowish brown
Loamy sand texture; non-sticky and non-plastic, non-calcareous

115-132 cm : Dry colour (not observed)
Wet colour: 10 YR 6/4, light yellowish brown
Sand texture, calcareous

General observations

The main crops in this locality are bajra and moong. Many Acacia trees.

16. Fatehpur

Location: About 4 kilometres from the town on Sikar road in a virgin land. Topography slightly sloping microtopography, numerous hummocks.

0-35 cm : Dry colour, 10 YR 6/4, light yellowish brown
Wet colour, 10 YR 5/4, yellowish brown
Texture is loamy sand, slightly plastic and slightly sticky; highly calcareous, porosity is good; many roots are found.

35-140 cm : Dry colour, 10 YR 6/3, pale brown
Wet colour, 10 YR 5/3, brown
Loamy sand to sandy loam texture lighter than above horizon, not calcareous, bigger roots are seen; porosity is good

General observations

Bigger trees are mainly Acacia. Luxuriant growth of weeds is found.

17. Sikar

Location: Outside the town on Fatehpur road in a cultivators' field. Land form fairly flat region, slopes less than 2 per cent.

0-135 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light pale brown
Sand texture, loose, non-sticky, non-plastic, non-calcareous.

General observations

Agriculture is rather intensive in the area. Comparatively many tubewells are seen and vegetables like radish, beans and chillies are grown with tubewell irrigation. Fodder crops are also grown. Luxuriant growths of trees like neem, is observed in addition to the usual Acacia tree wherever the tubewells are located. Crops grown under the tubewell irrigation were found to be good. Even orchards could be maintained in the area if water is available.

18. Ramgarh

Location: Outside the village in a farmer's field, where bajra was harvested. Bajra was grown along with cluster beans as mixed crops. Many Acacia trees are found in the field. Topography, undulating, microrelief, locally hummocky.

0-100 cm : Dry colour, 10 YR 7/4, very pale yellow
Wet colour, 10 YR 6/4, light yellowish brown
Loamy sand texture, loose, non-calcareous

100-130 cm : Dry colour (not observed)
Wet colour, 10 YR 6/6 brownish yellow
Loamy sand, wet horizon, non-calcareous

General observations

Many Acacia trees are found in the area. Under the tubewells, wheat, radish and other vegetable crops and fodder crops are grown in this area. Sand dunes seen are more or less stabilized.

19. Kuchaman

Location: Five kilometres from town on the way to Anandpura in a farmer's field. Bajra harvested, crop has good growth.

0-130 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Sand, non-calcareous, loose structure, aeration is good

General observations

Land farm slightly undulating. Microtopography scattered hillocks. Roots throughout the profile. Soil is moist from 25 cm depth.

20. Didwana

Location: Four kilometres outside the town on the way to Kuchaman city via farmer's field. Previous crops bajra and pulse mixed crop.

0-75 cm : Dry colour, 10 YR 7/1, light gray
Wet colour, 10 YR 6/1, gray
Sand, calcareous, kankar concretions of about 1 cm in diameter.

75-100 cm : Dry colour, 10 YR 8/2, white
Wet colour, 10 YR 7/2, light gray
Loamy sand, calcareous, concretions not seen, loose structure

100-125 cm : Dry colour, 10 YR 8/1, white
Wet colour, 10 YR 7/1, light gray
Loamy sand, calcareous

125-132 cm : Colour same as above. C horizon, limestone concretions are seen.

General observations

Landform slightly sloping, average slope 3 per cent. Acacia trees are present.

21. Degana

Location: Outside the town on Luniawas road in a farmer's field.

0-100 cm : Dry colour, 10 YR 6/4, light yellowish brown
Wet colour, 10 YR 5/4, yellowish brown
Loamy sand texture, non-calcareous, loose structure.

100-130 cm : Wet colour, 10 YR 5/6, yellowish brown, loamy sand, non-calcareous

General observations

Relatively flat area, slopes less than 1 per cent, crops are good where tubewell irrigation is available.

22. Luniawas

Location: Outside the village in a farmer's field with mixed crop of bajra and cluster beans.

0-95 cm : Dry colour, 10 YR 6/4, light yellowish brown
Wet colour, 10 YR 5/4, yellow brown
Sandy loam, non-calcareous

95-130 cm : Wet colour, 10 YR 5/6, yellowish brown
Sandy loam, non-calcareous

General observations

Topography flat, the predominant crops in the area are cluster beans, bajra, gram, wheat, vegetables. Acacia and neem trees are present.

23. Merta City

Location: Five kilometres from town on the road to Berunda (near Dangawas) in a farmer's field. Bajra was previous crop.

0-30 cm : Dry colour, 10 YR 7/4, very pale brown
Wet colour, 10 YR 6/4, light yellowish brown
Loamy sand, highly calcareous, gravel also present

30-115 cm : Dry colour, 10 YR 5/4, yellowish brown
Wet colour, 10 YR 4/4, dark yellowish brown
Sandy loam, slightly sticky and plastic, gravel absent, calcareous

115-130 cm : Dry colour, 10 YR 5/4, yellowish brown
Wet colour, 10 YR 4/4, dark yellowish brown
Slightly calcareous sandy loam, slightly sticky and plastic

General observations

Topography, slightly slopes, microrelief fairly flat, roots throughout the profile, slope less than 1 per cent.

24. Samidialao

Location: Outside the village in a farmer's field, with gram as standing crop

0-40 cm : Dry colour, 10 YR 5/2, grayish brown
Wet colour, 10 YR 4/2, dark grayish brown
Sandy loam, highly calcareous, slightly sticky and plastic, when dry a bit hard

40-65 cm : Wet colour, 10 YR 5/2, grayish brown
Sandy loams, mixture of parent material and soil, calcareous, slightly sticky and plastic

below 65 cm : C horizon, calcareous, limestone concretions

General observations

Flat region, sparse trees, mainly Acacia.

25. Chenar

Location: Outside the village in virgin land.

0-13 cm : Dry colour, 7.5 YR 6/2, pinkish gray
Wet colour, 7.5 YR 5/4, brown
Sandy loam, weakly sub-angular structure, dry consistency, weak, slightly sticky, medium plasticity, calcareous, pore space good, roots are seen.

13-40 cm : Dry colour, 7.5 YR 7/2, pinkish gray
Wet colour, 10 YR 5/3, brown
Fairly cemented, not much root development, calcareous, cementation might be due to $CaCO_3$, sub-angular structure, Sandy loam, pore space is less than in above horizon, slightly sticky and plastic.

40-60 cm : Dry colour, 10 YR 5/3, brown
Wet colour, 10 YR 7/2, light gray
C horizon, parent material with same sandy loam weathered sandstone, small root development, much more sticky, quite plastic, fine angular structure, mottlings are seen; they form 75 per cent, lenticular pores, calcareous

60-110 cm : C-R horizon, parent material with slightly disintegrated bedrock, calcareous

General observations

Virgin land, fairly flat, microrelief slight depressions here and there, slope less than 1 per cent, moderately stony, compacted surface, grasses and other weeds constitute 40 per cent of the cover. Acacia trees are seen around.

26. Manasir

Location: Outside the village in a farmer's field.

0-30 cm : Dry colour, 7.5 YR 5/4, brown
Wet colour, 7.5 YR 4/4, dark brown
Loamy sand, slightly calcareous, non-plastic, pore space open

30-60 cm : Wet colour, 7.5 YR 4/4, dark brown
Sandy loam, slightly calcareous

60-105 cm : Moist colour, 7.5 YR, 4/4 brown
Sandy loam, slightly plastic, slightly sticky, slightly calcareous

105-130 cm : Moist colour, 7.5 YR 5/4, brown
Sandy loam, lime increases with depth, few kankar nodules present, weak consistency

General observations

Flat land, with many trees. Microrelief flat, many weeds.

27. Kathoti

Location: Outside the village on the road to Nagaur in a farmer's field, land ploughed for gram crop.

0-30 cm : Dry colour, 10 YR 6/4, light yellowish brown
Wet colour, 10 YR 5/4, yellowish brown
Loamy sand, dry consistency moderately hard, non-sticky, non-plastic, slightly calcareous

30-90 cm : Wet colour, 10 YR 5/4, yellowish brown, non-calcareous, sandy loam, non-plastic

90-110 cm : Wet colour, 10 YR 4/3, dark brown
Sandy loam, calcareous $CaCO_3$ concretions increase with depth, sticky and plastic

General observations

Fairly flat land, microrelief flat, slope less than 2 per cent.

Annex 15

Index to locations, Rajasthan area

Site	Latitude (N)	Longitude (E)
Akasar	27°52'	73°06'
Amarpura	27°24'	74°33'
Anandpura	27°12'	74°50'
Aniala	26°30'	74°12'
Antroli	26°49'	74°26'
Badauli	26°30'	74°09'
Bagot	26°49'	74°36'
Bamna	26°59'	74°14'
Bandnau	28°21'	74°22'
Barwala	27°09'	74°47'
Basni-Belima	27°11'	74°39'
Barnil	26°53'	74°27'
Baklia	27°34'	74°25'
Bhainsra	26°32'	74°08'
Bhamatsar	27°40'	73°20'
Bhaleri	28°33'	74°47'
Bhanipura	28°37'	74°22'
Bichawa	27°15'	74°22'
Bidasar	27°50'	74°19'
Bigga	28°04'	74°08
Biramsar	28°03'	74°47'
Bithnok	27°52'	72°43'
Buchas	28°37'	74°51'
Bursu	27°09'	74°44'
Butati	26°55'	74°00'
Chandarun	26°56'	74°21'
Chaapri Bari	27°20'	74°47'
Chondian	26°36'	74°05'
Churu	28°18'	74°59'
Dadhia	27°43'	75°13'

Annex 15 (continued)

Site	Latitude (N)	Longitude (E)
Dangawas	26°39'	74°04'
Dayalpura	27°29'	74°44'
Dataramgarh	27°18'	75°11'
Daulatpura	27°23'	74°38'
Deatra	27°47'	72°49'
Degana	26°50'	74°20'
Dhankoli	27°20'	74°49'
Dhaneri	26°26'	74°11'
Dhandarwa	27°09'	74°33'
Dhaod	27°29'	74°59'
Didwana	27°24'	74°34'
Dulmera	28°26'	73°27'
Dundlodh	27°54'	75°14'
Dungargarh	28°04'	74°57'
Fatehpur	28°00'	74°57'
Gadhwala	27°58'	73°27'
Gachhipura	26°58'	74°28'
Gailasar	27°15'	74°42'
Gajner	27°58'	73°02'
Jael	27°13'	74°11'
Jaesingsar	28°27'	74°39'
Jaisas	26°37'	74°11'
Jalwara	26°43'	74°11'
Jamsar	28°16'	73°24'
Jasrasar	27°42'	73°49'
Jhunjhunu	28°08'	75°24'
Jodhyasi	27°24'	73°48'
Kanasar	28°08'	73°19'
Karmisar	28°01'	73°16'
Kashnau	27°04'	74°04'
Kathoti	27°15'	74°18'

Annex 15 (continued)

Site	Latitude (N)	Longitude (E)
Kekind	26°27'	74°05'
Kerap	27°18'	74°24'
Khari-Charnan	28°01'	72°58'
Khara	28°12'	73°23'
Khatu Bari	27°07'	74°19'
Khatu Chhoti	27°09'	74°21'
Khunkhuna	27°19'	74°30'
Kitasar	28°04'	74°14'
Kitalsar	26°52'	74°23'
Kod	26°31'	74°21'
Kolasar	27°45'	74°39'
Kolayat	27°50'	72°58'
Kolia	27°21'	74°29
Koramdesar	28°03'	73°05'
Kuchaman	27°09'	74°52'
Kuchera	26°59'	73°58'
Kukni	27°43'	73°37'
Lachhmangarh	27°49'	75°02'
Ladnun	27°39'	74°23'
Lai	26°43'	73°53'
Lakhasar	28°07'	73°51'
Losal	27°24'	74°56'
Loha	28°02'	74°37'
Lunkaransar	28°30'	73°45'
Luniawas	26°46'	74°27'
Manasir	27°11'	73°44'
Mukandgarh	27°56'	75°13'
Makrana	27°07'	74°44'
Marwar Chapri	26°46'	73°55'
Malasar	28°14'	74°35'
Maulasar	27°19'	74°45'

