UNITED NATIONS DEVELOPMENT PROGRAMME

GROUND WATER SURVEY OF

THE JAISALMER (LATHI) AREA - RAJASTHAN, INDIA

TECHNICAL REPORT

MARCH 1971

This report is presented to the Government of India without prior approval of either the United Nations or the United Nations Development Programme and therefore does not necessarily represent the views of either organisation.

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ABSTRACT

Detailed hydrogeologic investigations were conducted in the arid Jaisalmer (Lathi) area, western Rajasthan, India from 1968 to 1970. The purposes of the project were to investigate and evaluate groundwater potentialities and to make appraisals of the feasibility of groundwater development.

It was determined that the Lathi formation, a thick, extensive, near shore deposited sandstone of Jurassic age, forms the most important aquifer in the entire UNDP project area. Fresh groundwater (TDS less than 2,000 ppm) occurs under 1260 square miles (3,272 sq. kms.) in the Lathi aquifer. Considerable quantities can be obtained for domestic, livestock and industrial uses although wells would have to be drilled to depths of more than 500 feet (150 m) in many places.

Recharge is considered as negligible for practical evaluations of large withdrawals. To extract large quantities of water, therefore, mining must be undertaken.

Soil and water analyses indicate that groundwaters can be safely used on selected tracts of land to grow crops such as wheat, cotton, alfalfa, barley, sugar beets, tomatoes and certain fodder crops.

A 129.4 square mile (335.2 sq. km.) tract in the Lathi - Chandhan - Bhairwa area has the greatest potential for medium to large scale groundwater development for irrigation. Selected tracts of land in a 200 square mile (518 sq. kms.) area would be within the reach of the pumped groundwater by way of canals and pipelines. Groundwater

stored in the Lathi aquifer could be used for about 200 year . The average pumpage would be about 42 US MGD (58 MCM/yr).

A socio-economic study should be undertaken prior to large scale groundwater development. If the results of the studies prove favourable, it is recommended that 42 high capacity production wells be installed in the Lathi - Chandhan - Bhairwa area. These wells should produce, in conjunction with existing wells (currently pumping about 2 USMGD or 2.8 MCM/yr) an average of 42 USMGD (58 MCM/yr). Wells would have to be replaced every 15 to 20 years. Data from prior operations could be used for guidelines for replacement well locations and for readjustment of pumpage to reduce the speed of brackish water encroachment.

About 10 proposed outpost observation wells should be installed to monitor regional changes of water quality and water levels. Data should also be collected from production wells. The composite TDS content from the 42 wells should initially be about 1,000 ppm and after 200 years of pumping it should still be within usable limits.

The 42-well proposal would probably be reasonably acceptable to a plan for rainfall supplementation rather than for a primary source. The present shakey economy of the region is due, to a large extent, to drought cycles.

Development of groundwater could substantially alleviate hardships and reduce Government expenditures for famine relief both in the immediate and distant future.

Management of water, soils and crops will be of utmost importance in obtaining efficient and beneficial uses of resources.

I. INTRODUCTION

Field work was organised under the direction of Mr. D. Pandey, Director, UNDP (SF) Project and hydrogeological investigations were carried out under the supervision of Dr. A. AchuthaRao, Chief Hydrogeologist, UNDP (SF) Project, Jodhpur. The drilling work was organized by Mr. M. N. Bahuguna, Executive Engineer, UNDP (SF) Project and Mr. S.K.Misra, Assistant Executive Engineer, UNDP(SF) Project, Jodhpur. The field work was carried out with the advice and guidance of the United Nations team.

The present report, under the supervision of Mr. D. Pandey, Project Director, was largely prepared by Dr. Achutha Rao, Chief Hydrogeologist with the assistance of Mr. D. V. N. Raju, Junior Geologist, Mr. V. M. Sikka, Assistant Geologist, Mr. P.C.Ghosh, Assistant Chemist, Mr. P.K. Nayar, Assistant Soil Chemist and Mr. V. K. Bhalla, Assistant Hydrometeorologist. The report was enhanced and reviewed by members of the United Nations team.

The following is a list of personnel involved in the field work:

Hydrogeology group

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Mr. I. P. Malik -do-

The project for groundwater surveys in western Rajasthan was undertaken by the Government of India through the Exploratory Tubewells Organisation now known as Central Groundwater Board, with the assistance of U. N. D. P. (SF). In agreement thereof, a Plan of Operation was signed on 2nd December 1966. The purpose of the project was to investigate and evaluate the groundwater potentialities for agriculture irrigation, for domestic and livestock water supply and industrial uses in western Rajasthan and to make appraisals of technical and economic feasibility of groundwater development. Under this programme, based on existing data, certain key areas were selected and field work was started. Exhibit 1 shows the total project area and outlines the large areas studied in detail. The Jalor project area in Jalor district ; Lathi formation area in Jaisalmer and partly in Barmer districts, and Barunda limestone area in Jodhpur district were large areas investigated in detail. Another area, not shown in Exhibit 1 is the Doli- Jhanwar - Pal sub area 5 to 15 miles (8 to 24 km) southwest of Jodhpur. This small region was studied in detail very late in the project for a supplemental water supply for Jodhpur.

This technical report presents the results of investigations in the Lathi formation area in the arid part of western India. These investigations are important because the presence of extensive tracts of desert lands in western and north-western Rajasthan have caused difficult living conditions. As in all deserts, there is low and sporadic rainfall, very poor and xerophytic vegetation, extensive sand dunes andheavy evaporation losses from surface water bodies. Above all there are frequent droughts and lack of potable water for domestic needs. Cattle wealth is the primary economy of these parts and their sustenance depends on availability of water and fodder.

The Lathi formation was known to contain a promising aquifer. This was determined from earlier exploratory investigations. Considerable basic geological information was available from earlier drilling activities, hence, the present investigations were oriented to assess the physical boundaries of the potential aquifers, . to evaluate the exploitable quantity of groundwater and to estimate the technical feasibility for beneficial development of the available groundwater resources.

The field work in Jaisalmer district was started in January 1968 and continued to September 1970. The areal extent of the Lathi formation is about 2900 sq.miles (7500 sq.kms.) between latitudes 26°15' and 27°45'; and longitudes 70°45' and 72°30'. The areal extent of the Lathi formation outcrop is essentially limited on the west and northwest by overlap of the Jaisalmer limestone of Middle to Lower Jurassic age; on the south by major faults; on the northeast by wedging out between Permo-Carboniferous and Eocene formations and on the east and southeast by feather edging against Pre-Cambrian rocks. The clastic sediments occuring within this area are stratigraphically grouped into the Middle to Lower Jurassic Lathi sandstone series and are near-shore deposits.

Based on 1961 census records, the population density of Jaisalmer and Barmer district is reported to be:

District	Total area (sq.km.)	Population density (Persons/per sq.km.)
Jaisalmer	39,000	4
Barmer	28,000	23

Barmer district has a higher density of population due to relatively better precipitation.

2. REVIEW OF EARLIER WORK

The earliest geological investigations in western Rajasthan were carried out by Blanford (1877) who attempted to delineate the stratigraphy of the region. Oldham (1886) mapped large parts of the erstwhile Jaisalmer State. He classified and described the various stratigraphic units and reported, for the first time, the occurrence of red sandstones near Devikot classifying them as possible members of the Gondwana series. The area was re-examined La Touche (1902) who designated the sandstones as the Lathi series, and later by Daru (1916-17) who mapped the area covered by toposheet No.40 N. Heron (1932) critically reviewed the earlier works. Pascoe (1959) also studied the area and described the Lathi series under the Gondwanas of West Rajasthan as an ill exposed thick series of dark red shaley sandstones and clay occurring stratigraphically between the Permo-Carboniferous Bap boulder beds and the marine limestones of the Jaisalmer series. He further reported the occurrence of isolated outcrops surrounded by sandy deposits between Pokaran and Jaisalmer.

In recent years, officers of the Geological Survey of India carried out more detailed studies. The officers of the Oil and Natural Gas Commission (ONGC) carried out detailed geological mapping and geophysical surveys of almost the entire Jaisalmer area.

Geological investigations for groundwater was given emphasis by Auden (1950), who attempted generalized appraisal on the groundwater occurrence in western Rajasthan. In 1955, the semi-arid and arid tracts of western Rajasthan were further examined with a view to locate exploratory borehole sites. One of the sites located at Chandhan, gave impetus for continuing further exploratory drilling into the Lathi sandstones. In 1961, detailed studies of groundwater occurrence in the productive part of the Lathi series were carried out by a systematic well inventory made by the Geological Survey of India.

Prior to the present study, Central Groundwater Board (ex-E.T.O.) had drilled 56 boreholes in the Lathi outcrop area of Jaisalmer and Barmer District and basic data were compiled in the form of basic data reports. Some of these data are presented in Table 1.

The Central Arid Zone Research Institute (CAZRI) is engaged in the collection of hydrometeorological data for the region. The Rajasthan Groundwater Board has constructed a few production wells for drinking water supplies.

The collection and evaluation of all available information from different agencies were made early in the project period and have been freely used in the present investigation. The geological and hydrogeological data from ONGC and CGWB were especially helpful in the present studies.

3. METHODOLOGY OF PRESENT SURVEY

In order to establish the quantity of exploitable reserves of groundwater in the Lathi aquifer, the following program was carried out;

(a) delineation of the geological boundaries and outcrop area of the Lathi series,

(b) selection of observation well net-work for qualitative and quantitative evaluation of groundwater,

(c) supplementing meteorological data - rainfall, temperature, wind velocity and evapotranspiration, etc.,

(d) establishment of river gauge and lake gauge stations in the Lathi area to assess the run-off and infiltration to groundwater bodies.

(e) drilling of key holes for supplementing subsurface geological information to establish dimensions of the aquifer and to evaluate aquifer characteristics such as coefficients of transmissibility, permeability and storage,

(f) collection of data pertaining to existing draft from the groundwater body for agriculture and other uses,

(g) collection of data on existing pattern of land utilisation and soil characteristics.

The field work was started in January 1968 and was continued to September 1970. Water level measurements are being continued.

Geological mapping was carried out using topographic maps at 1:63,360 (1"=1 mile) scale. Detailed studies were made in an area of about 4,000 sq. miles (10,000 sq. kms.). Areal photos of portion of the area were also utilised to help delineate the outcrop are of sandstones. These studies in conjunction with previous data have established the areal limits of the Lathi formation which are shown on the 1" = 4 miles base map. Accordingly the area of the Lathi formation is considered to be about 2,900 sq. miles (7,500 sq. kms.). The actual outcrop area is estimated to be only about 400 sq. miles (1,000 sq. kms) because much of the sandstone is covered by a relatively thin veneer of aeolial or alluvial deposits.

Observation wells were established for monthly and seasonal water level measurements. The following cross-sections were made from data obtained from the observation wells:

	Section	Number of observation wells
(a)	Northwest of Lathi	10 (8 dugwells; 2 tubewells)
(b)	Central area(main Lathi area)	37 (36 dugwells;1 tubewell)
(c)	Western area	13 dugwells
(d)	Southern area	12 (11 dugwells; 1 tubewell)
	Total:	72

Two hydrologic(stream gauge)stations, along the Sukri Nadi near Chandan and a stream near Akal,were located. Additionally, 4 lake gauge stations and 5 raingauge stations were established to estimate runoff,and rainfall. The data from CAZRI observatory at Chandhan were also collected. Data from other stations were collected during the 1968, 1969 and 1970 monsoon periods.

Water samples from 72 wells measured monthly for two years (1968-70) were analysed for the following major components;

Ca, Mg, Na, K, Cl, SO_4, HCO_3, CO_3,TDS, pH, Electrical Conductivity

Samples for carbon 14 and silicon 32 dating were also collected in collaboration with Tata Institute of Fundamental Research (TIFR), Bombay for dating of groundwater etc.