Annex 15 (continued)

Site	Latitude (N)	Longitude (E)
Megasar	27°57	73°09'
Merta Road	26°43'	73°55'
Merta City	26°39'	74°02'
Mudh	27°52'	72°54'
Mundwa	27°04'	73°49'
Muktanagar	28°03'	74°19'
Nagaur	27°12'	73°45'
Napasar	27°58'	73°33'
Nawa	27°01'	75°00'
Nawalgarh	27°54'	75°16'
Nal	28°04'	73°12'
Nimbod	27°15'	74°48'
Nimbi Bari	27°20'	74°38'
Nokha	27°35'	73°28'
Nokhra	27°38'	72°39'
Oladan	26°49'	73°50'
Paili	27°26'	74°48'
Palana	27°52'	73°15'
Padukalan	26°37'	74°16'
Palri	27°02'	73°38'
Panchwa	27°18'	74°50'
Parbatsar	26°53'	74°46'
Parihara	27°56'	74°33'
Pharrod	27°08'	74°02'
Punlota	26°49'	74°23'
Ramgarh	27°15'	75°10'
Ranasar	27°12'	74°44'
Raneri	27°44'	72°45'
Ratangarh	28°05'	74°37'
Ratan Nagar	28°13'	74°56'
Rajod	26°51'	74°01'

Annex 15 (continued)

Site	Latitude (N)	Longitude (E)
Rajpura	28°31'	73°55'
Rashidpura	27°17'	74°45'
Rian	26°32'	74°15'
Rol Qazian	27°10'	73°56'
Sadalpur	28°39'	75°23'
Salasar	27°44'	74°44'
Sanju	27°00'	74°10'
Sandwa	27°45'	74°10'
Samidialo	26°30'	74°05'
Sarupdesar	27°54'	73°12'
Sardarpura	27°23'	74°50'
Sardarshahr	28°27'	74°29'
Setolao	27°32'	75°03'
Sheobari	28°00'	73°21'
Sikar	27°37'	75°08'
Sital	27°58'	73°36'
Sias	26°36'	74°05'
Sirsana	26°47'	74°11'
Soa	27°48'	73°29'
Suntli	27°11'	74°39'
Surpura	27°43'	73°27'
Sujandesar	27°58'	73°17'
Sujangarh	27°42'	74°28'
Talab Ki Dhani	27°45'	74°47'
Tamroli	26°52'	74°17'
Tausar	27°11'	73°45'
Tara Nagar	28°40'	75°02'
Tilokpura	27°32'	75°16'
Tosina	27°11'	74°23'

Annex 16

Details of test wells drilled by Project in Gujarat Area, 1971-1974

Name of borehole and location	Elevation above MSL (m)	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth of perforated sections bgl (m)	Designation of aquifer	SWL bgl Oct. 1973 (m)	Tested discharge m^3/day	Drawdown (m)	Duration of test and date (min)	Spec. capacity after 24 h of pumping m^3/h	Coefficient of transmissivity m^2/day	Thickness of aquifer (m)	Coefficient of permeability m/day	Storativity x 10^{-4}	TDS ppm	Coefficient of leakage m/sec x10^{-8}
Charasan TW II with one OH (23°31'; 72°08')	43.76	80	Not reached	29-49 58-67	A	5.06	118	42.0	130 14/8/73	No result as well was not developed properly					1,630	
Jadavpur TW (23°10'; 72°07')	33.18	107	-do-	31-38 45-50 52-61 82-88	A	9.75	818	3.6	4320 6/11/73	10.9	78	34	11.1	1.054	1,800	
Kamliwara TW I with one OH (23°52'; 72°14')	97.27	62	-do-	35-44	A	12.72	894	4.8	4320 28/7/73	7.8	239	38	6.3	0.730	1,300	0.36
Karora TW II (23°40'; 72°08')	61.70	98	-do-	30-40 46-54 76-95	A	4.74	2,115	14.4	3180 9/10/73	11.4	471	34	13.9	-	8,100	
Khimiyana TW (23°46'; 72°07')	72.41	96	-do-	35-62 77-87	A	6.13	118	17.2	5760 28/6/73	0.3	28	36	0.8	-	7,000	
Mahi TW III with one OH (24°02'; 72°22')	164.30	166	-do-	76-91	A	12.40	274	16.3	7404 2/9/73	0.9	38	23	1.7	1.161	-	

Annex 16 (continued)

Name of borehole and location	Elevation above MSL	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth of perforated sections bgl (m)	Designation of aquifer	SWL bgl Oct. 1973 (m)	Tested discharge m^3/day	Drawdown (m)	Duration of test and date (min)	Spec. capacity after 24 h of pumping m^3/h	Coefficient of transmissivity m^2/day	Thickness of aquifer (m)	Coefficient of permeability m/day	Storativity $x10^{-4}$	TDS ppm	Coefficient of leakage m/sec $x10^{-8}$
Panchasar TW (23°25'; 71°49')	27.78	107	Not reached	44-50 60-66 74-78 88-96 102-104	A	5.01	818	11.3	4320 / 27/10/73	3.0	73	29	2.5	-	3,900	
Vasana TW II with one OH (23°55'; 72°05')	75.93	98	-do-	59-66 74-87	A	3.06	504	36	4320 / 18/7/73	0.7	31	43	0.7	1.802	1,786	0.16
Vagrol TW (24°17'; 72°20')	161.84	49	44 Granite	25-31 36-40	A	11.52	2087	2.8	4320 / 19/9/73	31.4	*1,000	-	-	-	332	
Kamliwara TW II with one OH (23°52'; 72°14')	96.31	226	Not reached	127-131 144-146 156-159 165-168 191-196	B	24.95	1989	8.8	4364 / 8/7/73	9.6	239	50	4.8	12.380	1,200	
Karora TW I (23°40'; 72°08')	62.55	213	-do-	110-116 121-123 130-131 147-149 156-160 169-174 185-192 204-208	B	12.69	2055	8.3	4320 / 30/7/73	6.2	210	44	4.8	-	1,300	

* Approximate.

Annex 16 (continued)

Name of borehole and location	Elevation above MSL	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth of perforated sections bgl (m)	Designation of aquifer	SWL bgl Oct. 1973 (m)	Tested discharge m^3/day	Drawdown (m)	Duration of test and date (min)	Spec. capacity after 24 h of pumping m^3/h	Coefficient of transmissivity m^2/day	Thickness of aquifer (m)	Coefficient of permeability m/day	Storativity $x10^{-4}$	TDS ppm	Coefficient of leakage m/sec $x10^{-8}$
Mahi TW I with one OH (24°02'; 72°22')	163.46	214	Not reached	148-154 159-175	B	20.60	1,090	26.5	10,080 28/6/72	1.8	47	30	1.6	0.630	448	
Rasana TW (24°13'; 72°15')	160.78	162	-do-	105-123 128-135 146-158	B	25.88	2,725	2.1	11,160 24/10/73	49.4	3,487	60	58.1	2.607	486	1.47
** Saola PH I (23°40'; 72°30')	108.63	201	-do-	161-189	B	24.39	954	4.7	1,100 6/10/73	8.4	638	40	16.0	-	1,780	
Vasana TW I with one OH (23°55'; 72°05')	75.94	213	-do-	102-109 116-121 131-135 139-144 151-154 162-165 173-177 186-191	B	4.41	4,311	20.9	4,290 19/4/73	8.8	540	46	11.7	2.089	3,328	1.65
Charasan TW I with one OH (23°31'; 72°08')	43.80	212	-do-	175-185 187-201	C	46.78	910	18.9	9,340 18/8/73	2.8	94	34	2.8	-	2,500	
Saola TW with one OH (23°40'; 72°30')	108.75	249	-do-	204-221 227-233	C	21.99	3,240	7.1	10,080 30/1/73	21.3	787	23	34.2	2.117	1,180	

** tested piezometric hole.

Annex 16 (continued)

Name of borehole and location	Elevation above MSL	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth of perforated sections bgl (m)	Designation of aquifer	SWL bgl Oct. 1973 (m)	Tested discharge m^3/day	Drawdown (m)	Duration of test and date (min)	Spec. capacity after 24 h of pumping m^3/h	Coefficient of transmissivity m^2/day	Thickness of aquifer (m)	Coefficient of permeability m/day	Storativity $x10^{-4}$	TDS ppm	Coefficient of leakage m/sec $x10^{-8}$
Dhinoj TW with one OH (23°40'; 72°17')	73.30	472	Not reached	410-422 426-432 437-449 457-462	D	0.70	1,090	38.5	6,810 14/2/73	1.3	69	39	1.8	1.083	2,160	
** Charasan PH III (Artesian well) (23°31'; 72°08')	43.68	453	-do-	401-408 411-422	F	23.62 (agl)***	894	25.3	6,960 7/9/72	2.7	76	46	1.7		1,342	
** Seriyad PH I (Artesian well) (23°58'; 72°00')	67.64	613	-do-	465-467 470-473 479-482 488-494 501-508	F	10.2 (agl)	48	9.5	11,520 8/5/74	0.2					1,464	
** Charasan PH I (Artesian well)	44.05	601	-do-	494-512	G	20.97 (agl)	739	25.5	10,000 23/8/72	2.2	59	52	1.1		2,564	
Pilwai TW with one OH (23°32'; 72°43')	123.29	614	-do-	221-227 249-254 263-279	G	17.75	273	5.6	1,500 15/10/73	2.1	70	44	1.6	0.850	1,246	
Mahi TW II with one OH (24°02'; 72°22')	161.94	330	Granite	215-220 254-259 268-274 299-305 321-327	H	17.60	1,363	35.7	1,902 20/8/73	1.7	86	73	1.2	2.810	1,200	

** tested piezometric hole

*** agl - above ground level.

Annex 17

Details of piezometric holes drilled by project in Gujarat area, 1971-1974

Name of borehole and location	Elevation above MSL (m)	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth to perforated section bgl (m)	Designation of aquifer	Depth range cored (m)	WL bgl Oct. 1973 (m)	Salinity of water (ppm)	
								TDS	Chloride
Khimiyana III (23°46';72°07')	72.51	180	Not reached	148-152 155-168	B	174-180	28.35	942	225
Rasana II (24°13'; 72°15')	162.67	150	-do-	121-137	B	Nil	27.21	272	60
Charasan II (23°31';72°08')	43.52	190	-do-	155-159 162-167 169-174	C	Nil	16.32	6,088	2,450
Kamliwara (23°52';72°14')	96.95	594	-do-	343-349 406-413	C	Nil	34.47	840	285
Khimiyana II (23°46';72°07')	72.32	330	-do-	265-270	C	326-330	5.04	1,484	680
Mewad II (23°32';72°23')	83.30	196	-do-	157-160 165-174	C	Nil	23.74	1,300	650
Rasana I (24°13';72°15')	163.04	216	175 (Granite)	185-198	C	215-216	28.56	346	80
Sariyad II (23°58';72°00')	67.64	214	Not reached	186-205	C	Nil	2.83	3,734	1,160
Dhinoj (23°40';72°17')	77.16	611	-do-	414-417 421-427 434-441	D	Nil	2.99	2,440	920
Khimiyana I (23040';72007')	72.54	517	-do-	404-409 414-417 420-429	D	456-461	7.52	2,480	1,050
Mewad III (23°32';72°23')	83.30	196	-do-	157-160 165-174	D	Nil	18.25	772	280
Maktupur (23°50';72°22')	117.16	600	-do-	282-287 289-301	D	277-283 397-400 475-477 599-600	32.18	1,018	250