The test drilling was classified into 3 categories;

(i) pumping test wells,

(ii) observation wells,

(iii) stratigraphic bore holes.

30 holes were drilled in the area of which 5 were completed as pumping test wells, 12 as observation wells and 13 as stratigraphic bore holes. Drilling sites are shown on the base map (Ex.4) . Data from 41 existing pumping wells and 15 earlier abandoned boreholes were also compiled and are shown in Table 1.

The following cross-sections were made;

(i) Bhopa - Chhor - Akal - Rajwai

(4 bore hole sites, 1 pumping test well and 1 observation well each at Rajwai and Chhor were constructed),

(ii) Duwara- Bhairwa- Jetha

(3 bore hole sites, 1 pumping test well and 6 observation wells including one not used, were constructed at Bhairwa),

(iii) Ajasar (Tota) - Bardhana-Loharki

(only one site at Ajasar (Tota) was drilled for supplementary information, 1 pumping test well and 4 observation wells were constructed),

(iv) Sirwa- Sangar- Fatehgarh

(2 stratigraphic bore holes at Sirwa and Fatehgarh were drilled).

The remaining holes (shown on the base map - Exhibit 4) were distributed throughout the general area. One pumping test well was completed at Rama.

Drilling was done by conventional direct rotary drilling techniques, using WABCO-2500 and 1500 rigs. Table 2 gives details of bore holes drilled during the project. Drill cuttings were collected , studied and recorded. Some coring of aquifer material and bedrock was undertaken to study lithologic and hydrologic characteristics. All boreholes were electric logged for more precise correlation of individual beds. Microfossil and pollen studies to identify marker horizons were also attempted. Mechanical analyses of aquifer samples were conducted.

Test and observation wells were cased and gravel packed by conventional techniques. Pumping test wells tap the complete thickness of the aquifer. Diesel powered turbine pumps were used for performing step tests and constant rate pump tests. Details are given in Table 3. Non-equilibrium equations were utilised for analyses of the pumping test results (Table 4.).

Analyses of water samples were made at certain intervals in each well. Water samples were collected using the compressor and other methods.

4. HYDROMETEOROLOGICAL CONDITIONS

Available hydrometeorological data from Jodhpur, Jaisalmer and Barmer districts were collected and used for the evaluation of precipitation, runoff, temperature, humidity, wind velocity and evaporation from lakes and tanks.

A regional map showing normal annual rainfall (1901-67) is shown in Exhibit 2. Runoff is virtually non-existant in the Lathi formation area except in the ridge areas underlain by hard sandstone. Small intermittant surface flows occur in small rivulets in these areas but the surface flow either evapotranspires for the most part or infiltrates into the sandy plains on leaving the hills. The mean annual runoff from 220 sq. miles (568 sq. kms.) of hilly and rivulet areas in the general region is estimated at 930 MCF (26.5 MCM). A runoff coefficient of 0.27 was used for calculations.

Annual precipitation 1901-67 (mm)

Normal annual precipitation	165-185
Annual precipitation of 10% probability	300-320
Annual precipitation of 25% probability	220-240
Annual precipitation of 50% probability	140-160
Annual precipitation of 75% probability	 85-100
Annual precipitation of 90% probability	..... 52- 66

The monsoon (June-September) contributes about 90% of the total annual precipitation.

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Mean monthly and annual rainfall 1901-67 (mm)

	J	F	M	A	M	J	J	A	S	O	N	D	Annu
Jaisalmer	2.8	4.7	3.7	2.5	7.1	14.6	58.7	68.2	22.3	1.3	1.3	1.9	189.1
Sheo	1.9	2.0	2.8	1.4	6.3	19.6	73.1	75.3	26.9	2.7	0.7	0.7	213.3
Phalodi	3.3	5.1	4.4	3.3	9.5	25.0	71.8	86.1	27.4	2.2	1.1	1.9	241.1
Shergarh	2.3	3.6	4.2	1.0	8.0	23.5	82.6	92.0	37.6	2.0	1.0	1.1	258.9
Barmer	2.3	3.2	3.8	1.3	8.0	20.2	88.3	106.0	35.7	2.8	1.1	1.6	274.3

Annual rainfall 1968, 1969, 1970 and 1901-67 Normal (mm)

	1968	1969	1970	1901-67
handhan	56*	60	260	171
alodi	95	138	371	241
ergarh	61	60	208	259
rmer	49	64	160	274
eo	31	77	140	213
isalmer	83	19	232	189
karan	27	29	190	179
hpadra	47	42	316	263
tora	60	9	288	274
tehgarh	0	0	125	171

	1968	1969	1970	1901-67
Ramgarh	13	2	150	140
Devikot	33*	16	NR	160
Akal	57*	22	NR	175*

* Extrapolated

NR = No Record.

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Mean number of rainy days monthly and annual 1901-50

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Jaisalmer	0.40	0.48	0.38	0.30	0.78	1.06	3.44	3.68	1.42	0.16	0.10	0.16	12.36
Phalodi	0.32	0.58	0.32	0.30	0.84	1.66	3.96	4.88	2.02	0.14	0.10	0.14	15.26
Barmer	0.20	0.36	0.30	0.24	0.66	0.98	4.16	4.56	1.96	0.16	0.08	0.18	13.84
Shergarh	0.24	0.42	0.30	0.14	0.68	1.54	4.16	4.62	1.92	0.16	0.06	0.18	14.42
Sheo	0.18	0.26	0.14	0.10	0.54	0.86	3.04	3.66	1.20	0.12	0.00	0.04	10.14
Ramgarh	0.14	0.10	0.22	0.04	0.18	0.31	1.88	1.84	0.49	0.02	0.02	0.02	5.26

Mean maximum temperature – 1958-70 (C°)

	J	F	M	A	M	J	J	A	S	O	N	D
Jaisalmer	24.1	28.1	33.1	37.9	42.1	41.2	38.5	36.1	36.4	36.7	30.9	25.2
Phalodi	23.6	27.2	33.1	38.0	41.6	41.1	37.7	35.4	35.9	36.2	30.3	24.8
Barmer	26.0	29.9	34.9	39.0	42.5	40.4	37.0	35.2	35.5	37.1	32.1	27.2

Mean minimum temperature 1958-70 (C°)

Jaisalmer	7.2	10.5	16.5	21.8	25.4	26.6	26.2	25.5	23.7	20.4	12.0	3.6
Phalodi	6.6	10.4	16.3	21.9	25.7	27.5	26.7	25.7	24.1	19.9	13.3	7.8
Barmer	11.0	13.5	19.0	24.3	27.0	27.1	26.5	25.8	24.7	22.6	17.2	11.9

Mean wind velocity 1958-70 (k.p.h.)

Jaisalmer	7.5	7.6	9.4	10.7	15.8	23.7	20.2	18.1	13.7	7.3	5.9	6.7
Phalodi	6.6	8.2	10.9	11.9	17.0	24.4	20.2	17.5	14.5	9.7	7.2	6.9
Barmer	5.2	5.7	6.5	8.1	8.6	11.6	10.2	8.9	7.0	5.0	4.9	5.1

Mean air humidity, morning 1968-70 (%)

	J	F	M	A	M	J	J	A	S	O	N	D
Jaisalmer	59	50	47	49	53	70	68	72	68	55	51	58
Phalodi	58	54	47	46	49	68	71	77	73	55	53	53
Barmer	50	51	44	40	48	65	76	77	76	58	50	53

Mean maximum temperature 1968-70 (C°)

		J	F	M	A	M	J	J	A	S	O	N	D
Jaisalmer	1968	21.9	-	-	-	-	-	41.4	-	-	-	-	-
	1969	-	27.7	32.9	40.4	42.5	42.5	41.0	32.0	38.8	37.9	31.5	27.7
	1970	24.1	27.5	32.4	40.5	44.0	41.9	38.7	37.3	36.0	37.8	31.7	26.8
Phalodi	1968	20.8	23.4	33.1	38.7	40.0	41.2	39.6	36.3	38.9	36.9	-	26.2
	1969	24.9	27.7	36.4	39.2	41.4	42.1	40.1	36.5	38.3	37.8	31.9	28.2
	1970	24.9	27.0	31.9	39.8	43.3	41.1	37.4	31.9	35.3	36.7	31.4	26.7
Barmer	1968	-	-	-	-	-	-	-	-	-	-	33.5	25.4
	1969	25.5	29.3	37.6	37.2	42.1	40.1	38.3	35.7	38.4	38.3	33.5	29.4
	1970	26.4	28.1	33.1	40.4	43.8	40.3	37.1	35.1	33.4	36.7	32.1	27.8

Mean minimum temperature 1968-70 (C°)

		J	F	M	A	M	J	J	A	S	O	N	D
Jaisalmer	1968	5.2	-	-	-	-	-	24.3	-	-	-	-	-
	1969	-	10.3	18.2	21.7	24.4	26.7	25.4	26.1	23.9	21.8	15.6	9.1
	1970	8.9	-	12.4	21.6	25.7	26.9	25.0	25.2	23.1	20.3	10.9	6.5
Phalodi	1968	5.4	8.5	16.6	21.5	23.9	27.2	27.3	25.7	28.1	19.1	-	7.3
	1969	6.4	9.4	17.0	21.3	24.7	27.0	27.0	24.7	23.8	22.6	15.0	8.7
	1970	7.7	10.0	15.5	22.5	28.0	28.5	25.9	24.4	19.9	16.9	9.3	8.2
Barmer	1968	-	-	-	-	-	-	-	-	-	-	17.4	12.2
	1969	10.3	9.3	-	-	-	-	26.8	25.3	25.9	24.5	25.9	13.8
	1970	12.0	13.3	17.5	24.8	28.2	28.5	27.0	26.8	24.7	24.1	15.9	10.3

Mean wind velocity 1968-70 (k.p.h.)

		J	F	M	A	M	J	J	A	S	O	N	D
Jaisalmer	1968	11.2	9.3	10.7	10.2	12.0	22.2	17.4	19.7	13.5	6.6	-	16.3
	1969	6.2	7.9	7.5	11.6	16.1	27.7	26.4	26.0	4.4	8.1	8.2	5.8
	1970	10.2	9.5	10.0	12.1	17.0	-	26.3	17.0	14.7	8.6	4.1	4.7
Phalodi	1968	4.0	4.6	7.5	11.3	14.0	33.4	16.8	23.0	17.1	7.2	-	6.7
	1969	10.4	9.9	8.9	13.7	17.4	26.9	25.0	20.8	14.9	10.6	7.7	5.1
	1970	9.0	10.0	11.1	13.3	16.1	19.0	20.1	10.7	14.4	9.8	5.6	7.1
Barmer	1968	3.0	2.1	5.5	4.0	4.7	7.6	7.0	6.0	6.0	1.8	4.0	5.5
	1969	7.2	6.9	6.9	7.9	10.8	13.9	10.3	10.9	9.9	7.1	5.8	4.5
	1970	1.5	3.0	4.3	9.8	1.6	16.5	16.2	6.7	6.9	3.0	0	0

Mean air humidity, morning 1968-70 (%)

		J	F	M	A	M	J	J	A	S	O	N	D
Jaisalmer	1968	78	-	-	-	-	-	-	-	-	-	-	-
	1969	47	46	42	42	53	73	72	61	74	61	53	50
	1970	62	58	51	42	68	59	77	80	82	64	52	60
Phalodi	1968	68	58	50	48	50	67	33	72	65	45	-	46
	1969	36	42	37	31	50	72	68	-	-	-	-	-
Barmer	1968	59	59	46	43	43	62	64	68	64	61	51	51
	1969	45	51	33	22	25	43	72	72	64	41	45	45
	1970	45	44	41	28	34	54	74	55	82	58	52	52

Annual pan evaporation for 10,25,50,75 and 90 percent probabilities and normal 1959-67 (mm)

	10%	25%	50%	75%	90%	Normal
Jaisalmer	2890	2800	2720	2640	2410	2710
Phalodi	2850	2680	2640	2560	2400	2630
Barmer	3140	2860	2770	2720	2470	2790

Normal monthly pan evaporation 1959-70 (mm per day)

	J	F	M	A	M	J	J	A	S	O	N	D
Jaisalmer	3.1	5.0	6.3	10.5	14.1	13.4	9.6	6.6	7.4	7.3	4.5	2.8
Phalodi	3.0	4.7	6.9	10.6	13.5	13.5	8.7	6.2	7.3	6.8	4.3	2.8
Barmer	3.7	5.9	3.0	11.3	14.4	12.[illegible]	7.6	6.1	6.8	7.8	5.0	3.3

Mean monthly and annual pan evaporation estimated 1959-70 (mm)

	J	F	M	A	M	J	J	A	S	O	N	D	Annu
Jaisalmer	97	141	212	316	436	403	297	205	223	225	134	88	2777
Phalodi	94	132	214	317	420	404	270	192	218	212	129	87	2689
Barmer	116	166	248	339	445	377	235	188	205	241	149	102	2811

Mean annual evaporation from lakes and tanks 1959-67 (mm)

Jaisalmer	2030
Lathi	2000
Phalodi	1970
Barmer	2090
Devikot	2020

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Annual lake evaporation for Lathi area 1959-67 (mm)

Normal lake evaporation	..	1990-2030
Annual evaporation of 10% probability	..	2060-2210
Annual evaporation of 25% probability	..	2070-2090
Annual evaporation of 75% probability	..	1950-1990
Annual evaporation of 90% probability	..	1790-1810

-.