Annex 17 (continued)

Name of borehole and location	Elevation above MSL (m)	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth to perforated section bgl (m)	Designation of aquifer	Depth range cored (m)	WL bgl Oct. 1973 (m)	Salinity of water (ppm) TDS	Salinity of water (ppm) Chloride
Sariyad III (23°58';72°00')	67.02	305	Not reached	268-274 278-282 286-291 295-298	D	Nil	3.96	1,972	900
Serhao II (23°18';72°34')	82.86	401	-do-	257-271 344-356 382-387	D,E	Nil	5.10	400	135
Bhatsan (24°07';72°10')	126.05	609	-do-	448-464	E	Nil	6.17	356	90
Khimiyana IV (23°46';72°07')	72.41	614	-do-	515-524 527-530 539-545	E	611-614	15.37	3,844	1,975
*Sariyad III (23°31';72°08')	43.96	453	-do-	401-408 411-422	F	Nil	23.62 agl	1,342	600
Mewad I Parbatpura 23°24'; 72°38')	97.26	598	-do-	399-407 434-447 456-465	F	198-200 329-331 479-480 597-598	12.59	750	210
*Charasan I (23°58';72°00')	67.64	613	-do-	465-467 470-473 479-482 488-494 501-508	F	364-366 472-474 610-613	10.2 agl	1,464	530
Saola (23°40';72°30')	108.97	603	-do-	408-420 431-436	F	317-322 468-471 600-603	1.09	1,100	310
*Charasan I (23°31';72°08')	44.05	601	-do-	494-512	G	187-193 305-312 430-462 596-601	20.97 agl	2,564	1,100

* Flowing well

Annex 17 (continued)

Name of borehole and location	Elevation above MSL (m)	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth to perforated section bgl (m)	Designation of aquifer	Depth range cored (m)	WL bgl Oct. 1973 (m)	Salinity of water (ppm) TDS	Salinity of water (ppm) Chloride
Pilwai (23°32';72°43')	123.29	614	-do-	221-227 249-254 263-279	G	74- 75 114-115 269-272 293-294 400-402 478-479 562-564 611-614	18.30	1,290	540
Serhao I (23°18';72°34')	82.89	611	Not reached	466-476 488-497 510-523	G	205-206 376-377 494-496 610-611	0.98	908	320
Mahi (24°02';72°22')	163.96	321	314 (Granite)	213-219 245-251 268-275	H	Nil	19.90	1,200	550
Malekpur (23°46';72°36')	133.01	346	344 (Granite)	201-213 248-259	H	132-135 244-247 277-279 344-345	28.00	2,746	1,080

Annex 18

Details of exploratory boreholes previously drilled by Central Ground Water Board in and around Project area, Gujarat

Name of Borehole and location	Elevation above MSL (m)	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth of perforated sections bgl (m)	SWL bgl (m)	Tested discharge m^3/day	Drawdown (m)	Spec. capacity $m^3/h/m$	Co-eff. of transmissivity m^2/day	Thickness of aquifer (m)	Co-eff. of permeability m/day	Remarks
Agathala (24°18';71°53')	101.06	610	Not reached	27-31 35-41 47-57 60-67	21.5	2,452	7.9	12.90	346	27	12.8	Production well
Agrol (23°09';72°16')	-	304	-do-	95-125	6.4	850	17.9	1.97	-	30		Abandoned, low discharge
Asjol (23°30';72°10')	-	307	-do-	-	-	-	-	-	-	-	-	Abandoned, poor water quality and low discharge
Baspa (23°43';71°41')	28.05	612	-do-	-	-	-	-	-	-	-	-	Abandoned, poor water quality
Bhabbar (24°04';71°34')	-	307	-do-	30-60 83-94 138-173	flowing	-	-	-	-	75	-	Production well
Bhatasan (24°12';71°30')	-	256	-do-	186-200 245-256	flowing	509	21.0	1.01	-	25	-	Production well
Daidarda (24°29';71°44')	-	305	Not reached	80-95 116-117 128-133	5.6	2,114	9.5	2.29	790	21	37.6	Production well
Daran (23°12';72°17')	-	299	-do-	110-116 129-135 169-176 195-202 234-247	5.7	-	-	-	-	39	-	Abandoned, low discharge
Delmal (23°38';72°00')	-	304	-do-	-	-	-	-	-	-	-	-	Abandoned, poor water quality
Dhima (24°28';71°31')	-	307	-do-	-	-	-	-	-	-	-	-	Abandoned

Annex 18 (continued)

Name of Borehole and location	Elevation above MSL (m)	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth of perforated sections bgl (m)	SWL bgl (m)	Tested discharge m3/day	Drawdown (m)	Spec. capacity m3/h/m	Co-eff. of transmissivity m2/day	Thickness of aquifer (m)	Co-eff. of permeability m/day	Remarks
Dodgam (24°19';71°36')	-	308	-do-	10-46	Flowing	1,242	21.3	2.42	-	35	-	Production well
Galodra (23°16';72°14')	-	299	-do-	81-87 139-153 166-173 185-192 199-211	4.0	981	11.3	3.62	-	46	-	Abandoned, low discharge
Gadhi (23°26';72°57')	134.71	-	-do-	-	-	-	-	-	-	-	-	Abandoned, poor water quality
Harij (23°42';71°55')	-	307	-do-	-	-	659	12.2	2.25	-	-	-	Abandoned
Jagana (24°07';72°25')	-	168	161 (Granite)	44-48 51-57 62-67 79-92 95-97 100-102 108-123	-	1,360	17.4	4.88	89	47	1.9	Production well
Jakhel (23°42';71°52')	65.91	621	not reached	-	-	-	-	-	-	-	-	Abandoned, poor water quality
Joraji (23°16';72°57')	100.57	503	493 Pegmatite	-	-	-	-	-	-	-	-	Abandoned
Kaswa (23°15';72°19')	-	306	not reached	45-52 92-99 110-117 124-130 142-155	6.1	850	12.2	2.90	-	40	-	Abandoned
Khardol (24°18';71°25')	-	306	-do-	-	-	-	-	-	-	-	-	Abandoned, lack of granular zones

Annex 18 (continued)

Name of Borehole and location	Elevation above MSL (m)	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth of perforated Sections bgl (m)	SWL bgl (m)	Tested discharge m^3/day	Drawdown (m)	Spec. capacity $m^3/h/m$	Co-eff. of transmissivity m^2/day	Thickness of aquifer (m)	Co-eff. of permeability m/day	Remarks
Manka (23°46';71°54')	-	306	-do-	-	-	-	-	-	-	-	-	Abandoned
Modhera (23°35';72°03')	-	458	-do-	311-318 328-346 365-373	8.5	2,223	7.6	12.16	-	34	-	Production well
Morwada (24°02';71°25')	-	307	-do-	-	-	-	-	-	-	-	-	Abandoned, poor water quality
Munjpur (23°35';71°51')	39.53	615	not reached	-	-	-	-	-	-	-	-	Abandoned, poor water quality
Nananpur (23°30';72°51')	131.85	155	142 (granite)	-	-	-	-	-	-	-	-	Slim hole
Odhwa (23°53';72°03')	-	306	not reached	-	-	-	-	-	-	-	-	Abandoned, poor water quality
Panchasar (23°25';71°49')	28.88	614	-do-	209-212 216-226 233-236 240-254 266-269 276-311 350-355 365-371	Flowing	-	-	-	-	81	-	Production well
Panchot (23°37';72°23')	-	308	-do-	119-135 168-194 223-250	Flowing	2,223	21.9	4.22	144	68	2.1	Production well
Parantij (23°26';72°51')	-	417	403 (granite)	-	-	-	-	-	-	-	-	Slim hole
Radhanpur (23°50';73°36')	27.41	619	not reached	129-132 260-267 287-291 295-300 305-311 319-332 340-355 361-366 376-379	Flowing	-	-	-	-	61	-	Production well

Annex 18 (continued)

Name of Borehole and location	Elevation above MSL (m)	Depth drilled bgl (m)	Depth and nature of basement (m)	Depth of perforated sections bgl (m)	SWL bgl (m)	Tested discharge m^3/day	Drawdown (m)	Spec. capacity $m^3/h/m$	Co-eff. of transmissivity m^2/day	Thickness of aquifer (m)	Co-eff. of permeability m/day	Remarks
Roda (23°49';71°54')	-	305	not reached	128-148 153-159 178-218 221-228 258-279	Flowing	2,637	8.2	13.37	-	94	-	Production well
Sonasan (23°29';72°55')	128.92	192	183 (granite)	65-68 77-81 97-100 110-129 141-153	-	1,646	14.6	4.70	85	40	2.1	Production well
Vadgam (24°05';72°29')	216.42	77	66 (granite)	27-31 35-41 47-57 60-67	21.5	2,452	7.9	12.90	346	26	13.3	Production well
Tervada (24°01';71°44')	-	457	not reached	-	-	-	-	-	-	-	-	Abandoned, poor water quality
Vajapur (24°12';71°34')	54.35	98	-do-	73-79 85-98	-	1,635	7.6	8.94	-	18	-	Production well
Valam (23°42';72°28')	-	308	-do-	77-98 203-280	3.5	3,597	6.1	24.62	1,139	95	12.0	Production well
Varahi (23°47';71°27')	17.86	587	-do-	-	-	-	-	-	-	-	-	Abandoned, poor water quality
Vav. (24°22';71°30')	-	457	not reached	80-119	Flowing	643	25.0	1.07	-	39.00	-	Production well
Wadhroda (23°11';72°12')	-	308	-do-	43-49 72-84 101-107 112-123 152-174 192-204 246-262	3.2	3,030	8.2	15.35	329	80	4.1	Production well
Waghpur (23°29';72°49')	-	320	318 Trap	-	-	-	-	-	-	-	-	Slim hole

Annex 19

Chemical analyses of water from dug wells, aquifer A, Gujarat area

(Analysed by Project Chemical Laboratory, Central Ground-Water Board, samples collected May, 1973)

Location	Topo sheet No.	pH	1* Conductivity	TDS	meq/litre											Boron mg/litre	2** Total hardness	SAR	RSC
				mg/litre	SiO_2 mg/litre	Ca^{2+}	Mg^{2+}	Na^{2+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	F				
Wasana	45D/4A/2	7.45	1,102	624	34	2.90	1.30	8.13	0.09	Nil	5.3	5.50	1.60	0.31	0.01	0.44	210	5.62	1.10
Danta	45D/4D/2	7.60	1,120	730	57	6.80	1.80	3.07	0.04	Nil	7.0	2.61	1.00	1.05	Nil	0.28	430	1.48	-1.60
Nahargarh	45D/4C/5	7.50	583	440	29	4.80	0.40	1.43	0.13	Nil	4.8	0.92	0.60	0.50	Nil	0.27	260	0.89	-0.40
Gola	45D/4C/8	7.25	907	768	28	6.00	1.40	1.22	0.51	Nil	3.6	2.54	0.70	2.42	Nil	0.45	370	0.68	-3.80
Rupal	45D/4C/20	7.35	938	688	30	4.30	0.90	5.09	0.06	Nil	5.8	3.10	0.90	0.52	Nil	0.38	260	3.16	0.60
Gathamen	45D/4B/18	7.50	668	460	36	4.00	2.00	2.39	Tr	Nil	5.3	1.10	1.75	0.53	Nil	0.28	300	1.38	-0.70
Hajipur	46A/1A/11	7.40	636	394	28	2.70	0.90	2.76	0.09	Nil	4.2	2.11	Tr	0.09	0.01	2.08	180	2.06	0.60
Rajpur	46A/2B/21	7.65	1,521	1,020	42	5.40	7.40	2.87	0.05	Nil	5.0	5.92	0.60	3.95	0.05	0.62	640	1.135	-7.80
Wadwasa	46A/3D/16	7.20	966	468	28	3.20	1.40	4.66	0.41	Nil	5.5	1.83	0.50	1.87	Nil	0.27	230	3.08	0.90
Sonasan	46A/3D/8	7.30	1,138	730	61	2.40	2.90	6.39	1.10	Nil	8.8	3.38	0.90	0.10	Nil	0.30	265	3.95	3.50
Magroda	46A/2C/11	7.40	3,179	2,016	40	4.70	5.00	19.62	0.60	Nil	9.4	17.34	0.20	3.22	Nil	0.92	485	8.9	-0.30
Undai	46A/1C/18	7.40	1,186	732	24	3.60	2.00	6.92	0.17	Nil	4.8	5.08	2.10	0.54	0.03	2.56	280	4.15	-0.80
Dedhasen	46A/1D/3	7.50	636	348	44	4.00	1.00	2.28	0.04	Nil	4.1	2.33	0.50	0.48	Nil	0.24	250	1.44	-0.90
Dandpur	41M/2C/2	7.20	3,333	2,040	18	1.80	0.70	32.84	0.05	Nil	2.6	29.61	4.20	0.09	Nil	0.89	125	29.3	0.10

* Electrical conductivity in micromhos/cm at 25°C

** Total hardness (Ca, Mg) as $CaCO_3$ expressed in meq/litre

Annex 19 (continued)

Location	Topo sheet No.	pH	*1 Conductivity	TDS mg/litre	SiO2 mg/litre	meq/litre										RSC	SAR
						Ca^{2+}	Mg^{2+}	Na^{2+}	K^{+}	CO_3^{2-}	HCO_3^{2-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	F		
Patan	46A/1A/13	7.80	3,854	2,230	24	3.4	5.2	27.0	1.7	-	11.0	20.16	3.8	1.52	-	43.2	13.0
Vitora	46A/1C/5	7.65	4,495	3,014	26	5.8	16.8	24.52	0.70	-	9.8	35.96	1.4	0.05	0.07	-12.8	7.3
Vadnagar	46A/1C/21	7.20	4,294	2,440	15	1.2	1.2	37.20	0.06	-	3.4	34.26	2.2	Tr	0.08	1.0	34.0
Timba	46A/1D/1	7.10	793	410	44	3.6	2.2	0.80	0.46	-	3.2	2.11	0.40	1.34	0.15	-2.6	0.47
Basna	46A/2B/10	7.40	4,562	2,514	25	3.0	3.4	36.4	0.03	-	9.6	28.76	3.60	1.08	0.10	3.2	20.3
Jantral	46A/2C/4	7.90	798	364	32	3.4	2.4	1.8	0.20	-	5.0	1.96	0.40	0.34	0.02	-0.8	1.06
Kharod	46A/2C/6	7.60	1,403	872	28	3.8	4.6	3.7	0.47	-	6.0	4.65	0.80	0.88	0.02	-2.4	1.81
Rampura	46A/2D/10	7.50	885	472	30	2.2	1.8	5.7	0.05	-	6.8	1.97	1.0	0.34	0.09	2.8	4.02
Beharaji	46A/3A/2	7.90	2,407	1,446	24	3.4	4.2	15.8	0.24	-	5.0	13.82	4.8	0.05	-	-2.6	8.1
Budatalpura	46A/5A/3	7.55	1,874	1,180	25	2.2	4.6	9.29	1.4	-	7.2	9.17	0.6	0.05	-	0.4	5.04
Paliyad	46A/3C/9	7.40	1,634	1,018	30	1.0	3.0	12.6	0.11	-	9.8	5.64	0.64	0.45	0.08	5.8	8.95
Bardipur	46A/3C/11	7.40	1,482	934	60	1.0	2.6	11.3	0.35	-	11.2	3.81	Tr	0.27	0.03	7.6	8.42
Junapaddar	46A/4A/4	8.55	10,070	7,148	9	1.2	3.6	100.4	0.44	2.0	15.4	49.35	40	Tr	0.39	10.6	65.0
Budarna	46A/4C/21	7.80	603	320	39	1.2	3.2	1.41	0.12	-	3.8	1.13	0.2	0.58	0.21	-0.6	0.955
Bhilot	41M/1C/5	7.35	6,667	4,064	15	7.0	17.0	48.0	0.10	-	3.8	55.58	13.0	Tr	0.10	-20.2	13.8
Memana	41M/2C/4	7.60	4,817	3,048	19	3.8	5.4	37.4	0.20	-	3.6	35.96	7.2	0.06	0.11	-5.6	17.5
Kapranotha	45D/3A/4	7.40	1,123	716	29	2.6	2.6	5.60	0.43	-	6.2	3.24	0.80	1.00	0.05	0.6	3.46
Palanpur	45D/4B/8	7.50	614	350	30	2.4	2.2	1.56	0.02	-	4.6	1.27	Tr	0.31	0.04	0	1.02
Jagana	45D/4B/12	7.40	793	426	-	3.0	2.8	1.8	0.16	-	5.0	2.11	Tr	0.68	-	-0.8	1.06
Satlosha	45D/4D/3	7.65	763	380	42	3.8	2.4	1.2	0.08	-	5.0	1.97	Tr	0.65	0.05	-1.2	0.68
Lunawa	40B/3C/4	7.30	6,422	4,146	26	13.4	8.4	41.21	1.50	-	9.0	45.97	7.8	1.18	0.05	-12.8	12.5
Vasna	40P/3D/5	7.50	1,007	534	31	2.4	2.8	4.21	0.57	-	5.6	2.82	0.80	0.79	0.08	0.4	2.61
Mera	40P/4C/3	7.70	6,869	4,054	29	3.2	9.4	63.04	0.59	-	9.2	46.95	20.0	Tr	0.17	-3.4	25.2
Vatan	40P/4D/1	7.40	1,406	816	27	2.0	2.2	8.05	0.68	-	6.2	3.95	2.0	1.26	0.12	2.0	5.55

Annex 19 (continued)

Location	Topo sheet No.	pH	Conductivity	TDS mg/litre	meq/litre							SO_4^{2-}	RSC	SAR
					Ca^{2+}	Mg^{2+}	Na^{2+}	K^+	CO_3^{2-}	HCO_3^{2-}	Cl^-			
Janaverora	46A/1A/4	7.7	11,510	7,090	16.4	11.6	76.0	2.17	-	6.4	98.7	2.0	-21.6	20.3
Kamlivara	-do- /9	7.6	2,723	1,744	14.0	7.0	12.6	0.13	-	5.6	18.61	2.6	-15.4	3.9
Kunger	-do-/17	7.60	7,570	4,914	1.8	6.0	75.0	0.61	-	22.6	53.30	6.6	20.2	38.5
Khimiyana	-do-/18	7.90	3,210	2,372	0.6	1.6	36.3	0.03	-	18.4	13.68	7.0	16.2	34.5
Rajapura	46A/1B/6	7.80	872	494	1.4	4.8	27.2	0.30	-	6.6	2.54	tr	0.4	1.55
Sunax	-do- 19	7.55	3,154	2,050	2.4	9.6	22.6	0.19	-	10.4	20.30	2.6	-1.6	9.20
Unad	46A/1C/15	7.80	1,182	642	1.4	1.4	11.10	0.20	-	11.4	2.26	0.2	8.6	9.4
Takodi	46A/2A/11	8.8	11,400	7,154	7.6	4.0	110.00	10.42	-	3.6	101.52	12.40	-8.0	45.8
Ranella	-do- 12	7.4	1,391	936	1.6	1.2	10.9	0.21	-	5.6	7.19	1.20	2.8	9.22
Bhandu	46A/2B/4	7.4	2,864	1,626	6.4	6.4	18.15	0.22	-	12.8	16.78	0.80	-0	7.26
Kawasna	46A/2B/5	7.55	2,370	1,475	1.4	2.0	22.6	0.30	-	13.8	6.49	0.80	15.4	17.4
Nawanagar	46A/2D/8	7.20	1,061	532	5.8	1.4	4.57	0.05	-	8.2	3.10	0.60	1.0	2.4
Vijapur	46A/2C/9	7.6	1,448	864	1.8	4.6	8.3	0.22	-	6.6	6.76	1.60	0.2	4.51
Ambaliaban	46A/3B/8	7.40	2,290	1,500	3.6	7.6	13.0	0.20	-	6.8	15.79	1.2	-14.4	5.5
Langhnag	-do-/19	7.50	4,294	2,524	4.2	8.6	32.6	1.00	-	19.6	27.97	2.0	6.8	12.9
Julasan	-do- 17	7.55	2,805	1,668	1.6	5.8	22.9	0.15	-	12.2	14.81	2.4	4.8	12.0
Kadavpura	-do- 22	7.80	4,496	2,896	1.4	3.4	44.6	0.07	-	15.8	27.07	4.8	11.0	28.7
Balasar	-do- 23	7.90	1,625	954	3.0	4.8	8.0	0.20	-	8.4	6.9	1.0	0.6	4.05
Budasan	-do- 25	7.60	562	304	1.2	2.0	2.74	0.03	-	5.0	0.71	tr	1.8	2.16
Bhadol.	46A/3C/14	7.40	637	340	1.8	3.8	1.0	0.99	-	6.0	0.42	0.20	0.4	0.592
Viranagar	46A/4A/7	7.30	4,087	2,464	4.0	3.4	34.13	1.43	-	9.2	26.09	5.4	1.8	17.8
Jakhwada	46A/4A/8	7.45	8,021	5,440	10.4	12.6	65.20	0.20	-	12.8	70.50	3.4	-10.2	19.3
B hovenmote	46A/4B/5	7.15	5,540	3,830	10.0	9.0	43.5	0.09	-	8.2	50.04	3.0	-10.8	14.1
Kangari	-do- 9	7.40	1,011	620	4.0	2.2	5.0	0.32	-	7.8	2.68	0.8	1.6	2.85
Serthanapara	46A/4C/2	7.70	4,749	2,850	4.2	10.0	34.8	0.11	-	10.2	36.66	2.4	-4.0	13.1

Annex 19 (continued)

Location	Topo sheet No.	pH	Conductivity	TDS mg/litre	meq/litre							SO_4^{2-}	RSC	SAR
					Ca^{2+}	Mg^{2+}	Na^{2+}	K^+	CO_3^{2-}	HCO_3^{2-}	Cl^-			
Lodra	41M/1B/1	7.20	4,375	2,930	9.2	8.8	23.0	0.90	-	3.0	37.2	2.6	-15.0	7.67
Arganbar	41M/1C/4	7.5	7,240	4,930	12.0	18.0	49.0	1.50	-	8.1	63.45	9.0	-21.9	12.7
Motipipli	41M/1C/8	7.20	4,375	2,960	11.0	6.8	23.8	0.80	-	3.0	35.11	4.20	-14.8	7.65
Onchanath	41M/1C/9	7.4	212	112	1.6	0.2	0.53	0.11	-	2.0	0.28	tr	0.2	0.558
Daudpur	41M/2C/1	7.2	5,000	4,160	10.4	16.2	33.04	0.08	-	3.6	51.2	2.8	-23.0	9.4
Lankeshwar	41M/2D/8	7.50	6,800	4,554	3.6	16.6	48.9	2.3	-	12.8	43.0	12.6	-7.4	15.4
Lant	45D/3A/1	7.5	749	444	2.2	2.4	3.15	0.30	-	6.2	1.41	tr	1.6	2.06
Rasana	45D/4A/1	7.60	3,030	1,980	1.6	1.0	25.0	2.10	-	13.8	11.8	5.8	11.2	21.9
Ghad	45D/4B/4	7.40	2,850	1,636	3.6	4.6	19.70	0.64	-	10.0	14.81	2.8	1.8	9.75
Chbapi	45D/4B/16	7.40	1,087	600	1.4	2.4	8.5	0.11	-	8.2	3.67	0.40	4.4	6.15
Sandar	40P/3C/5	7.90	5,725	3,546	5.6	17.2	35.4	0.09	-	7.0	41.3	3.8	-15.8	10.5
Bhabhar	40P/4C/7	7.80	3,290	2,164	3.2	7.4	26.10	0.07	-	4.6	25.5	5.0	-6.0	11.3
Tuwar	41M/2D/6	7.20	2,620	1,474	1.70	0.70	23.29	0.14	-	3.1	18.24	3.6	0.70	21.40
Runi	40P/4C/6	7.45	2,799	1,624	1.30	0.50	27.84	0.05	-	2.8	22.21	3.50	1.00	29.30
Tanuaed	40P/4C/8	7.50	2,546	1,488	1.40	-	22.73	0.04	-	3.4	19.51	2.10	2.00	27.10