Mean monthly evaporation from surface water 1959-67 (mm per day)

LATHI AREA

J	F	M	A
2.3-2.5	3.7-3.8	5.2-5.3	7.6-7.8

M	J	J	A
10.2-10.4	9.7-10.0	6.2-6.5	4.7-5.0

S	O	N	D
5.1-5.4	5.2-5.3	3.2-3.4	1.9-2.1

It is seen that potential evaporation is more than ten times greater than normal annual precipitation.

Studies by Krishnan and Thanvi (1969), have shown, based on data from 1941 through 1960, that high water surplus which would produce runoff and recharging of aquifer beyond the soil mantle, generally occurs once in 20 years. Even in the wettest years the moisture deficiency during January to the onset of monsoon is high. The soil moisture storage upto water holding capacity generally is utilized by the end of December. During the period 1941-60, Barmer had surplus water only once, amounting to 444 mm in August 1944. Jaisalmer also had surplus water only once which amounted to 112 mm in August 1955.

5. GEOMORPHOLOGY AND DRAINAGE

Geomorphological features of the region are shown in Exhibit 3. Land surface elevations in the area of the Lathi formation outcrop (including areas covered by aeolial and alluvial deposits) range from about 520 feet (159 m) to about 1100 feet (336 m) above mean sea level. The lowest area is near Jetha. The highest elevations are generally on the tops of residual hillocks and in some cases on dune crests.

A prominent scarp located as close as 5 miles (8 km.) southeast of Jaisalmer is at the contact between the Lathi formation and the younger Jaisalmer limestone. This scarp, trending NE-SW, was formed because of differential erosion. The basal limestone member of the Jaisalmer limestone formation is more resistant than the upper part of the Lathi sandstone formation and forms the cap of the scarp.

The aerial extent of the Lathi formation includes vast tracts covered by aeolial and alluvial deposits. Consequently, most of the Lathi area consists of sandy plains of typical desert floor environment and parabolic, longitudinal and transverse sand dunes.

Two systems of dunes are distinguished. The older system consists of high and stabilized longitudinal dunes trending NE-SW. The average length is about one mile (1.6 km.) and chains of dunes occur about 3 miles (4.8 km.) apart with fused fronts. The average width is about 500 feet(153 m) and heights generally range from 100 to 150 feet (30 to 46 m). Some dunes are as much as 8 or 10 miles (13 or 16 km)long and some are as high as 300 feet (91 m). The alignment of these dunes was caused by the prevailing southwesterl wind. In places, dune modifications are found due to weaker northwesterly winds and to dust storms.

The newer system consists of active parabolic dunes which can also have impressive proportions.

In the southwestern part of the Lathi area, southeast of Jaisalmer, prominent ridges trend NE-SW. These ridges are the erosional result of the occurrence of ferruginous cemented Lathi sandstone outcroppings. Ridges are separated by gently sloping pediments locally forming the desert floor. Some isolated sandstone ridges are also found in the southern part of the area in the Fatehgarh-Rama-Devikot region. Saline depressions (playas) are common. Local runoff collects in these playas during heavy precipitation but most of the year they are dry. These playas are underlain by clayey soils with evaporite incrustations. Larger playas, called ranns, are found northwest of the contact between the Lathi formation and the Jaisalmer limestone. These ranns may be of hydrogeologic significance because their low elevations may be conducive to groundwater discharge through evapotranspiration.

The drainage system is poor, disorganised and mainly of interior type. There are no rivers worthy of the name, nor are there any perennial streams in the area. The streams are purely seasonal and ephemeral with the result that there is lack of effective discharge when there is heavy precipitation. Such streams are marked by slopes and depressions without well defined channels. Stream beds are occasionally shifted by moving sand dunes. Only short streams running off scarp slopes are somewhat parallel.

Sukri Nadi is the most prominent ephemeral stream of the region. It originates in the gently rising hills west of Sankra and follows a gently undulating north-westerly ocurse until it disappears in the sand dunes north-west of Ghandhan. A small tributary joins the Sukri Nadi about 3 miles (4.8 km.) north of Javandh. As a result of the unusually heavy precipitation in 1961 (532 mm) this stream appears to have shifted westward.

Often one or more tanks are associated with each village. The tanks occupy shallow depressions and are filled with pools of accumulated rain water. They are probably relics of former depressions occupied by shifting ephemeral streams and are often governed by the position of sand dunes. Most tanks have been deepened and developed by local villagers. It is in these ponds that most of the soft clayey soils are found in and otherwise vast expanse of sand. These tanks are one of the main sources of drinking water supply.

6. GEOLOGY

The Guide to the Tectonic Map of India (1968) shows that the structure of the region is essentially a shelf known as the Rajasthan Shelf. A diagrammatic cross-section in the guide shows the sedimentary sequence dipping gently to the northwest. Normal faulting has occurred but the only major faults shown on the base map are those that are known to have hydrogeologic significance.

Exhibit 3 shows the geology and gives the geologic sequence of the general region. Lathi clastics are classified as the lowest member of the Mesozoic group of sedimentary rocks. The Lathi formation is an extensive cross-bedded, near shore deposited sandstone of Jurassic age. Ferruginous cemented sandstones have formed ridges especially in the southwestern part of the project area. These ridges clearly show a NE-SW strike. The general dip is to the NW with dips ranging from 1° to 6°.

Much of the Lathi formation at depth is composed of white, yellow and reddish brown poorly to moderately cemented medium-grained sandstone. Large lenses of poorly cemented red or greenish grey siltstone and shale are interspersed in the sandstone. There is considerable textural heterogeniety. The upper part of the Lathi formation contains considerable fine grained material which causes along with intespersed lenses, confined aquifer conditions where potentiometric levels are higher than the tops of the highest water yielding zones.

Lathi sediments were deposited on an eroded basement of folded and partially metamorphosed geosynclinal deposits containing igneous intrusions. The eastern boundary of the Lathi formation is where the feather edge abuts against outcropping Pre-Cambrian and Paleozoic rocks.

The configuration of the basement complex is shown in Exhibit 4. This configuration undoubtedly has had a major effect on the deposition of Lathi sediments. A prominent buried ridge is located in the Bhope-Sirwa-Chachra region which causes the bedrock surface to dip southward to the south of an E-W line running through Sirwa. North of this line, the bedrock surface dips northwestward. Exhibit 5 is a generalized geological cross-section in the southern region which shows the geologic relationship between the buried ridge and the Lathi formation. The cross section line is located on Exhibit 4.

A series of normal faults with large displacements mark the southern boundary of the Lathi formation. Impermeable Tertiary clays and shales and Jaisalmer limestone lie at the surface and at depth on the downdropped side of the faults. Although Lathi sandstones probably occur at great depths in the downdropped blocks, they are considered to be hydrogeologically unimportant since their depths of occurrence would preclude economic groundwater development. Bore holes drilled at Bariyara (Ex. 5), Bhiyar and Harba were drilled exclusively in rocks younger than Lathi. At Harba the depth drilled was 1993 feet (608 m). Pollen studies from samples collected at Harba indicate Cretaceous Sediments at the top and Jaisalmer (Jurassic age) at the bottom. Additionally, the quality of water in the deep sandstones would probably be very poor. Faulting is clearly seen 5 miles (8 km) south of Fatehgarh near the road. At this site, jointed ferruginous, dark red and yellow cemented Lathi sandstones containing manganese and ironstone concretions, dip 15° southward at the contact with light grey claystone and chert of Tertiary age. A few hundred feet north of the contact, the sandstone is flat lying which indicates that the dip near the contact is the result of fault drag. Exhibit 5 illustrates in a general way the effect of the faulting.

The Jaisalmer limestone overlies the Lathi formation on the west and northwest as illustrated in Exhibit 5; Near the Jaisalmer-Lathi contact, there are facies changes in the Lathi from sand and sandstone to essentially shale and clay. Consequently, even though the Lathi formation underlies the Jaisalmer limestone, the areal extent of the potentially productive part of the Lathi can be taken as a line a few miles westward of the contact. One exception to this general rule is in the Ajasar-Tota area where Lathi aquifer materials probably extend a considerable distance west of the contact. The Jaisalmer limestone consists of compact yellow limestones interstratified with gray, brown and black sandstones. Minor faults were mapped at the Jaisalmer- Lathi contact by the O.N.G.C. and are shown in Exhibit 3 and the base map (Ex. 4.). These faults probably have little or no hydrogeologic significance.

Test drilling at Kanasar (northern area) and Sunargaon has shown that there is a facies change between Kanasar and the Ajasar-Bardhana-Loharki line (Ex.4). The predominantly sand/sandstone sequence gradually changes to clay/shale northeast of the latter line. As a consequence, a NW-SE line was drawn on the base map which essentially limits the Lathi aquifer in the northeast.

Lathi sandstones show only minor structural features. Some flexing has taken place along with minor en-echelon faulting. Jointing is widespread in the consolidated sandstone. Facies changes are very common and have great hydrogeological significance. Because fine grained lenses have only limited aerial extent, the Lathi aquifer reacts as one hydraulic unit. Since the fine grained lenses contain considerable silt and very fine sand, leaky aquifer conditions are the rule. Between Chhor and the fault south of Fatehgarh, fairly prominent red clay horizons appear to be covered by a thin veneer of alluvial and windblown sand. Some calcareous material is found in the Lathi series north of the Pokaran-Jaisalmer road.

Because cementation of the arenaceous section of the formation is incomplete at depth, water is transmitted through interstices. Consequently permeabilities are relatively high and the aquifer has great transmitting capabilities.

Mechanical analyses were performed on ditch samples collected during rotary drilling operations from 30 holes drilled during project operations. Because contamination of samples is prevalent, the results give only general information. Some results are tabulated below:

Zone	Depth range b.g.l. feet	Depth range b.g.l. meters	Median 50% size (mm)	Sorting Coefficient (Ratio at 25% and 75% quartiles)
I	220-328	67-100	0.20-0.30	1.20-1.30
II	490-650	150-200	0.25-0.75	1.40-1.70
III	780-950	240-280	0.30-0.90	1.50-2.00

Generally, aquifer materials become coarser at depth although they tend to be more poorly sorted. The results of the mechanical analyses indicate near shore depositional environment.

The sediments supplied to the Lathi domain seem to have been the result of various local environments and have been differentiated according to local energy inputs. The sands are the product of high energy turbulent environments similar to those along present day beaches and river channels. Alternatively, silts and clays are the product of low energy or still water environments such as those present in coastal lagoons and alluvial swamps. The sedimentation pattern of the Lathi series is similar to "paralique type" described by Tercier (1940). This type of sedimentation can be expected in areas peripheral to or within the continental framework characterised by intensive terrigenous alluviation. Deposits are, in part, marine but mostly they are continental. The presence of dark grey pyritic shales in the geologic sections of Dabhala, Kita, Moklat, Rajwai and Jetha is undoubtedly characteristic of deposition under anaerobic (absence of free oxygen) conditions. It is probable that these shales were derived from shallow lagoonal or estuarine muds. The association of lignite with shales suggests a strongly acid environment characteristic of swamps. The shale occurring in bore holes at Sanwala, Sagra and Jetha reflect association with marine muds(marl). At Sribhadria the condition of marine intercalation is more pronounced. Some of these transitional conditions give strong support to a possible overlapping of marine Jaisalmer series with the Lathi series.

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7. CHEMICAL CHARACTERISTICS OF GROUNDWATER.

Water containing upto 3,000 parts per million (ppm) of total dissolved solids (TDS) is used for drinking supply by many of the inhabitants of the Lathi region. Water containing 2,000 ppm TDS or less is arbitrarily considered as fresh in this study. Water containing from 2,000 to 3,000 ppm TDS is considered as brackish and water containing more than 3,000 ppm TDS is classified as saline.

The quality of groundwater from the Lathi formation was broadly studied in terms of areal distribution and chemical changes with time. The study was based on standard analyses of water samples collected from 1968 to 1970 from 26 tubewells and 45 dug wells. Chemical analyses data from samples collected in May 1970 are given in Tables 5 and 6. and are shown in Exhibit 6. Exhibits 7, 8 and 9 diagramitically present some chemical characteristics of groundwater.

Exhibit 6 is the May 1970 isocone map, showing the areal distribution of mineralization of groundwater in the Lathi region. The Lathi aquifer is considered as a single hydraulic unit, and as a consequence, vertical changes in quality are considered as minimal. This has essentially been proven during the test drilling and test pumping operations except near the 3,000 ppm TDS line passing south of Sribhadria. In this transtional zone, the TDS content increases with depth. The isocone map shows that the main Lathi formation area underlain by the best quality water is roughly located south of the Jaisalmer-Pokaran road and north of an east-west line passing through Sangar. At Sribhadria, the unusually high TDS concentration may be due to saline beds connected with the deeper zones. The isocone map indicates that in general, groundwater quality deteriorates down dip.

Regional changes in the degree of mineralization of groundwater of the Lathi area was reviewed in detail along the following cross-sections.

A) Mulana-Baroragaon-Bhaguragaon-Jesurana ,

B) Lathi-Chandhan-Sagra-Jesurana,

C) Devikot-Chhor-Dabhala-Rajwai ,

D) Bhilani-Fatehgarh-Rama ,

E) Kanasar-Undu .

The section from Mulana to Jesurana indicates that concentration of dissolved solids increases from the former to the latter. The increases are accompanied by ionic changes in the types of the water i.e. from HCO_3 type at Mulana through HCO_3-Cl, Cl-HCO_3 to Cl-SO_4 type at Jesurana. Simultaneous increases in $\frac{rCl}{rHCO_3}$ and decreases in $\frac{rSO4}{r\,Cl}$ ratios are very significant features to indicate the extent of saturation equilibrium of groundwaters. To the north of Chandhan-Baroragaon the groundwater encountered is Na-Ca-Cl-SO4 type which tends to approach dilute sea water composition at Jesurana.

In the midwestern section of Devikot-Rajwai the water is of mixed type up to Dabhala, changing to Cl-HCO_3 type at Rajwai. At Chhor, the groundwater is relatively fresh and continues fresh up to Dabhala. Beyond Dabhala the groundwater becomes progressively more mineralized.

It was noted that the lowest saturated zones at Devikot and Bhilani showed similarity in the chemical character of groundwaters. The concentration of dissolved solids from dugwells and tubewells at Devikot and Bhilani are comparable, whereas the concentrations of dissolved solids, Na and Cl ions, increase gradually towards the south and southwest.

In the southeastern extension of the Lathi formation, the type of water at Kanasar is $Cl-HCO_3$ (mixed type) which changes to $Cl-SO_4$ type at Undu. Mineralisation increases from Kanasar eastward to Undu. A tabulation showing regional changes in the degree of mineralisation of groundwater in the Lathi area is given in the following tabulation.

Location	TDS	HCO_3^{-}	SO_4^{--}	Cl^{-}	$\frac{rCl^{-}}{rHCO_3^{-}}$	$\frac{rSO_4^{--}}{rCl^{-}}$	Geochemical type	Equilibrium stage change in water
	(in parts per million)							
				A. Northern dip section				
Mulana	450	268	48	120	0.70	0.51	Na-Ca-HCO_3-Cl	1st stage
Baroragaon	880	[illegible]	125	290	1.41	0.37	Na-Ca-Cl-HCO_3	1st stage
[illegible]gaon	2138	305	250	900	5.08	0.20	Na-Ca-Cl-SO_4	2nd stage
Jesurana	2168	329	307	890	4.64	0.25	Na-Ca-Cl-SO_4	2nd stage
				B. Northern strike section				
Lathi	860	403	77	285	1.22	0.20	Na-Ca-Cl-HCO_3 (mixed)	1st stage
Chandhan	934	363	58	300	1.41	0.14	Na-Ca-Cl-HCO_3 (mixed)	1st stage
Sagra	1734	268	163	795	5.09	0.15	Na-Ca-Cl-HCO_3	1st stage
Jesurana	2168	329	307	890	4.64	0.25	Na-Ca-Cl-SO_4	2nd stage

Location	TDS	HCO_3^-	SO_4^{--}	Cl^-	$\frac{rCl^-}{rHCO_3^-}$	$\frac{rSO_4^{--}}{rCl^-}$	Geochemical type	Equilibrium stage change in water
				C. Midwestern dip section				
Devikot	940	354	96	250	1.216	0.283	Na-Ca-Cl-HCO_3 (mixed)	1st stage
Chhor	722	263	77	170	1.09	0.34	Ca-Mg-Cl-HCO_3 (mixed)	1st stage
Dabhala	816	351	115	250	1.21	0.34	Na-Ca-Cl-HCO_3 (mixed)	1st stage
Rajwai	1286	342	114	485	2.44	0.22	Na-Ca-Cl-HCO_3	1st stage
				D. Southern section				
Bhilari	1092	390	134	390	1.72	0.26	Na-Ca-Cl-HCO_3	1st stage
Rama	1564	329	173	640	3.34	0.20	Na-Ca-Cl-HCO_3	1st stage
Fatehgarh	2818	305	238	1290	7.28	0.17	Na-Ca-Cl-SO_4	2nd stage
				E. Southeast section				
Kanasar	840	342	159	270	1.36	0.43	Na-Ca-Cl-HCO_3 (mixed)	1st stage
Undu	1928	439	211	770	2.98	0.21	Na-Ca-Cl-SO_4	2nd stage

It is observed that 15% of the waters are HCO_3 type having HCO_3 more than 50% of total anions. Na+K are the only dominant cations in combination with HCO_3 type waters. These are considered to be the first stage waters in the area. The second group of fresh waters are the mixed type mainly Cl-HCO_3 which are 31% of the total samples examined. These waters cover the triangular area bounded by Mulana, Lathi and Rajwai. The third type of waters contain Cl as the dominent anion. This type constitutes 54% of the samples. These are considered as second stage waters and are highly mineralized. Exhibit 8 shows that the concentration in equivalents per million(epm) of Na^+ and Cl^- ions increases with concentration of dissolved solids. This water tends to reach a physical and chemical equilibrium with the rock material through which it flows.

The relationship between the dominant anions and the TDS concentration of the water samples are tabulated below.

TDS (ppm)	+50% HCO_3-CO_3	+50% SO_4	+50% Cl	Mixed	Total
Less than 1,000	4 (Dhaisar, Jerat, Karmeri, Mulana	-	2 (Chandhan, Barcragaon	8 (Bhairwa, Bhojak, Chandhan, Site No.7, Dabhala, Lathi, Devikot, Kanasar	14(53.6%)
1001-2000	-	-	8 (Ajasar, Sagra, Kita, Rajwai, Bhilani, Rama, Rajmathi, Undu	-	8(31%)
2001-3000	-	-	3 (Jesurana, Bhagurgaon, Fatehgarh	-	3(11.6%)

TDS (ppm)	+50% HCO_3-CO_3	+50% SO_4	+50% Cl	Mixed	Total
Greater than 3,000	-	-	1 (Sribhadria	-	1 (3.8%)

From the above tabulation, it is apparent that 54% of the samples have dissolved salt concentrations of less than 1,000 ppm. The waters are either HCO_3, HCO_3-Cl or Cl-HCO_3 types. They are located in the central region of the Lathi area. The increase in the degree of mineralisation leads to a change from Cl-HCO_3 to Cl-SO4 type of waters which are mainly in the brackish and saline regions.

The characterisation of groundwater with respect to $CaCO_3$ saturation was also attempted. The saturation indices ($CaCO_3$) for groundwaters in Lathi area have been calculated based on the following equation.

Saturation index = pHd-pHc i.e. pH of water (determined minus the pH (obtained by calculation) which the water has when it is in equilibrium with $CaCO_3$).

The values obtained are tabulated in columns 10 and 11 in Table 5. Analyses suggests that the groundwater in the Lathi aquifer is predominently saturated with respect to $CaCO_3$. This indicates that water has been in contact with the aquifer material for a considerable time and that the addition of fresh water has been practically nil in recent times.

Schoeller (1967) has suggested the following indices of disequilibrium in groundwater.

$$\frac{rCl - r(Na + K)}{rSO_4 + rHCO_3 + rCO_3}$$

The negative value will indicate an exchange of Na+K from strata with Ca+Mg in the water.

The waters from the Lathi aquifer have negative indices, having greater values in the fresher regions and approaching zero in the less saline parts. The alkali-chloride proportion in relation to salt concentration is shown in Exhibit 8. The values for Na^+ and Cl^- ions plot at wider spaces for fresher water which gradually narrows down for the samples from saline regions. Thus the saline waters attain a stage of chemical equilibrium in respect to Na^+ and Cl^- ions and the possibility of further base exchange is doubtful.

Sulphate reduction causes decrease in sulphate concentration with simultaneous increase in the bicarbonate content thereby increasing the salt concentration. This is not noticeable in the groundwaters from the Lathi area. The concentration due to $SO_4^{=}$ reduction is not present or expected in these waters.

The quality of groundwater in the central part of the region does not show marked change in chemical composition, which has remained as $HCO_3 > Cl > SO_4$ or $Cl > HCO_3 > SO_4$ type over a long period of time. Addition of fresh water through recharge appears to have been negligible except during humid climatic phases in the past.

Sodium seems to have come from base exchange reaction from rock material. The Pre-Cambrian and Paleozoic complex initially, and then the aquifer material itself, caused the cationic facies as Na > Ca > Mg.

The occurrence of less mineralised water in the central part of the area, even after long retention time intervals, is attributable to relatively high permeability, lack of contact with the atmosphere and dissolved carbon dioxide-bicarbonate equilibrium i.e. buffered system with carbonic acid. It may be relevant to mention that even though the pH values range from 7.6 to 8.8 for Lathi aquifer water samples, not much reliance is placed on the determinations.