Annex 20

Chemical analyses of water from tubewells and slim holes drilled by project, aquifer A, Gujarat area

Location	Topo. sheet No.	pH	Conductivity	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K	CO_3^{2-}	HCO_3^{2-}	Cl^{-}	SO_4^{2-}	Total hardness	RSC	SAR
Charasan	46A/23	7.45	17,230	13,646	6.10	21.50	171.0	- Nil	17.50	160.74	16.40	1,380	10.1	46.2	
Jadavpur	46A/4A	7.40	3,207	1,852	0.70	1.70	27.5	- Nil	11.20	13.20	6.60	120	8.8	25.0	
Kamliwara	46A/1A	7.25	2,222	1,342	2.60	6.40	15.0	- Nil	9.00	13.39	1.40	450	0.0	7.1	
Karora	46A/2A	7.35	13,560	8,168	3.40	12.60	114.0	- Nil	14.00	104.34	12.50	800	2.0	40.0	
Khimiyana	46A/1A	7.10	9,622	-	4.20	14.60	76.0	- Nil	11.20	77.83	6.40	940	7.6	24.8	
Panchasar	41M/3D	7.60	6,296	3,900	2.20	3.30	23.60	- Nil	5.40	15.25	8.50	275	0.1	14.2	
Vagrol	45D/3B	7.50	541	332	3.20	1.20	1.70	- Nil	4.60	1.13	0.20	210	0.4	1.2	
Vasava	46A/1A	7.50	2,928	1,786	2.00	4.40	17.70	- Nil	8.40	9.74	4.00	320	2.0	9.5	

Annex 21

Chemical analyses of water from tubewells of aquifer B, Gujarat area

(Analysed by Project Chemical Laboratory, Central Ground Water Board, Samples collected May 1973)

Location	Topo Sheet no.	pH (lab)	Conductivity *1	TDS mg/l	SiO_2 mg/l	meq/litre									F	Total iron mg/l	Boron mg/l	*2 Total hardness	SAR	RSC
						Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}						
Wasai	46A/20-17A	7.50	846	-	26	3.00	0.90	4.96	0.07	-	6.70	1.87	0.10	0.35	0.06	-	0.60	195	3.56	2.80
Biledra	46A/20-18	7.35	982	686	27	3.70	0.90	5.13	0.09	-	6.70	2.82	-	0.42	-	0.06	0.20	230	3.38	2.10
Vijapur	46A/2D-9A	7.35	1028	634	39	2.40	2.40	5.87	0.06	-	9.00	1.97	0.20	0.27	0.01	-	0.20	240	3.80	4.20
Mewi	46A/3C-10	7.20	2121	1258	34	4.50	3.60	12.39	0.05	-	8.40	9.45	1.60	1.93	-	-	0.30	405	6.18	0.30
Khamboi	46A/2A-6	7.30	4049	2624	24	7.70	3.10	26.64	0.19	-	2.20	32.20	4.10	0.17	-	0.12	0.08	540	11.50	-8.60
Mudhera	46A/2A-15	7.20	2305	1250	16	3.60	1.80	15.20	0.24	-	3.60	14.66	3.30	0.11	-	0.06	0.46	270	9.30	-1.80
Unjha	46A/2D-9B	7.50	1519	986	28	3.00	0.90	11.96	0.14	-	7.20	6.20	3.10	0.05	0.18	0.05	0.49	195	8.60	3.30
Bhandu	46A/2D-4B	7.50	7022	5006	28	5.60	12.50	65.23	0.11	-	12.00	66.33	4.90	0.10	0.01	-	2.18	905	21.60	-6.10
Rajpur	46A/3B-20	7.40	2056	1346	28	2.60	2.80	15.51	0.03	-	8.30	9.45	1.70	0.85	0.03	0.06	0.46	270	9.45	2.90
Panchet	46A/2B-11A	7.35	3414	2078	36	5.20	3.10	27.62	0.08	-	10.80	22.14	1.40	0.89	0.08	0.06	0.99	415	13.60	2.50
Mehsana	46A/2B-14	7.40	3152	2817	34	6.10	3.90	19.79	0.07	-	9.80	15.66	2.90	0.95	-	-	0.73	500	8.95	-0.20
Sampwara	46A/2A-16	7.30	2817	1604	24	2.40	2.60	25.23	0.41	-	8.80	17.15	4.50	0.22	-	0.18	0.59	250	16.10	3.80
Jagannathpur	46A/1B-13	7.35	706	460	29	2.60	1.00	5.00	0.02	-	5.20	2.04	0.90	0.39	-	0.06	0.27	180	8.72	1.60
Vadnagar (Sultanpur)	46A/1B-19	7.15	3365	2954	25	3.60	1.40	24.97	0.05	-	15.90	11.14	2.80	0.16	0.03	0.06	0.94	250	15.70	10.90
Wangah	46A/1B-22	7.70	1942	1122	24	2.40	2.40	14.66	0.20	-	7.60	9.59	2.30	0.39	-	0.06	0.40	240	9.45	2.80
Armana	41M/2D-5	7.15	3107	1718	19	1.90	1.00	25.62	0.14	-	2.70	22.14	4.10	0.09	-	0.06	0.09	145	21.40	-0.20
Fulpur	41M/1D-2	7.15	4117	2468	6	2.20	1.40	40.59	0.32	-	4.80	37.08	1.70	0.27	-	0.37	0.70	180	30.30	0.20
Arjansar	41M/2C-	7.35	2546	1356	19	1.20	0.20	23.05	0.03	-	2.50	19.60	2.70	0.06	-	0.12	0.62	70	27.90	1.10
Bhadrara	41M/2C-3	7.05	5203	2856	18	3.80	2.60	42.87	0.22	-	3.80	41.17	4.20	0.21	-	14.80	0.52	320	23.90	-2.60
Radhanpur	41M/1C-7	7.30	4644	2520	21	4.90	2.50	34.06	0.29	-	2.70	34.05	4.30	0.03	-	0.34	0.41	370	70.80	-4.70
Khakol	41M/1D-1	7.10	3716	2466	22	8.80	5.00	24.10	0.09	-	3.50	28.63	5.50	0.11	-	0.06	0.30	690	9.15	-10.30
Bhabhar	40P/40-7	7.50	2522	1524	20	1.30	0.50	24.10	0.04	-	3.20	19.32	2.60	0.06	-	0.06	0.75	90	25.30	1.40
Tharadi	40P/30-2	7.20	2222	1350	20	2.20	1.10	17.68	0.13	-	3.00	14.92	2.90	0.04	-	0.06	0.65	165	14.80	-0.30
Chatra	40P/4B-1	7.60	1647	1034	20	0.80	1.20	15.64	0.04	-	4.40	9.31	4.70	0.02	-	-	0.60	100	15.64	2.40
Dabhoda	46A/1C-3	7.50	1641	1000	-	1.60	2.10	13.96	0.04	-	11.00	5.00	-	-	-	-	-	185	11.5	7.3
Dedasan	46A/2B-17	7.25	1355	792	-	3.20	3.80	7.60	0.09	-	6.60	7.10	0.60	-	-	-	-	350	4.0	-0.4
Dhamsan	46A/3C-4a	7.65	637	358	-	2.10	1.60	2.65	0.02	-	4.80	0.99	0.30	-	-	-	-	185	1.9	1.0
Gothva	46A/2C-9	8.35	784	430	-	0.60	2.00	6.30	0.06	0.40	5.20	1.76	0.20	-	-	-	-	130	5.5	3.0
Nadol	46A/1D-2a	7.75	471	288	-	2.60	1.40	0.43	0.04	-	3.60	0.71	0.40	-	-	-	-	200	0.3	-0.4
Vamlivara+	46A/1A-	7.40	2032	1246	-	1.80	1.40	1.90	-	-	11.00	8.04	3.00	-	-	-	-	160	15.0	7.8
Karbatia	46A/1C-21a	7.75	770	476	-	1.40	1.40	4.95	0.02	-	6.60	0.99	0.20	-	-	-	-	140	4.2	3.8
Karora +	46A/2A-7	7.60	2137	1324	-	2.50	3.10	16.5	-	-	7.50	10.45	4.00	-	-	-.	-	280	9.8	1.9
Kayasna	46A/2C-5	8.55	1026	580	-	0.60	2.00	8.30	0.10	1.20	6.00	3.02	1.10	-	-	-	-	130	4.9	4.6
Khimiyana +	46A/1A-	8.00	1554	942	-	1.20	1.60	12.50	-	-	8.00	6.34	0.80	-	-	-	-	140	10.5	5.2
Mahi +	45D/4B	7.45	779	448	-	2.20	1.20	4.20	-	-	5.80	1.40	0.40	-	-	-	-	170	3.2	2.4
Mewad +	46A/2B	7.60	2328	1300	-	3.00	2.40	14.50	-	-	1.60	18.33	trace	-	-	-	-	290	8.8	-3.8
Punjpur	45D/4C-4a	7.30	740	340	-	3.80	2.30	0.65	0.04	-	4.00	2.59	0.50	-	-	-	-	305	0.4	-2.1
Rasana +	45D/3A-	7.50	872	484	-	2.80	2.20	3.80	-	-	6.40	1.60	0.80	-	-	-	-	250	2.4	1.4
Saola +	46A/2B	7.20	3352	1780	-	0.80	3.80	26.80	-	-	6.60	23.97	0.80	-	-	-	-	230	17.8	2.0
Talotra	45D/4C-7	7.60	414	260	-	2.70	1.50	0.23	0.03	-	3.50	0.71	0.60	-	-	-	-	210	0.2	-0.7
Vasana +	46A/1A	7.55	6208	3328	-	1.20	6.20	48.10	-	-	4.00	49.35	2.20	-	-	-	-	370	25.0	-3.4
Vishalvasna	46A/1B-17a	7.70	1740	962	-	1.50	1.10	16.53	0.06	-	8.20	8.74	1.60	-	-	-	-	130	14.5	5.6

1* Electrical conductivity in micromhos/cm at 25°C

2* Total hardness (Ca,Mg) as $CaCO_3$ expressed in mg/litre

\+ Test wells and slim holes drilled by the project

Annex 22

Chemical analyses of water from tubewells, confined aquifers C, D, E, F, G and H, Gujarat area

(Analysed by Project/Chemical Laboratory, CGWB)