The waters in the outer peripheries of the basin, especially along the north-northwest line from Chandhan to Jesurana, are of Cl SO_4 HCO_3 type having high mineral contents. This may be due to slow circulation of groundwater causing longer time for dissolution of soluble matter from argillaceous strata.

Further concentration due to dissolution may not go beyond the existing chemical composition as the waters have reached almost physical and chemical equilibrium with the surrounding aquifer material.

In the area of investigation, a study was made to identify chemical changes over a period of time. For this purpose 7 samples from the saline front of Lathi-Jesurana section and 5 samples from the fresh water area were compared for their ionic concentrations in 1966 and 1969. Changes in percent reacting values of anions for the two sets of values are shown in Exhibit 9. Percentages of change for anions and cations are given below:

	Saline water Front Mean change for 7 tubewell samples (1966-1969)	Fresh Water Area Mean change for 5 tubewell samples (1966-1969)
Ca^{++}	-0.91	-3.72
Mg^{++}	-1.06	+0.12
$Na^{+} + K^{+}$	+2.31	+3.59
$CO_3^{--} + HCO_3^{-}$	-2.70	+4.58
SO_4^{--}	-1.74	-1.55
Cl^{-}	+4.47	-2.92
TDS (epm)	+3.40	+1.46

The above figures indicate that there was an increase in TDS during the period from 1966 to 1969 in both areas.

Na^{+} and Cl^{-} ions have increased in samples from saline regions whereas Na^{+} and HCO_3^{-} have inreased in samples from fresh water areas.

The changes observed are too small for great concern but the trend is significant to warrant study of future regional changes in waters of the two areas. The question of saline front from north encroaching on the HCO_3 -Cl waters of the main Lathi area is a possibility which cannot be ignored. The rise may be due to present pumpage. An increase of pumpage may cause accelerated mixing.

Waters in dugwells are mostly perched. It was observed that these waters are either fresh or moderately saline.

The results of chemical analyses of water samples collected from 45 dugwells are given in Table 6 and the general chemical character of the water is shown in Exhibit 7. Percentage breakdowns of combinations of cations and anions of 45 dugwells water samples are given below.

Dominant +50%	HCO_3^{--}	SO_4^{---}	Cl^-	Mixed	Total
Ca^{++}	2	-	-	-	2
Mg^{++}	-	-	-	-	-
$Na^+ + K^+$	7	-	18	7	32
Mixed	7	-	1	3	11
Total	16(35.5%)	-	19(42.2%)	10(22.3%)	45(100%)

The water samples from perched water table zones can be broadly categorised into HCO_3, Cl and mixed types. 36% of samples are HCO_3 - type and 22% of the samples are mixed type with HCO_3, SO_4 and Cl in almost equal proportions. Thus the majority of the dugwell water samples are HCO_3 to Cl-HCO_3 type and are fresh.

The predominant cation is Na in almost all the samples. Two of the samples having predominant Ca are from perched water zones at shallow depths belonging to HCO_3 type. For mixed cations, mainly Na-Ca facies prevail. For waters having TDS contents of less than 500 ppm Ca-Na facies were also observed where HCO_3 was the dominant anion. The relationship between the dominant anions and the TDS concentration of 45 dugwell water samples are tabulated below.

Dissolved solids	+50% HCO_3^- + CO_3^{--}	+50% SO_4^{--}	+50% Cl	Mixed	Total
Less than 500 ppm	7	-	-	-	7(15.5%)
501-1000	6	-	5	6	17(37.7%)
1001-2000	3	-	8	4	15(33.5%)
2001-3000	-	-	6	-	6(13.3%)
Total	16	-	19	10	45

About 53% of water samples from dugwell zones in the region have total dissolved solid contents of less than 1000 ppm and 33.5% contain between 1000-2000 ppm. These percentages are almost the same as those for the tubewell samples.

The central part of the area has fresh waters of HCO_3-Cl type with dissolved solid concentration of less than 1000 ppm in the dugwell zones. The Cl-HCO_3 type saline waters are confined to the northern and southern part of the area, where the water level is shallow and concentration of salt in the zone of aeration is of common occurrence. Generally the dugwell waters are used for drinking supply on restricted scales. It was noticed during 1969 that some dugwells had gone dry due to lowering of the water table.

8. SUITABILITY OF SOILS AND GROUNDWATER FOR IRRIGATION

A reconnaissance survey was undertaken to evaluate the land and soils of the Lathi area.

Soils are mostly calcareous and coarse textured, primarily derived from red and grey sandstones, carbonaceous shales and variegated clays.

Coarse textured soil with very small proportions of clay (about 2 to 5 percent) is derived from disintegration of the parent material under conditions of high temperature and low moisture. Chemical weathering and subsequent alternations in the soil are practically negligible. Lack of sufficient soil moisture and moving water in the soil profiles are well reflected in the poor development of alluviation and zone of differentiation.

Soils are either in the eroded or depositional phases the latter occurring as sandy plains or dunes.

The soils of the area can be categorised as belonging either to interdunal plains or sand dunes. Dunes are either permanent or shifting. Rock outcrops or stony gravelly wastes occur alongside interdunal plains. Sandy plains with or without low hummocks, isolated outcrops and stony wastes are seen to the south of the Pokaran-Jaisalmer road from Chandhan westward and also to the east and west of the Jaisalmer- Barmer road, south of Jaisalmer. Rock outcrops and shallow compact sandy and gravelly soils are prominantly distributed near the villages of Dabhala, Akal, Devikot, Fatehgarh, Bhaguragaon, Baroragaon, Bhojak, Mulana and Bhopa.

The soils of the interdunal plains are light textured, shallow to very deep soils of light yellowish, brown to pale red colour. The top layers are invariably sandy (fine sand) dry; loose and structureless with slight increase in heaviness in depth to form loamy sand texture, sometimes with weak subangular blocky or platy structure. Occasionally, the bottom layers also tend to be sandy loam.

Soils are calcareous and the $CaCO_3$ content increases in depth to form lime accumulation (Kankar) zones either as concretionary nodules or coatings on weathered sandstones at depths of 60 to 150 cms. The content of the calcium in the subsoil is nearly 10 times the amount found in the top layers of soil.

Because these soils are low in clay contens and organic matter and are high in fine sand, they have low moisture equivalents (2 to 5 percent) and water retention capacities (20 to 25 perdent). Soils are normal with respect to pH, being in the range of 8 to 8.2. They are poor in fertility, the average constituents of the available phosphorous, potassium and organic carbon in the surface soil being 7 kg/ha, 100 kg/ha and 0.1 % respectively.

Field examinations from Chandlan to Mulana and Fatehgarh, reveal that depth of soil cover is variable. Towards Mulana and Fatehgarh there are frequent occurrences of compact pale red, fine sandy to loamy sand soils on the top, the depth range being from a few cms to 1 meter. Sometimes, dry, loose, sandy soil exists below the compact layer. The wind blown nature and occasional impact from rainfall followed by the long dry spells must have been responsible for compactness of soil in depth and on the surface.

Much of the project area is characterised by dunes of different shapes and sizes due to high mobilization and accumulation of fine sorted sands. They are either of permanent or of stabilized nature supporting characteristic shruby vegetation. Shifting dunes are under high mobilization.

There is practivally no horizon differentiation in these sand dunes except slight alluviation in the stabilized ones with respect to $CaCO_3$ content (1.0 to 1.5%).

Water samples obtained from 25 tubewells and 45 dugwells located in the area of investigation have been studied to assess their suitability for irrigation under arid conditions. The tubewell water sample from Sribhadria was excluded from the analysis because of the high TDS content. Tables 5 and 6 give the data used in the study.

While projecting the data in various conventional classifications, most emphasis was given to characterise the tubewell waters. Chemical data have been derived from the modified Hill-Piper diagram as outlined by Handa (1965). The classes are identified to characterise groundwater in detail with respect to the type, whether primary or secondary degree of salinity and alkali hazard.

Classes of tubewell waters based on the modified procedure (Handa 1965) are given below:

Tubewell water sample No.	Location	Classes of water
1	Ajasar	A_3 C_4 S_3
2	Baroragaon	B_3 C_3 S_2
3	Bhaguragaon	A_3 C_4 S_3
4	Bhairwa	B_3 C_3 S_3
5	Bhilani	B_3 C_3 S_3
6	Bhojak	B_3 C_3 S_2
7	Chandhan	B_3 C_3 S_3
8	Chhor	A_2 C_3 S_1
9	Dabhala	B_3 C_3 S_3
10	Devikot	B_3 C_3 S_2
11	Dhaisar	B_2 C_3 S_2
12	Fatehgarh	A_3 C_5 S_3
13	Jerat	B_2 C_3 S_1
14	Jesurana	A_3 C_4 S_3
15	Kanasar (southern area)	A_3 C_3 S_1
16	Karmeri	B_3 C_3 S_2
17	Kita	A_3 C_3 S_2
18	Lathi	B_3 C_3 S_3
19	Mulana	A_3 C_3 S_1
20	Rajmathai (4 miles NE of Kana Ji Ki Dhani)	A_3 C_3 S_2
21	Rajwai	A_3 C_3 S_3
22	Rama	A_3 C_4 S_3
23	Sagra	A_3 C_4 S_3
24	Site No. 7	B_3 C_3 S_3
26	Undu	A_3 C_4 S_3

The above tabulation reveals that the majority of samples are distributed in A_3 and B_3 classes, the number being 12 and 10 respectively. The waters falling under A_3 are different from B_3. The former have no RSC and permanent hardness, whereas the reverse is true with the latter. The common characteristics of both classes is that waters are $Cl-SO_4$ or secondary type of waters, since the strong acid ions exceed the bicarbonate ions. Regarding salinity (C) they mostly belong to medium to high (C_3) followed by high to very high (C_4), and low to medium (S_2) and medium to high (S_3) with respect to sodium content. This modified classification undoubtedly gives a systematic classification of data to characterise the most important hydrogeochemical grouping of water and to a certain extent gives the quality classification for irrigation suitability under local conditions.

Based on the local practices of using groundwater of very high salinity (sometimes exceeding 7,000 ppm TDS and SAR 31 and above for sandy soils of highly drained nature), Central Arid Zone Research Institute (CAZRI), Jodhpur had made an attempt to classify groundwater suitability.

The tabulation given below shows distribution of wells in respect to salinity (C) and alkali hazard (S). The classification is based on crop performance from 500 wells as determined by CAZRI.

SAR		Type of well (TDS ppm)	C_1 180	C_2 180-500	C_3 500-1500	C_4 1500-3200
0-6	S1	T.W.		1	3	
		D.W.		8	13	
6-16	S_2	T.W.			14	7
		D.W.			8	14
16-26	S_3	T.W.				
		D.W.			1	1

Groundwaters fall within the safe limit with respect to salinity (C) and alkali hazard (S) for much of the arid tract of Rajasthan. It is interesting to note that these waters could be used in the predominently highly drained soils of the arid tract even without adopting the practice of fallowing. The percentage distribution of wells with relatively higher salinity and alkali hazard is however greater for tubewell waters thaan for dugwell waters. Further classification based on the standards prepared by Eaton (1950) and Wilcox (1948) has also been presented.

The distribution of wells with respect to RSC (Eaton, 1950) and SSP (Wilcox, 1948) is tabulated below

	RSC (me/L)			SSP		
	0-1.25	1.25-2.5	2.5	60	60-80	80
Tubewells	13	5	7	3	19	3
Dugwells	28	6	11	17	24	4

The table shows that only very few wells (10-15%) of the total are of doubtful quality. However, the possibility of their judicious utilisation in deep, well drained soils with relatively low clay content is not ruled out.

Although, in general, the TDS is relatively low in these groundwaters, the proportion of Na^+ and Cl^- is relatively very high and is characteristic of the arid tract. An emphasis on proper evaluation especially with respect to sodium hazard is therefore worth considering.

It has been proven by many workers that plants sensitive to Cl^- are also sensitive to Na^+. As far as Na^+ is concerned, the effect is both direct and indirect, the latter being through Na^+ getting into the exchange complex of soil (ESP). Because of the solubility of minerals or precipitation of ions, such as Ca and Mg from solution, the equilibrium in soils becomes upset and hence the ESP calculated from SAR of irrigation water, as detailed in USDA Hand Book 60 (1954), generally does not agree with the observed values in the field. In modification to this, the steady state of ESP in soils from SAR and pH values of water is calculated using parameter saturation index (for $CaCO_3$) Bower (1961).

$$\text{Saturation index} = pH_a - pH_c$$

pH of water (determined) - the pH (obtained by calculation) which the water has when it is in equilibrium with $CaCO_3$.

In all calculations, pH 8.4 of a non-sodic soil in equilibrium with $CaCO_3$ is substitued for pH_a, since the irrigation waters are poorly buffered. The ESP is then worked out from the equation.

$$ESP = 2\ SAR + 2\ SAR(pH_a - pH_c)$$

Based on this, the ESP calculated from the SAR values of tubewell waters fall mostly within moderately tolerant (ESP 20-40) and tolerant groups (ESP 40-60) as per the standard of USDA. Below is the tabulation of distribution of 25 tubewell samples in terms of various ESP limits of crop tolerance. The well numbers refer to samples given in Table 5.

	Extremely sensitive	Sensitive	Moderately tolerant	Tolerant	Most tolerant
ESP	2-10	10-20	20-40	40-60	60
Tubewell water sample no.	8	15,19	2,4,6,7,9, 10,11,13, 16,17,20, 21,24	1,3,5,12, 14,18,22, 23,26	Nil

The analysis shows that for the wells falling under tolerant group the ESP calculated seldom exceeds 50. This grouping also helps to establish that these waters can safely be used for growing crops such as wheat, cotton, alfalfa, barley, sugar beets, tomatoes and certain fodder crops.

9. HYDROGEOLOGY

Although groundwater in most of the Lathi formation occurs under confined conditions, water table conditions do occur in perched situations throughout the area, especially near the eastern margin where the Lathi sediments feather-edge against older rocks. Perched water zones, where the quality is acceptable, are the principle groundwater sources of potable water supplies for many villages. It is reported that there are about 80 dugwells in the region. Perched water zones also occur in the thin veneer of aeolial or alluvial sands covering most of the Lathi formation. These small water yielding zones are replenished by local precipitation during prolific monsoon seasons and supply very limited recharge to the main Lathi aquifer by essentially horizontal flow down the dip or by vertical leakage through semi-permeable confining material.

The depth of perched water levels mostly vary from about 20 to 100 feet (6 to 30 m) below ground level. Depths to piezometric levels from confined water zones vary from about 80 to over 400 feet (24 to over 122 m). Exhibit 10 shows confined static water level depths in May 1970 in wells below the desert floor. Localized topographic features were eliminated in composing the map. Obviously, if a well were to be drilled on a local ridge, depth to static water level would be greater than indicated. The area that has shallowest piezometric levels is northwest of the Jaisalmer-Pokaran road where a topographic low occurs near Jetha. Greatest depths to water levels in wells are encountered in the Kita-Sirwa-Rama area where desert floor elevations are appreciably higher. The shape of the piezometric surface in May 1970 is shown in Exhibit 11. The total relief of the surface is about 100 feet (30 m) varying from a low in the Jetha-Sujio area to a high in the Bihyar-Kanesar area in the southeast. The piezometric surface slopes downdip possibly due, in a few places, to some limited recharge from perched water zones in the so-called " dry zone " of the Lathi formation. The most pronounced local gradient is between the Bhilani-Fatehgarh axis and Rama where the slope is about 5 feet per mile. Another prominent gradient is seen northwest of the Bhopa-Rasla area where low transmissibility might be the cause.

The flattest part of the piezometric surface is mostly encompassed by lines connecting Lathi-Jetha-Jesuram-Chhor-Duwara-Lathi. Most of this area lies in the zone of high transmissibility and it is believed that the overall flatness of the surface is predominently due to this factor. The gradual northwest slope of the potentiometric surface northeast of Jaisalmer may be due to upward seepage and eventual limited discharge by the ranns northwest of the Jaisalmer-Lathi-contact (Ex.3).

A groundwater divide caused by a strip of low transmissibility runs southward from Moklat veering SSE to the west of Sagona-Ki-Dhani and finally abuts against the buried ridge near Sirwa. In general, the piezometric surface is relatively flat reflecting near equilibrium in an essentially non-recharged aquifer.

Recharge is considered as negligible for practical evaluations of large withdrawals.

In the section on hydrometeorologic conditions, it was stated that potential evaporation is greater than ten times the normal annual precipitation. It was also pointed out that high water surplus, which would produce recharge of aquifers, can be expected to occur only once in 20 years. Additionally, CAZRI, Jodhpur, has computed the potential transpiration losses of one xerophyte tree to be 121 kg. per day.

In the section on chemical characteristics of groundwater, it was pointed out that $CaCO_3$ saturation index indicates that the water has been in contact with the aquifer material for a considerable time and that addition of fresh water has been practically nil in recent years.

Geologic and soil investigations indicate that limited infiltration capacities exist in much of the area because of the nature of surficial materials and the fine grained composition of the top of most of the Lathi formation. Deep water levels (Ex. 10) in the eastern and southeastern sections also indicate lack of appreciable infiltration.

Water levels were measured in tubewells and dugwells distributed throughout the Lathi area before (May) and after the monsoon season (November) in 1968, 1969 and 1970. Average changes are tabulated below.

Year	Number of wells measured	Average change from pre-monsoon to post-monsoon water levels (m)
1968	24	+ 0.066
1969	47	- 0.075
1970	46	+ 0.365

Effects of local pumpages have undoubtedly affected some of the readings. The average of 3 years of water level measurements show that the change from pre-to post-monsoon has been only + 0.119 m. This indicates that negligible recharge has occurred to the Lathi aquifer between May 1968 and November 197[illegible].

Carbon-14 dating of groundwater from the Lathi aquifer was carried out by the TFRI Bombay. The age results are presented below

Sample No.	Site	Zone/depth range in feet	Confirmed age (Carbon 14)
TF. 1096	Bhairwa Testwell	1) 240'-420'	7095 ± 155 years
TF. 1097	-do-	2) 445'-545'	7000 ± 115 years
TF. 1095	-do-	3) 650'-730'	8080 ± 160 years
TF. 1120	Ajasar Testwell	1) 240'-290'	8385 ± 200 years
TF. 1122	-do-	2) 335'-390'	9500 ± 400 years
TF. 1121	-do-	3) 455'-550'	17595 ± 230 years

The estimated age for these waters is in the range of 7000 to 9500 years. This suggests that humid climatic phases were prevalent in these parts prior to onset of the present dry climate. Additional support for this theory comes from palaeoclimatic and prehistoric studies of western Rajasthan. Geologists and archeologists have reasons to believe that western Rajasthan was once a flourishing and hospitable country (National Institute of Sciences, 1952). Some of the extracts from the above references are reproduced below.

" It is considered during one million years of the Pleistocence Epoch that there have been four major glacial periods, intervened by three arid periods. The last glacial period ended about 7000-10000 years ago. The present trend of hotter and drier conditions is considered to be post glacial."

" Pre-historical evidences show that Indus Valley civilisation and Harappa culture flourished during 4000 to 3000 B.C. i.e. 5000 to 6000 years ago; in the Saraswati River Valley, a great river in Vedic times. There are also evidence to support that some rivers drained through western Rajasthan in WSW and SW courses before meeting the Arabian Sea, prior to setting in of dry spell. The alignment of present day ranns and dry river beds Ghaggar are often conjectured as proof of earlier river courses."

" These evidences indicate that present day desert areas once enjoyed moist conditions with moderate rainfall. The dry conditions seem to have started about 1000 years ago, by gradual desication of the area".

Based on the mass of data from various sources, it is therefore concluded that the major portion of groundwater in the Lathi aquifer had accumulated thousands of years ago during humid phases of the climate and that present recharge can be condidered as negligible for practical evaluations concerning large withdrawals.

There are generally three saturated zones which are hydraulically interconnected due to lateral discontinuities in the silty and sandy clay lenses. This was proven at Bhairwa and Ajasar where pumpage from wells perforated only in distinct zones caused instantaneous drawdowns in Observation wells open to other zones. Data from specialized tests are shown in Table 3.

Exhibits 12, 13, and 14 are hydrogeologic cross-sections. The locations of these sections are shown on Exhibit 4. Some results of the test drilling and test pumping are shown in the exhibits and the sections are representative of the major hydrogeologic framework of the Lathi aquifer.

Exhibit 12, the cross-section along the Rajwai-Bhopa line shows the relationship of the buried ridge near Bhopa to the Lathi aquifer. There appears to be a tendency for downward flow of water at Rajwai and Akal as noted by static water levels from different zones.

Exhibit 13, the cross-section along the Jetha-Duwara line shows that there is upward flow of groundwater at Jetha based on static water levels and chemical quality determinations, while at Bhairwa there are essentially stagnant conditions vertically.

Exhibit 14, the cross-section along the Tota-Loharki line shows that the permeable Lathi aquifer lies below Jaisalmer limestone and unsaturated Lathi sandstone. Loharki is in the " dry zone" of the Lathi formation.

Exhibit 15 is a map showing isopachs of the aquifer portion of the saturated Lathi formation. Fine grained materials are not included. The map shows that the aquifer thickens downdip. North of the buried ridge in the southern part of the area, thicknesses increase northwestward whereas south of the ridge thicknesses increase generally southwestward. The configuration of the isopachs is markedly similar to that of the basement contours (Ex. 4). The isopachs are also controlled by the shape of the piezometric surface (Ex. 11) but because of the relative flatness of the latter, the effects are of minor importance.

Porosities and lab coefficients of permeability were determined from a few core samples of sandstones, shales, siltstones and intercalated rocks obtained during drilling operations. It was not possible to core loose material or coarse-grained, friable sandstone with existing equipment. Results of laboratory determinations are given below.

Data from pumping tests run during project operations are given in Table 3 and aquifer coefficients derived from the long duration tests using the test wells are given in Table 4. Five long duration constant-rate tests, in addition to several short tests run for specific purposes were performed during the present project. Semi-logarithmic graphs showing drawdown and recovery data from the long duration tests are presented in Exhibits 16, 17, 18, 19, and 20. Four of the tests showed definite leaky aquifer effects and one showed the presence of a negative boundary although leaky aquifer conditions also undoubtedly prevail. The latter is felt to be merely a localized situation wereas the former is considered to be generally widespread in most of the Lathi aquifer. The test at Rajwai (Ex.16) indicated that a negative boundary is located about 4000 feet(1200 m) from the site. The direction of the boundary from the test site is uncertain but there are indications that it may be either a facies change NW of the site (Ex.5) or an undetected but suspected fault east of the site. The latter is suggested by a decrease in transmissibility eastward(Ex.21) as well as decrease in permeability in the same direction (Ex.22).

Exhibits 17, 18, 19 and 20 show that the effects of leakage become pronounced at about 100 minutes after start of pumping or shutdown. The effects are noted by upward veering of plotted points from the initial straight line trend (after U becomes small). The leakage is due to slow vertical drainage from semi-permeable silt, fine sand and mixed zones throughout the saturated section. (Ex. 5, 12, 13, and 14). The reaction is similar to that from a recharge boundary. The widespread leaky conditions are significant because drawdowns produced by pumpage are considerably less than those predicted by straight storage depletion calculations. This effect is due to contributed water drained from semi-permeable materials. It should be pointed out, however, that large withdrawals from the leaky aquifer would cause regional land subsidence in a few years. This would be of minor significance to the area.