Location	Topo.Sheet No.	Aqui-fer	pH (Lab)	Conducti-vity 1*)	TDS ppm	Meq/litre								*2) Total hardness	RSC	SAR
						Ca^{2+}	Mg^{2+}	Na^{2+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}			
Charasan	46A/2B	C	7.60	9,455	6,088	2.60	7.40	74.0	-	Nil	6.80	67.68	10.00	500	-3.2	33.2
Khimiyana	46A/1B	C	7.40	2,698	1,484	0.80	0.80	25.5	-	Nil	6.00	19.18	2.20	80	4.4	27.5
Rasana	45L/3A	C	8.10	621	346	1.00	0.20	4.90	-	Nil	4.20	1.97	Tr.	60	3.0	6.3
Saola	46A/2B	C	7.20	2,039	1,180	3.60	0.80	17.40	-	Nil	11.20	8.46	2.20	220	6.8	11.7
Sariyad	46A/1B	C	8.25	6,829	3,734	0.20	1.20	61.60	-	Nil	12.20	45.83	5.00	70	10.8	73.5
Dhinoj	46A/2B	D	8.50	3,568	2,160	1.80	1.80	31.00	-	1.60	9.40	21.15	3.00	230	6.4	20.5
Kamliwara	46A/1B	D	8.10	1,390	840	1.80	2.20	10.60	-	Nil	7.20	5.22	2.20	200	3.2	7.5
Khamiyana	46A/1A	D	7.95	4,394	2,480	2.80	3.40	27.00	-	Nil	6.40	29.61	4.20	310	0.2	15.3
Maktupur	46A/1B	D	8.40	1,606	1,018	1.00	1.20	14.00	-	0.40	7.60	7.06	1.20	110	7.0	13.3
Newad	46A/2B	D	7.50	1,825	920	1.40	3.40	14.50	-	Nil	2.00	13.39	4.00	240	-2.8	9.5
Serhao	46A/3C	D	7.95	803	400	0.40	1.40	6.20	-	Nil	3.20	3.81	1.00	90	0.4	6.5
Sariyad	46A/1A	D	8.00	3,617	1,972	0.80	3.20	29.00	-	Nil	4.80	25.38	2.80	200	0.8	19.8
Rhatasan	45A/4A	E	7.75	681	356	1.40	0.6	5.50	-	Nil	4.60	2.54	0.40	100	2.6	5.5
Khimiyana	46A/1A	E	7.70	6,829	3,844	6.40	1.20	48.00	-	Nil	1.80	55.71	8.80	380	-5.8	24.5
Charasan	46A/2B	F	7.90	2,600	1,342	2.40	3.20	16.90	-	Nil	3.80	16.92	1.80	280	-1.8	10.1
Newad	46A/2B	F	7.90	1,403	772	1.00	0.20	11.20	-	Nil	3.20	8.04	1.80	90	1.4	11.8
Pilwai	46A/2C	F	7.50	2,040	1,246	3.80	3.20	13.80	-	Nil	4.40	13.96	2.40	350	2.6	7.4
Saola	46A/2B	F	7.80	4,010	2,390	3.40	3.60	32.10	-	Nil	3.40	35.53	0.20	350	-3.6	17.1
Sariyad	46A/21A	F	7.80	2,673	1,460	3.60	4.20	14.90	-	Nil	4.00	14.10	4.60	390	3.8	7.6
Charasan	46A/2B	G	7.30	4,121	2,564	7.60	8.20	22.0	-	Nil	3.80	29.61	4.60	790	-12.0	7.8
Nahi	45D/4B	G	7.40	2,248	1,200	3.80	1.20	13.8	-	Nil	5.00	12.41	1.40	250	0.0	8.8
Serhao	46A/3C	G	7.80	1,513	908	3.00	2.20	9.20	-	Nil	3.40	9.02	2.00	260	- 1.8	5.7
Malekpur	46A/1C	H	7.70	3,427	2,146	3.20	3.40	30.4	-	Nil	11.60	16.21	5.00	330	8.0	16.7

*1) Electrical conductivity in micromhos/cm at 25°C

*2) Total hardness (Ca, Mg) as $CaCO_3$ expressed in ppm

Physical characteristics of soils in Gujarat area
(Analysed by Project Soil Laboratory, Jodhpur)

Location	Depth	Mechanical analysis (%)				Bulk density	Hydraulic conductivity cm/h	Moisture percentage at		Available moisture
		Clay	Silt	Fine sand	Coarse sand			0.3 atm	15.0 atm	
Pilwai	0- 50	7.2	10.6	80.6	1.2	1.48	6.20	3.42	1.94	1.48
-do-	50- 80	10.2	11.6	76.5	1.2	1.39	3.60	4.21	2.02	2.09
-do-	80-120	15.4	7.8	76.3	1.0	1.38	3.80	4.25	2.10	2.15
-do-	120-170	11.8	12.9	75.3	0.7	1.37	3.70	4.35	2.05	2.30
Jadavapura	0- 58	20.4	21.8	29.7	20.6	1.35	0.00	16.78	10.43	6.35
-do-	58- 82	25.6	20.0	39.4	12.4	1.37	0.00	15.71	9.70	6.01
-do-	82-113	20.3	16.5	55.9	5.1	1.39	0.00	17.68	9.98	7.70
Lanwa	0- 82	25.8	22.5	50.0	1.6	1.38	0.00	18.64	11.84	6.80
-do-	82-120	23.7	27.1	48.6	1.4	1.38	0.00	19.08	12.11	6.97
Harij	0- 36	25.3	19.7	48.2	2.4	1.37	0.00	18.76	11.48	7.28
-do-	36- 80	13.5	6.6	70.8	3.0	1.41	0.10	11.47	5.98	5.49
-do-	80-103	14.8	16.3	56.5	7.7	1.39	0.00	15.96	9.84	6.12
-do-	103-132	18.3	11.7	56.2	9.6	1.40	0.02	16.34	10.21	6.13
Radhanpur	0- 22	28.5	13.8	44.8	11.2	1.36	2.40	18.28	12.08	6.20
-do-	22- 36	14.0	12.1	56.8	15.3	1.44	3.64	10.74	7.03	3.71
-do-	36-120	11.0	6.4	69.7	8.8	1.47	3.78	10.01	6.94	3.07
Jesada	0- 44	11.2	10.9	72.0	1.7	1.47	3.62	9.04	5.78	3.26
-do-	44- 73	21.4	13.8	59.6	1.1	1.41	3.71	14.78	10.02	4.76
-do-	73-110	27.8	22.4	39.5	5.6	1.37	0.20	18.63	11.73	6.90

Annex 23 (continued)

Location	Depth	Mechanical analysis (%)				Bulk density	Hydraulic conductivity cm/h	Moisture percentage at		Available moisture
		Clay	Silt	Fine sand	Coarse sand			0.3 atm	15.0 atm	
Damasan	0-100	22.4	15.6	51.7	10.0	1.41	0.89	14.88	9.76	5.12
-do-	100-125	24.0	14.1	52.5	10.0	1.41	1.01	14.51	8.98	5.53
Balwa	0- 39	10.9	16.3	69.4	3.7	1.48	3.06	10.98	6.43	4.55
-do-	39-130	14.5	2.44	60.1	3.0	1.45	1.28	14.84	7.38	7.46
Parantij	0- 40	7.6	5.9	81.3	5.6	1.49	5.98	3.32	1.82	1.50
-do-	40- 70	15.2	8.4	69.1	7.5	1.44	4.69	9.46	6.21	3.25
-do-	70- 90	18.0	8.2	68.6	4.9	1.44	4.10	10.38	6.75	3.53
-do-	90-130	14.3	21.8	58.5	5.0	1.38	3.28	13.42	7.31	6.11
Visnagar	0- 28	9.8	17.6	66.8	6.0	1.47	3.19	9.98	6.43	3.55
-do-	28- 65	8.9	10.0	73.6	5.4	1.48	5.83	6.98	4.92	2.06
-do-	65- 83	7.0	11.6	74.0	4.0	1.48	4.23	7.60	5.38	2.22
-do-	83-110	7.2	13.8	73.2	4.6	1.47	4.45	12.43	8.55	3.88
-do-	110-130	11.8	30.2	50.2	4.6	1.34	2.36	17.60	12.45	5.15
Pipaldar	0- 64	8.2	13.9	66.4	11.1	1.38	4.83	12.49	8.37	4.12
-do-	64- 80	11.7	22.8	47.8	7.7	1.34	2.78	16.38	10.80	5.58
-do-	80-115	20.0	29.7	44.4	5.7	1.32	1.89	17.38	12.21	5.17
Kherau	0- 90	7.5	12.4	71.2	7.1	1.44	3.66	10.02	6.42	3.60
-do-	90-130	8.1	11.9	69.3	8.5	1.40	3.60	10.72	6.66	4.06
Bilia	0- 10	6.2	5.0	76.7	12.5	1.48	6.89	5.02	2.93	2.09
-do-	10-120	8.1	10.1	63.5	14.6	1.37	5.94	13.29	7.22	6.07
Patan	0-110	7.0	3.1	86.7	0.8	1.43	6.74	4.60	2.67	1.93
-do-	110-120	3.5	5.2	72.9	15.7	1.42	7.89	1.83	1.22	0.61
Bhansoria	0- 90	7.8	12.3	63.4	12.9	1.43	5.64	6.86	4.80	2.06
-do-	90-130	10.4	12.7	58.2	15.3	1.42	4.67	10.14	6.56	3.58

Annex 23 (continued)

Location	Depth	Mechanical analysis (%)				Bulk density	Hydraulic conductivity cm/h	Moisture percentage at		Available moisture
		Clay	Silt	Fine sand	Coarse sand			0.3 atm	15.0 atm	
Dhoria	0- 45	8.3	9.9	57.9	21.5	1.39	5.09	9.13	5.61	3.52
-do-	45- 90	10.4	12.0	57.0	20.3	1.37	3.89	15.09	7.98	7.11
-do-	90-125	9.1	12.1	64.0	14.1	3.95	3.95	11.16	5.66	5.50
Deesa	0-110	6.4	8.7	58.3	26.5	1.45	4.34	5.45	3.51	1.94
-do-	110-130	6.0	4.2	66.2	20.8	1.43	6.67	6.23	3.13	3.10
Chadothar	0- 35	5.2	4.6	61.5	26.2	1.44	6.85	5.05	2.29	2.76
-do-	35- 70	8.3	8.4	54.0	26.5	1.43	4.64	5.90	3.13	2.77
-do-	70-120	6.1	7.2	49.6	34.6	1.43	4.84	5.92	3.30	2.72
Mahi	0-130	4.8	6.0	43.0	46.2	1.61	5.01	2.91	2.54	0.37
-do-	130-165	6.3	9.8	44.5	37.2	1.53	4.89	5.01	3.30	1.71
Ratanpur	0- 30	7.1	9.7	66.0	15.0	1.37	4.78	7.40	4.41	2.99
-do-	30-120	9.8	9.1	72.8	7.5	1.36	4.68	6.04	3.19	2.85
Punjapura	0- 60	9.0	10.2	76.6	4.2	1.45	4.73	7.76	3.91	3.85
-do-	60- 90	8.7	23.3	64.7	3.0	1.44	3.89	11.41	6.06	5.35
Sarotra	0- 15	22.4	16.5	54.1	6.5	1.46	2.94	16.27	8.54	7.73
-do-	15- 60	25.8	22.3	44.9	7.1	1.44	2.84	19.79	12.51	7.28
-do-	60- 95	26.8	25.1	41.8	6.3	1.37	2.64	21.92	12.60	9.32
-do-	95-120	20.6	24.2	49.8	6.5	1.37	3.01	20.29	11.05	9.24
Bantiwada	0- 15	3.8	4.6	74.6	15.2	1.63	7.48	2.48	0.31	2.17
-do-	15-125	4.0	4.5	70.2	21.3	1.53	7.31	3.16	1.19	1.97

Annex 23 (continued)