Coefficients of storage given in Table 4 indicate that confined conditions occur. This is due to potentiometric levels being considerably higher than the tops of permeable aquifer zones. Therefore, heavy pumpage would not cause significant dewatering of the saturated sands and sandstones for many years.

Because cementation is incomplete, water is transmitted through interstices of aquifer material, consequently, permeabilities are high. Although not infinite, the aquifer is considered to have tremendous transmitting capabilities due to its widespread areal extent.

Exhibit 21 is a contour map showing variations in transmissibility of the Lathi aquifer. The map was drawn using data from pumping tests run during present and past operations. Transmissibilities increase downdip south and west of the buried ridge but the negative boundaries caused by the proximity of the "dry zone" of the Lathi formation and the faults that form most of the southern boundary of the Lathi aquifer, would preclude large scale pumpages over a period of many years. The same situation is seen in the southeast extension of the aquifer in the Bhiyar area. As mentioned before, the strip of low transmissibility south of Moklat is probably responsible for the groundwater divide (Ex. 11). This strip may be due to faulting although no determinations could be made from the basement contour map (Ex. 4) or the isopach map of the Lathi aquifer (Ex. 15). This may be due to lack of adequate control in the area. Erratic drilling at Chhor which led to great difficulty in completion of wells, was highly suspicious, and was attributed to possible faulting in the area.

The most obvious and important feature of the transmissibility map is the zone of high transmissibility that straddles the Jaisalmer - Pokaran road between Lathi and Jesurana. This zone generally lies in a favourable water quality area (Ex. 6) where depths of static water levels are relatively shallow (Ex. 10). The overlap of these three favourable features has placed the Lathi-Chandhan-Bhairwa region in prime position for potential medium to large scale groundwater withdrawals.

Transmissibilities decrease toward the "dry zone" of the Lathi formation because of aquifer thinning due to overlap on to the basement complex. The margin of the dry zone marked on the base map as "limit of Lathi aquifer" is a negative boundary and wells located near the margin will show the negative boundary effects similar to the one experienced at Rajwai (Ex. 16). There may be further negative boundary effects from possible facies changes several miles northwest of a line passing through Sujio and Ajasar. The line near Baru, which approximately indicates lack of aquifer material to the northeast, is another facies change that will cause negative boundary effects.

Exhibit 22, the permeability contour map of the Lathi aquifer area was largely drawn by combining the transmissibility map (Ex. 21) with the isopach map of the Lathi aquifer (Ex. 15). Permeability values are averages of total aquifer material portions of the saturated section. The permeability map gives some insight on the depositional history of the Lathi sandstone. The contours follow the strike both in the north - central area and the region south of the ridge. This implies that deposition of coarse grained clastics occurred parallel to the strike. In the Moklat-Chhor region, the anamolous area of lower permeability may reflect faulted conditions. The decrease of permeability north and west of Sujio is due to facies changes. In the Lathi - Chandhan - Bhairwa region, the occurrence of high permeability has been the major cause of the configuration of the zone of high transmissibility.

Present pumpage from the Lathi aquifer is low. Table 7 gives pumpage data for tubewells from 1968 through 1970. Withdrawals from dugwells are small and can be ignored for all practical purposes. The figures for 1969 are greater than for 1970 because 1969 was a year of deficient precipitation whereas in 1970 above normal precipitation generally occurred. The pumpage was especially reduced in the Dabhala wells which supply Jaisalmer. The total pumpage from the Lathi aquifer in 1969 amounted to about 3100 acre feet per year (2.75 U.S.M.G.D. or 3.8 M.C.M./yr). The present pumpage (1970) in the Lathi-Chandhan-Bhairwa region is about 2100 acre feet per year (1.85 USMGD or 2.6 MCM/yr), with the greatest concentration within the triangular area between site No. 7, Sagra and Karmeri. In this latter sub-area the 1970 pumpage was about 1300 acre feet (1.15 MGD or 1.6 MCM/yr).

Exhibit 23 is a map showing favourable areas for fresh groundwater development from the Lathi aquifer. Four major fresh water acreas were delineated. The outer limits of the division boundaries were drawn by using the 2000 ppm isocone in Exhibit 6. The border of the base map can be accepted as the western boundary of Division II. Considerable quantities of relatively fresh water for domestic livestock and industrial uses can be obtained in the four divisions even though wells would have to be drilled to more than 500 feet (150 m) in some places.

Division I and II are separated by the groundwater divide (Ex. 11) caused by the strip of low transmissibility (Ex. 21) mentioned previously. Pumpage from either division can cause trans-mittal of fresh water across the groundwater divide by reversal of gradient. Divisions III and IV are self contained entities and virtually cannot transmit fresh groundwater into Division I & II.

Estimates for total recoverable (mineable) fresh groundwater from the Lathi aquifer are given below. Specific yield is taken as 10%. Mineable water is considered to be 80% of the total amount in storage. Average thickness of aquifer were taken from the isopach map (Ex. 15).

Zone Number	Area (sq.kms.)	Average thickness of aquifer (m)	Volume of aquifer (MCM)	Volume of fresh water in storage(MCM)	Mineable fresh water (MCM)
I	1,376	122.0	167,800	16,780	13,424
II	997	91.0	91,200	9,120	7,296
III	461	30.5	14,040	1,404	1,123
IV	438	30.5	13,360	1,336	1,069
TOTAL	3,272		286,400	28,640	22,912

Of the 22,912 MCM (6,060,000 million gallons) of mineable fresh water, 20,720 MCM (5,470,000 million gallons) or 90% are in Divisions I & II.

Zones A and B in Division I are the most favourable areas for relatively high capacity development based on three coinciding primary conditions.

The first factor was that present static water levels are less than 175 feet (53 m) b.g.l. (Ex. 10). The second factor used was that present TDS content of groundwater is less than 2000 ppm (Ex.6). The third was that the coefficient of transmissibility is more than 50,000 USgpd/ft (Ex.21).

Zone A comprises the prime area because coefficients of transmissibility are greater than 100,000 US gpd/ft and TDS content of groundwater is less than 1000 ppm. The remainder of the favourable region consists of Zone B. Zone A has an area of 83.5 sq. miles (216.3 sq. kms.) and Zone B has an area of 45.9 sq. miles (118.9 sq. kms). The combined area is therefore, 129.4 sq. miles (335.2 sq. kms.). Proposed development of zones A and B for agricultural irrigation is discussed in detail in the following section.

10. POTENTIAL FOR LARGE SCALE GROUNDWATER DEVELOPMENT

To predict future water levels resulting from large pumpages, several mathematical models were constructed using derivatives of the Theis nonequilibrium equation. Because lift is the most important single factor in economic use of groundwater for irrigation purposes, it was decided that pumping water levels should be limited as close as possible to 250 feet (76 m) b.g.l. in individual wells.

For the area covered by zones A & B, a 42 well model was selected as a favourable developmental scheme. The 42 well sites (Ex.23) were the maximum number that could be fitted into the 129.4 sq.mile (335.2 sq.km.) area of the two zones using a rigid 2-mile spacing. A 200 year water mining projection was mde after determining that the total withdrawal after 200 years of pumping an average of 42 USMGD (58 MCM/yr) would amount to 8400 million gallons (11,500 MCM) or about 55% of mineable water in Divisions I & II. It was determined that after 200 years of pumping, the average pumping water level would be 227 feet (69 m) b.g.l. and that the lowest level would be 257 feet (78 m) b.g.l. (Table 8). The following reasonable factors were used in constructing the model; regional coefficient of transmissibility of 100,000 USgpd/ft., 42 fully penetrating large diameter, 100% efficient wells each producing 1400 USgpm 50% of the time, initial coefficient of storage of .0005, leaky aquifer conditions causing time-drawdown graph effective departures from 100 minutes to 2 years after start of simultaneous pumpage, no hydrologic boundaries and no recharge.

Obviously there will be deviations from the assumptions under actual field conditions but it is felt that these idealizations will give a good projection based on known conditions.

Exhibit 21 indicates that in much of Zone 1 coefficients of transmissibility are actually greater than 100,000 and in places approach or exceed 200,000 USgpd/ft but values decrease in all directions away from the heart of the zone. It is, therefore, felt that the long term regional coefficient can be accepted as 100,000 USgpd/ft for reasonable long time projections. Consequently, the slope of the distance -drawdown graph (Ex.24) from which interference values were derived (Table 8) was computed by using coefficient of transmissibility of 100,000 USgpd/ft.

All wells in zone A and some wells in Zone B are considered to be affected by local and regional coefficients of transmissibilities of 100,000 USgpd/ft. Therefore estimates of drawdowns due to average single well pumpage of 1 MGD for 200 years as well as those due to additional 1 MGD pumpage after 1 day, that are given for most wells in Table 8, were derived from the aforementioned effects. These drawdowns were taken from the top time-drawdown graph (T= 100,000) in Exhibit 25. Both the initial (before 100 minutes) and final (after 2 years) slopes of the graph were drawn using T= 100,000. Because of local values of transmissibilities, estimates for proposed wells 1, 4, 5, 26 and 39 in Zone B were determined from the second graph (T= 80,000) in Exhibit 25. This graph was drawn using initial (local) T of 80,000 and final (regional) T of 100,000. Similarly, estimates for proposed wells 6 and 13 in Zone B were derived using the bottom graph (T= 60,000) in Exhibit 25. This graph was drawn using local T of 60,000 and regional T of 100,000.

Proposed wells should be effectively engineered, constructed and developed to allow maximum efficiency. Biodegradable mud should be used with standard mud rotary rigs so that the mud can be completely removed with development. Perforated sections should have maximum percentage of open area and largest possible perforations(considering the properly engineered gravel pack). Considering the proposed discharge, perforated sections should be minimum 10-inch diameter and gravel pack should be minimum 6 inches thick. Consequently, the minimum diameter of holes below the housing should be 22 inches.

The 1 minute drawdown values for the 3 graphs in Exhibit 25 were computed by assuming effective radii of 100% efficient wells to be 1 foot and initial coefficient of storage to be .0005. The graphs were projected from these points.

The effects of producing 1400 USgpm 50% of the time will essentially be equal to those from pumping 700 USgpm (1 MGD) 100% of the time. Consequently the graphs in Exhibits 24 and 25 were constructed assuming continual 1 MGD pumpage for 200 years. It should be pointed out that regional effects would be basically the same, if say, 84 wells each were to pump 1/2 MGD continually. The 42 well proposal was selected based on favourable cost factors. It was felt that properly constructed and equipped wells could efficiently pump 1400 USgpm and that the fewer wells, the more efficient the system. Future plans should, however, be based on pumpage from existing wells. Present and future pumpage from existing wells in the area can be taken as an average of 2 MGD. Because the present heaviest pumpage is in the Chandhan-Sagra region (Table 7), it is suggested that proposed wells 14 and 20 be pumped at an average rate of only 1/2 MGD each. In this way existing pumpage can be incorporated into the model without materially effecting projections and the total pumpage of the area will average 42 MGD (an addition of 40 MGD). The increased areal pumpage of an additional 40 MGD would cause water level declines and pump settings in existing wells may have to be deepened.

One of the major factors controlling the validity of the projection, is the continuation of leaky aquifer conditions. Unless leaky aquifer conditions would effectively persist for at least 2 years after start of major pumpage, water levels would be far lower than estimated in Table 8. Estimates indicate that enough water is available from aquitards to sustain leaky aquifer conditions for 2 years but only actual large scale pumping will prove that leakage will occur for a relatively long period of time. Pumping tests run during project operations indicate that leakage is a very important entity but the longest pumping test, at Bhairwa (Ex.18), lasted less than 1 week. Based primarily on results from the Bhairwa test, the long term extensions of graphs in Exhibit 25 and the position of the distance-drawdown projection (Ex.24), were extrapolated. It is believed, based on knowledge from aquifer-aquitard performances in other parts of the world, that leaky aquifer conditions would persist for 2 or more years. After that time, the aquifer would once again react as a storage depletion system. Because the net cone of influence would have extended itself enormous distances during the leaky aquifer stage, water levels should decline very slowly for the remainder of the 200 years.