Location	Depth	Mechanical analysis (%)				Bulk density	Hydraulic conductivity cm/h	Moisture percentage at		Available moisture
		Clay	Silt	Fine sand	Coarse sand			0.3 atm	15.0 atm	
Jangaral	0- 35	7.9	8.3	5.90	22.8	1.50	6.89	9.19	4.36	4.83
-do-	35- 60	10.8	15.2	50.5	23.2	1.49	4.82	11.44	5.21	6.23
-do-	60-135	24.2	21.7	47.9	6.5	1.39	3.68	17.23	9.89	7.34
Mehsana	0- 30	12.4	20.1	50.2	17.1	1.38	4.43	12.82	6.75	6.07
-do-	30- 90	16.2	19.3	46.6	18.8	1.37	3.78	13.37	5.87	7.50
-do-	90-130	12.7	19.2	44.2	25.1	1.36	4.42	12.43	7.66	5.77
Sankalpura	0- 10	7.8	12.4	74.9	4.6	1.44	5.04	7.27	3.95	3.32
-do-	10- 95	12.6	18.7	61.8	6.8	1.39	4.08	11.19	2.13	9.06
-do-	95-130	14.8	18.4	60.0	6.5	1.39	3.89	12.16	3.80	9.36
Endra	0- 40	11.2	14.7	63.7	11.0	1.39	3.94	9.37	3.30	6.07
-do-	40- 90	12.8	17.2	48.1	21.0	1.34	3.68	17.43	9.03	8.40
-do-	90-130	14.7	22.3	41.7	12.5	1.33	3.49	15.09	6.62	8.47

Annex 24

Chemical Characteristic of Soils in Gujarat Area

(Analysed by Project Soil Laboratory, Central Ground Water Board, Jodhpur)

Section	Depth (cm)	pH	E.C. micro-mhos/ cm at 25°C.	Analysis of saturation extract (meq/litre)				SAR	CEC	Exchangeable cations (meq/100 g)				ESP	Organic carbon (%)	$CaCO_3$ (%)
				Ca	Mg	K	Na			Ca	Mg	K	Na			
Pilwai	0- 50	7.4	316	1.6	2 00	0.14	0.13	0.09	2.28	1.37	0.33	0.36	0.22	9.64	0.182	Nil
-do-	50- 80	7.4	370	2.2	0.84	0.10	0.90	0.07	2.91	1.60	0.45	0.56	0.30	10.80	0.084	0.01
-do-	80-120	7.4	314	3.02	0.52	0.12	0.13	0.10	3.22	2.05	0.46	0.42	0.29	9.00	0.031	0.02
-do-	120-190	7.5	370	2.80	0.88	0.03	0.09	0.07	2.98	1.94	0.34	0.41	0.29	9.73	0.012	0.04
Jadavapura	0- 58	8.8	191	0.25	0.18	0.02	1.52	3.32	11.30	5.56	1.15	0.22	4.57	44.42	0.342	2.63
-do-	58- 82	9.2	6,967	11.10	5.80	0.01	34.70	11.93	12.30	4.43	1.41	0.21	6.25	50.81	0.037	6.84
-do-	82-113	9.1	9,661	11.10	7.90	0.02	60.8	19.22	6.95	2.74	0.47	0.24	3.50	50.35	0.014	10.28
Hanwa	0- 82	8.5	216	0.40	0.29	0.03	1.63	2.78	7.02	3.05	0.46	0.82	2.69	38.32	0.118	Nil
-do-	82-120	7.8	6,970	8.40	10.04	0.02	32.6	10.73	8.61	3.42	0.43	0.57	4.34	50.40	0.039	Nil
Harij	0- 36	8.1	34,874	77.00	122.08	2.00	165.00	16.58	6.96	1.99	0.20	0.62	4.14	59.48	0.077	4.75
-do-	36- 80	8.7	34,874	48.00	107.00	2.00	165.00	18.80	3.89	1.76	0.12	0.22	1.88	48.33	0.080	5.84
-do-	80-103	8.5	26,713	38.00	67.00	1.70	128.60	17.76	4.25	1.42	0.14	0.32	2.37	55.76	0.052	4.96
-do-	103-132	8.5	20,255	21.00	54.60	1.20	88.30	14.33	4.36	1.22	0.18	0.36	2.60	59.63	0.031	4.23
Radhanpur	0- 22	8.3	697	3.00	2.06	0.05	2.50	1.57	8.22	5.56	1.28	0.55	0.83	10.10	0.200	1.98
-do-	22- 36	8.3	1,046	6.04	1.72	0.07	3.80	2.07	4.65	2.96	1.92	0.28	0.49	10.54	0.077	2.04
-do-	36-120	8.8	897	3.06	1.98	0.05	5.73	3.61	4.28	2.93	0.60	0.09	0.66	15.42	0.025	3.89
Jesada	0- 44	8.5	142	0.27	0.25	0.08	1.08	2.25	4.78	2.51	1.12	0.28	0.85	11.78	0.140	4.82
-do-	44- 73	8.4	112	0.15	0.34	0.03	1.33	2.71	7.60	4.65	1.60	0.29	1.06	13.95	0.140	3.48
-do-	73-110	9.0	1,696	3.99	0.57	0.01	11.80	7.81	11.33	5.68	1.49	0.31	3.85	33.98	0.085	5.88
Damasan	0-100	8.6	1,083	2.98	0.57	0.01	7.70	5.78	9.13	4.05	1.88	0.31	2.89	31.65	0.184	0.48
-do-	100-125	8.4	722	2.98	0.14	0.01	5.20	4.38	10.69	6.61	1.38	0.25	2.45	72.92	0.038	0.31

Annex 24 (continued)

Section	Depth (cm)	pH	E.C. micro-mhos/cm at 25°C.	Analysis of saturation extract (meq/litre) Ca	Mg	K	Na	SAR	CEC	Exchangeable cations (meq/100 g) Ca	Mg	K	Na	ESP	Organic carbon (%)	$CaCO_3$ (%)
Balwa	0- 39	8.0	929	3.98	3.56	0.01	3.00	1.54	3.44	1.94	0.80	0.04	0.30	8.72	0.152	Nil
-do-	39-130	8.3	929	2.28	2.52	0.01	4.70	3.03	5.86	2.72	1.13	0.31	1.70	29.01	0.145	Nil
Parantiz	0- 40	7.1	521	1.99	2.00	0.03	1.60	0.80	2.47	1.25	0.57	0.39	0.26	10.53	0.120	Nil
-do-	40- 70	7.2	290	1.14	1.71	0.01	0.50	0.35	4.30	2.62	1.17	0.26	0.25	5.81	0.113	Nil
-do-	70- 90	7.2	260	1.14	0.30	0.10	1.40	1.94	4.34	2.92	0.82	0.32	0.28	6.45	0.123	Nil
-do-	90-130	7.2	271	0.85	1.10	0.4	1.10	1.13	4.28	3.08	0.68	0.24	0.28	6.54	0.122	Nil
Visnagar	0- 28	7.8	325	1.41	1.02	1.10	1.28	1.16	3.60	2.72	0.40	0.23	0.25	6.94	0.086	4.45
-do-	28- 65	7.6	592	2.14	1.42	0.10	2.41	1.80	2.66	2.14	0.34	0.06	0.12	4.55	0,060	2.32
-do-	65- 83	8.5	434	1.14	2.07	0.08	1.30	1.02	2.65	2.02	0.40	0.09	0.14	5.28	0.029	3.44
-do-	83-110	8.0	296	1.14	1.28	0.01	1.13	1.03	2.86	2.05	0.55	0.13	0.13	4.55	0.028	1.41
-do-	110-130	8.2	350	1.14	1.40	0.01	1.11	0.98	5.05	3.42	1.37	0.13	0.13	2.57	0.021	1.39
Pipaldar	0- 64	7.8	225	1.78	0.40	0.08	0.54	0.49	3.65	1.48	1.48	0.09	0.13	1.09	0.194	Nil
-do-	64- 80	7.4	198	1.14	0.40	0.07	0.80	0.91	4.01	2.28	1.57	0.11	0.11	0.70	0.140	Nil
-do-	80-115	7.9	193	1.40	0.40	0.08	0.60	0.63	6.75	4.96	1.37	0.19	0.23	3.41	0.122	Nil
Kherulu	0- 90	8.2	358	1.71	1.48	0.03	0.78	0.62	2.81	1.82	0.69	0.17	0.13	4.63	0.242	1.29
-do-	90-130	8.8	509	1.15	1.42	0.08	2.90	2.56	2.47	1.60	0.45	0.11	0.31	12.55	0.043	0.95
Lilia	0- 10	8.2	154	0.57	0.40	0.03	1.00	1.44	1.80	1.14	0.34	0.19	0.13	7.22	0.109	0.02
-do-	10-120	8.7	576	2.14	1.18	0.01	2.10	1.95	2.86	1.60	0.91	0.20	0.15	5.24	0.137	3.62
Patan	0-110	8.4	509	1.85	0.66	0.08	3.30	2.95	2.06	1.14	0.57	0.10	0.25	12.14	0.051	2.69
-do-	110-120	9.3	430	0.86	1.71	0.08	2.60	2.94	1.18	0.91	0.11	0.02	0.14	11.86	0.030	3.89
Lhamsoria	0- 90	8.4	265	2.20	0.46	0.08	0.60	0.52	2.35	2.17	0.57	0.10	0.08	3.40	0.205	2.67
-do-	90-130	8.6	221	1.70	0.20	0.08	0.60	0.62	2.55	1.82	0.57	0.08	0.08	3.14	0.191	2.89
Lhoria	0- 45	8.6	843	1.71	3.42	0.01	3.90	2.43	2.42	1.14	0.80	0.11	0.37	15.29	0.089	2.43
-do-	45- 90	8.1	662	1.99	1.79	0.01	3.50	2.55	2.63	1.68	0.55	0.06	0.34	12.93	0.014	0.78
-do-	90-125	8.0	210	1.70	0.40	0.04	0.60	0.59	2.23	1.37	0.43	0.07	0.36	16.14	0.011	0.72
Deesa	0-110	7.75	390	2.28	0.60	0.08	1.10	0.92	1.51	1.14	0.27	0.06	0.04	2.65	0.082	0.32
-do-	110-130	8.1	355	2.01	0.57	0.08	1.60	1.41	1.48	1.04	0.30	0.05	0.04	2.70	0.055	2.89

Annex 24 (continued)

Section	Depth (cm)	pH	E.C. micro-mhos/ cm at 25°C.	Analysis of saturation extract (meq/litre) Ca	Mg	K	Na	SAR	CEC	Exchangeable cations (meq/100g) Ca	Mg	K	Na	ESP	Organic carbon (%)	$CaCO_3$ (%)
Lhadother	0- 35	7.9	602	3.99	0.90	0.02	1.30	0.83	1.16	0.94	0.11	0.06	0.05	4.31	0.211	2.21
-do-	35- 70	8.0	378	2.85	0.90	0.01	0.50	0.37	2.24	2.01	0.14	0.05	0.04	1.73	0.168	2.48
-do-	70-120	8.0	414	2.85	0.90	0.08	1.20	0.88	2.12	1.89	0.12	0.05	0.06	2.83	0.028	2.31
Lahi	0-130	8.0	442	1.71	0.85	0.04	1.90	1.68	1.25	0.91	0.18	0.05	0.11	8.80	0.043	0.02
-do-	130-165	8.3	414	2.22	0.70	0.04	1.90	1.57	1.78	1.30	0.33	0.04	0.11	6.18	0.032	0.98
Latanpur	0- 30	8.2	519	3.14	1.42	0.02	1.10	0.73	2.22	1.85	0.23	0.08	0.06	2.70	0.088	1.88
-do-	30-120	8.2	397	1.28	1.90	0.08	1.30	1.03	2.86	2.39	0.35	0.05	0.07	2.45	0.024	2.01
Enjapura	0- 60	8.0	963	7.41	1.10	0.02	1.40	0.53	2.81	1.87	0.80	0.08	0.06	2.14	0.130	Nil
-do-	60- 90	7.9	321	1.85	0.48	0.08	1.30	1.20	2.63	2.05	0.42	0.07	0.09	3.42	0.113	Nil
Sarotra	0- 15	7.6	1,123	5.70	1.20	0.04	5.20	2.80	7.00	5.04	1.27	0.20	0.49	7.00	0.248	0.43
-do-	15- 60	7.7	539	2.14	0.80	0.08	2.10	1.49	8.08	6.64	1.12	0.09	0.23	2.85	0.232	0.01
-do-	60- 95	7.9	561	2.40	0.80	0.02	2.40	1.90	8.54	7.12	1.28	0.03	0.11	1.29	0.246	0.01
-do-	95-120	8.0	675	2.64	1.20	0.03	2.60	1.88	6.70	5.48	0.85	0.10	0.27	4.03	0.246	Nil
Dantiwada	0- 15	8.0	246	1.60	0.30	0.02	0.40	0.41	0.84	0.63	0.11	0.06	0.04	4.70	0.123	1.89
-do-	15-125	7.8	239	1.40	0.30	0.03	0.70	0.76	0.85	0.75	0.10	0.02	0.03	3.53	0.030	0.49
Jangaral	0- 35	7.8	963	4.56	1.74	0.11	3.80	2.17	1.80	1.22	0.38	0.08	0.12	6.67	0.301	1.89
-do-	35- 60	8.6	799	4.14	1.56	0.03	2.30	1.36	2.28	1.21	0.73	0.08	0.26	11.40	0.112	0.02
-do-	60-135	8.7	686	3.68	1.51	0.04	2.10	1.30	4.56	3.43	0.72	0.06	0.35	7.67	0.041	0.01
Mehsana	0- 30	8.0	426	2.28	1.70	0.03	0.9	0.64	2.96	2.43	0.36	0.09	0.08	2.70	0.215	Nil
-do-	30- 90	7.6	532	3.56	0.70	0.03	1.40	0.96	3.70	2.55	0.92	0.13	0.10	2.70	0.116	Nil
-do-	90-130	7.3	1,639	7.13	7.69	0.03	2.20	0.86	2.83	2.00	0.69	0.08	0.06	2.12	0.041	Nil
Sankalpura	0- 10	7.6	412	3.70	0.70	0.04	0.14	0.09	1.79	1.41	0.24	0.10	0.04	2.23	0.133	Nil
-do-	10- 95	7.5	210	1.50	0.50	0.03	0.12	0.12	2.77	2.30	0.31	0.09	0.07	2.53	0.082	Nil
-do-	95-130	8.1	319	2.28	0.50	0.03	0.42	0.36	2.81	2.12	0.56	0.07	0.06	2.14	0.029	0.89
Endra	0- 40	7.8	555	4.56	0.96	0.06	0.20	0.12	2.12	1.66	0.27	0.13	0.06	2.83	0.101	Nil
-do-	40- 90	7.9	387	2.70	0.20	0.03	1.30	1.08	2.92	2.35	0.36	0.11	0.10	3.42	0.137	0.38
-do-	90-130	8.6	456	4.56	0.20	0.03	0.23	0.15	3.24	2.64	0.42	0.09	0.09	2.78	0.041	8.92

Annex 25

Index to locations, Gujarat area

Site	Latitude (N)	Longitude (E)
Abu Road	24°34'	72°43'
Agathala	24°18'	71°53'
Agrol	23°09'	72°16'
Ahmadabad	23°02'	72°33'
Asjol	23°30'	72°10'
Baspa	23°43'	71°41'
Bhabbar	24°04'	71°34'
Bhatsan	24°07'	72°10'
Chanasma	23°43'	72°07'
Charasan	23°31'	72°08'
Daidarda	24°29'	71°44'
Dantivada	24°21'	72°20'
Danta	24°11'	72°46'
Daran	23°12'	72°17'
Delmal	23°38'	72°00'
Deesa	24°15'	72°11'
Dhenera	24°31'	72°01'
Dhima	24°28'	71°31'
Dhinoj	23°40'	72°17'
Diodar	24°06'	71°46'
Dodgam	24°19'	71°36'
Gadhi	23°26'	72°57'
Golodra	23°16'	72°14'
Harij	23°42'	71°55'
Himatnagar	23°36'	72°58'
Hirad	23°16'	72°59'
Panchot	23°37'	72°23'
Parbatpura	23°24'	72°38'
Patan	23°51'	72°06'
Pilwai	23°32'	72°43'
Jeraji	23°16'	72°57'
Kadi	23°18'	72°20'
Kalol	23°15'	72°30'
Kamliwara	23°52'	72°14'
Kankrej	24°00'	72°00'
Karora	23°40'	72°08'
Kaswa	23°15'	72°19'
Khardol	24°18'	71°25'
Kheralu	23°52'	72°37'
Khimiyana	23°46'	72°07'
Mahi	24°02'	72°22'
Maktupur	23°50'	72°22'
Malekpur	23°46'	72°36'
Mandal	23°17'	71°56'
Manka	23°46'	71°54'
Mansa	23°26'	72°39'
Mehsana	23°35'	72°24'
Mewad	23°32'	72°23'
Modhera	23°35'	72°08'
Morvada	24°02'	71°25'
Munjpur	23°35'	71°51'
Nananpur	23°30'	72°51'
Odbwa	23°53'	72°03'
Palanpur	24°10'	72°28'
Panchasar	23°25'	71°49'
Jadavpur	23°10'	72°07'
Jagana	24°07'	72°25'
Jakhel	23°42'	71°32'

Annex 25 (continued)

Site	Latitude (N)	Longitude (E)	Site	Latitude (N)	Longitude (E)
Prantij	23°26'	72°51'	Radhanpur	23°50'	71°36'
Rasana	24°13'	72°15'	Roda	23°49'	71°54'
Sami	23°41'	72°34'	Saola	23°40'	72°30'
Sariyad	23°58'	72°00'	Serhao	23°18'	72°34'
Sidhpur	23°55'	72°22'	Sihori	24°02'	71°57'
Sonasan	23°29'	72°55'	Tervada	24°01'	71°44'
Tharad	24°09'	71°38'	Vadgam	24°05'	72°29'
Vagrol	24°17'	72°20'	Vajapur	24°12'	71°34'
Valam	23°42'	72°28'	Varahi	23°47'	71°27'
Vasana	23°55'	72°05'	Vav	24°22'	71°30'
Vijapur	23°34'	72°46'	Viramgam	23°03'	72°02'
Visnagar	23°43'	72°33'	Wadhroda	23°11'	72°12'
Waghpur	23°29'	72°49'			

Annex 26

Project personnel

A. International experts		Periods of service (in months)			
Name	Title	1971	1972	1973	1974
Silas C. Brown	Project Manager	9	12	12	9
S.I. Strausberg	Sr. Hydrogeologist	9	12	1	-
Paul L.R. Illy	Sr. Hydrogeologist	-	-	3	9
C.D. Chenov	Hydrogeologist	8	-	-	-
Edward Fraczek	Hydrogeologist	-	10	12	9
B.M. Winder	Land and Water Use	-	-	3	9
L.H. Rhodes	Agricultural Economist	-	-	1 1/2	9
Arne Forsman	Consultant Hydrometeorologist	-	-	-	3
Marino Martini	Consultant Hydrochemist	-	-	-	3
Wilfried Oelmann	Consultant Drilling-Fluid Engineer	-	-	1 1/2	-
Dennis E. Williams	Consultant Digital Mathematical Model	-	1/3	1	2/3
B. Counterpart personnel					
D. Pandey	Project Director	9	12	12	9
A. Achuta Rao	Project Hydrogeologist	2	-	-	-
B.P.C. Sinha	Project Hydrogeologist	-	2	12	9
G.D.S. Singh*	Hydrogeologist	2	12	12	9
D.V.N. Raju**	Hydrogeologist	9	12	12	9
Ravi K. Jain	Executive Engineer	3	12	12	6
Y.P. Kakar	Chemist	-	3	12	9
L. Venkat Ratnam	Soil Chemist	-	-	5	9
P.C. Ghosh	Chemist	9	12	12	9
S.C. Goyal	Hydrometeorologist	-	-	8	9
Sushil Kumar	Accounts Officer	9	3	-	-
H.R. Sharma	Accounts Officer	-	9	12	9

Also 20 Senior Technical Assistants, Assistant/Junior Hydrogeologists

335 Total Government counterpart personnel in all categories

* Project Hydrogeologist for 12 months

** Project Hydrogeologist for 5 months

Annex 27

Fellowships

Recipient	Subject	Period of study
V.M. Sikka	Photogeology (The Netherlands)	Sep. 1973 - Apr. 1974
B.P. Verma	Hydrogeology (The Netherlands)	Apr. 1974 - Oct. 1974
A.K. Mishra	Electric Logging (USA)	Aug. 1974 - Dec. 1974
A.R. Bakshi	Electric Logging (USA)	Aug. 1974 - Dec. 1974
D.P.C. Sinha	Ground-Water Development (USA)	Aug. 1974 - Nov. 1974
S.K. Tyagi	Hydrogeology (USA and the Netherlands)	Aug. 1974 - Mar. 1975
S.C. Ghosh	Water Quality Studies (USA and Canada)	Aug. 1974 - Feb. 1975
S.P. Kakar	Water Quality Studies (USA and Canada)	Aug. 1974 - Apr. 1975
M.R. Kulkarni	Artificial-Recharge Studies (USA)	21 June - 31 Dec. 1975

Annex 28

Major items of equipment provided by UNDP

Drilling and allied equipment

1 Rotary Wabco Drill, capacity 2,500 feet
1 Rotary Wabco Drill, capacity 1,500 feet
2 Electric welding units
1 Air compressor 100 psi
1 Air compressor 250 psi
2 Water tank trailers
1 Electric logger, portable
2 Electric loggers 3,000 ft capacity
5 Baroid mud kits

Water-well screens, 300 m (1,000 ft)
Drilling mud chemicals (Baroid ± 1 1/2 tons)

Transportation

2 International Harvester 6 x 6 trucks
2 Chevrolet 4 x 4 station wagons
1 Ford, Fairmont station wagon

Chemical laboratory equipment (in part)

1 Flame photometer
1 Hach colorimeter
1 Turbidimeter

Field equipment (in part)

10 Electric water-level indicators
6 Brunton compasses
20 Water level recorders
2 Conductivity meters
2 Micro-altimeters

Office and map equipment (in part)

1 Map-reproduction unit
1 Photo-copier

Annex 29

Other UNDP projects and allied agencies with which contact was maintained.

Participating agency	Project title
United Nations Children's Fund (UNICEF)	Village Water Supply Programme, India Discussions and advice on hydro-geological exploration methods in hard-rock areas.
Food and Agriculture Organization of the United Nations (FAO)	Ground Water Surveys in Hard Rock Areas of Mysore State Discussions on hydrogeological exploration methods and procedures in hard-rock areas.
Food and Agriculture Organization of the United Nations (FAO)	Soil and Water Management Projects Land and Water Use and Management in the Chambal Irrigated Area, Rajasthan Discussions pertaining to Land and Water Use and Agricultural Economics to related areas in Rajasthan.
International Bank for Reconstruction and Development (World Bank)	Discussions on procedures and evaluation of various geological types and situations in various parts of India. Also system studies of the Punjab and Agricultural economics.
International Atomic Energy Agency (IAEA)	Nuclear Research in Agricultural Project Discussion and field collaboration on isotope tracer studies in the Sikar Basin, Rajasthan.
United Nations Educational, Scientific and Cultural Organization (UNESCO)	Warangal Regional Engineering College Collaborated on surface resistivity training in Sikar Basin of Rajasthan