The mathematical model assumes that no hydrologic boundaries exist and that no recharge will occur in 200 years of pumping. However, wells in the northeast section of the proposed well field would undoubtedly be affected by negative boundary conditions due to the cone of influence reaching the dry zone of the Lathi formation. The negative boundary effects would cause accelerated drawdowns and interferences. Proposed wells 6 and 13 would be the first to feel the effects which would become apparent within the first 20 years of pumpage. After the first 20 years, when wells would have to be replaced(maximum useful life of wells is accepted as 20 years), relocation or pumpage readjustment can be considered. This possibility will be discussed in more details later in this section.

Another negative boundary that might affect the model, probably exists northwest of the proposed well field near the contact of the Lathi formation and Jaisalmer limestone where there are facies changes. However, the effects from the boundary probably would not be appreciably noticeable during the first 100 years of pumping.

In 200 years there will undoubtedly be some recharge to the aquifer from precipitation during very wet years. Additionally there would be some recycling of water from the increased irrigation application. Consequently, it was decided that for computational purposes any detrimental effects from negative boundaries would be balanced by beneficial effects of limited recharge plus recycled water. Actual field operations will show relationships but it is felt that the present projection will not deviate appreciately from actual future results.

The life of each new well is expected to be from 15 to 20 years. Assuming that 42 wells would have to be replaced every 20 years, or ten times, in the 200 year period, the project could be divided into 10 time segments. Data from preceding cumulative time periods could be effectively used for guidelines for replacement wells. If it appears that particular zones of operational wells have become excessively saline or that the brackish water front has advanced excessively in a subarea, replacement wells can be constructed and located to avoid these adverse effects. About 10 proposed outpost observation wells located about 2 miles northward and southward of the periphery of the wellfield should be used to monitor regional changes of water quality and water levels.

Pumpage of 42 MGD will cause the brackish water front to advance southward along the northern margin and southeastward along the northwestern margin of the well field. The initial center of pumpage would be at proposed well 23. After the first 20 years of pumpage it may be desireable to shift the center southward by shifting locations and reapportioning pumpages.

The poorest quality from any individual well would initially be less than 2000 ppm TDS and some wells in Zone A would produce water containing less than 700 ppm TDS. The initial composite TDS content of water from the 42 proposed wells should be about 1000 ppm. Consequently, it may be desireable to have all wells connected by a network of pipes which could also be used for irrigation water distribution. After 200 years of pumping, the composite water would still be within usable quality limits. As mentioned previously, this groundwater would be suitable for irrigation purposes on selected land. About 200 sq. miles (518 sq. kms.) located in Zones A and B and in the low region immediately north and northwest of the outer margin of Zone B would probably be within the reach of pumped groundwater. However, only a portion of the land in the 200 sq. mile region would be suitable for irrigation and only selected crops could be grown.

Before the 42 well proposal is implemented a socio-economic study must be undertaken. This study should include economic effects of soil conditions, economic effects of water on the soil, types of crops to be grown, cost of irrigation ditches or pipe lines, maintenance, marketability, cost and socio-economic effects of electrical power extensions, cost of transportation of crops, sociological impact on the polulation, general economic effects on the state government and effects on famine relief programmes which presently cost the government large sums of badly needed funds.

The 42 well propcsal would probably be most readily adaptable to a plan for rainfall supplementation rather than for a primary source. The present shaky economy of the region is due, to a great extent, to drought cycles. Instead of relying on sporadic precipitation for crop growth, a dependable supply could be assured for hundreds of years by proper groundwater development and management. Large tracts of presently barren land could be irrigated with water mined from the prolific Lathi aquifer and the general economy in much of the region might be greatly improved. In wet years, it may not be necessary to pump any water at all whereas in drought periods the mined groundwater would considerably alleviate adverse climatic conditions.

It was estimated that each fully equipped well would presently cost about Rs. 1,65,000. This would include costs for construction and materials (exclusive of pipelines), turbine pumpwith belt drive, electric prime mover and pump house facilities. This estimate assumes that each well will be capable of producing 1400 USgpm will be 800 ft (244 m) deep, will have 14 inch casing for pump housing and will have ability to lift water from a depth of 260 feet (79 m) b.g.l.

The present annual maintenance, depreciation and electricity (estimated @ 15 paise per kilowatt) costs, assuming pumpage for 50% of the time, average yield of 1 USMGD and pumping water level of 250 feet (76 m) b.g.l., should be about Rs. 1,00,000. (Rs. One lakh).

Observations on existing practices followed by government agriculture farms (Seed Multiplication Farm, Jetha; Cattle Breeding Centre Chandhan) reveal certain points given below.

(i) The requirement of water to raise crops successfully works out to be almost double that of what is required in more hospitable regions. The highest irrigation water requirement in Jaisalmer district is reported as 54 inches (1365 mm). It is reported that one cubic foot per second (0.65 USMGD or 0.9 MCM/yr) of water can irrigate upto 90 to 100 acres of land.

(ii) Special care is needed to raise crops particularly during kharif season(July-October) for protection from blowing sand which otherwise would creep into fields and destroy channels and germinating crops.

(iii) Salt accumulation in these sandy to loamy sand soils consequent to the irrigation with groundwater having E.C. 2.65 m.mhos/cm seems to be appreciably low. The alkali hazards from such groundwater with SAR, SSP and RSC of 16.6, 85.8 and 1.44 respectively also seem to be remote.

(iv) No deterioration in the yield of crops with irrigation by groundwater in the successive seasons is recorded. During favourable seasons (1964-65) fairly good yields of crops were obtained by Jetha Seed Farm. The highest average yields recorded are quite appreciable and are as follows.

Crops	Yield kg/Ha
Wheat R S 31-1	2250
Kharchi Wheat	2800
Barley	2800

(v) It is roughly estimated that cost of irrigation(water charges) alone is 30 to 35 percent of the total cost of cultivation.

In order to obtain efficient and beneficial use of groundwater, it will be imperative that strict emphasis be placed on management of water, soils and crops.

11. CONCLUSIONS AND RECOMMENDATIONS

1. During the 1968-70 period of investigation, detailed studies were made in about 4,000 square miles (10,000 sq. kms.) of the arid Jaisalmer (Lathi) area in western Rajasthan. It was determined that the Lathi formation, a thick extensive, near shore deposited sandstone of Jurassic age, occupied an effective outcrop area of about 2,900 square miles (7,500 sq. kms.) and forms the most important aquifer in the entire UNDP project area.

2. There is virtually no runoff and drought conditions frequently prevail. About 90% of the precipitation occurs in the monsoon season from June through September.

3. Dugwells tapping perched water tables, and tanks are the two main sources of potable water for most of the small villages. Tubewells completed in recent years are the principal sources for Jaisalmer and many large villages. The total groundwater withdrawal in the entire Lathi area is presently about 3 USMGD (4.1 MCM/yr).

4. Cementation is incomplete and water is transmitted through interstices. Consequently, permeabilities are relatively high and the aquifer has great transmitting capabilities. Large lenses of poorly cemented siltstone and shale are interspersed in the sandstone but lateral discontinuities cause the entire Lathi aquifer to react as one hydraulic unit. The upper part of the formation contains considerable fine-grained material. Potentiometric levels are higher than the tops of the highest water yielding zone resulting in confined conditions. The numerous and widespread fine grained lenses

interspersed throughout the saturated section, contain considerable silt and very fine sand causing leaky aquifer conditions.

5. Considerable quantities of fresh water (under 2000 ppm TDS) for domestic, livestock and industrial uses, can be obtained in 1,260 square miles (3,272 sq. kms.) of the project area underlain by the Lathi aquifer. Depths to piezometric levels vary from about 80 to over 400 feet (24 to over 122 m.) b.g.l. In areas of deep piezometric levels, wells would have to be drilled to more than 500 feet (150 m) b.g.l.

6. Soil and water analyses indicate that ground-waters can be safely used on selected tracts of land to grow crops such as wheat, cotton, alfalfa, barley, sugar beets, tomatoes, and certain fodder crops.

7. Recharge is considered as negligible for practical evaluations of large withdrawals. The major portion of groundwater in the Lathi aquifer accumulated thousands of years ago during humid climatic phases. Therefore, to extract large quantities of water, mining must be effected.

8. A 129.4 square mile (335.2 sq. km.) tract in the Lathi - Chandhan - Bhairwa area has the greatest potential for medium to large scale groundwater development for irrigation. Selected tracts of land in a 200 square mile (518 sq. km.) area would be within the reach of the pumped groundwater.

9. It is recommended that a socio-economic study be implemented before large scale groundwater development is undertaken. This study should evaluate entities such as economic effects of soil conditions,

economic effects of water on the soils, types of crops to be grown, cost of irrigation ditches or lines, maintenance, marketability, cost and socio-economic effects of electrical power extension, cost of transportation of crops, sociological impact on the population, general economic effects on the state government and effects on famine relief programmes which presently cost government large sums of badly needed funds.

10. If the socio-economic study concludes that groundwater development for irrigation is feasible, it is further recommended that 42 high capacity production wells be installed in the Chandhan - Lathi - Bhairwa region. These wells would pump in conjunction with existing wells, 42 USMGD (58 MCM/yr). The existing pumpage in the development area is about 2 USMGD and consequently the 42 proposed wells would createan additional 40 USMGD draft on the aquifer in that area. Computations show that the amount of fresh water in storage and the transmitting capacities of the areally extensive Lathi aquifer are sufficient to sustain an average mineable draft of 42 US MGD for 200 years. At the end of 200 years of pumpage, water quality might become unacceptable in some places and water levels might decline to uneconomic depths. No major dewatering of the aquifer is predicted.

11. The useful life of wells is expected to be from 15 to 20 years. Assuming that 42 wells would have to be replaced every 20 years, it is recommended that the project be divided into 10 time segments. Data from preceding cumulative time periods should be effectively used for guidelines for replacement wells which could be reasonably relocated. Pumpages could be reapportioned at the beginning of each of the ten

time divisions to reduce speed of brackish water encroachment.

12. About 10 proposed outpost observation wells located about 2 miles northward and southward of the periphery of the wellfield, should be installed to monitor regional changes of water quality and water levels. Pumping and "static" (after ½ hr. shutdown) water levels should be measured and water samples should be collected monthly in the 42 production wells and 10 observation wells. Average monthly pumpage data from each production well should be obtained. The total data should be carefully analysed for trouble spots in the model so that when the time comes for well replacement, efficient guidelines would be available.

13. The poorest quality from any individual well would initially be less than 2,000 ppm TDS and some wells would produce water containing less than 700 ppm TDS. The initial composite TDS content of water from the 42 wells should be about 1000 ppm. Consequently, it may be desirable to have all wells connected by a network of pipes which could also be used for irrigation water distribution. After 200 years of pumping, the composite water would still be within useable quality limits.

14. The 42 well proposal would probably be most readily adaptable to a plan for rainfall supplementation rather than for a primary source. The present shaky economy of the region is due, to a great extent, to drought cycles. Instead of relying on sporadic precipitation for crop growth, a dependable supply could be assured for hundreds of years.

15. Each fully equipped well (exclusive of pipe lines) would presently cost about Rs. 1,65,000. The annual operating cost using electricity would be about Rs. 1,00,000 per well.

16. It is strongly emphasized that pumpage of an average of 42 USMGD (58 MCM/yr) from the Lathi aquifer will be a mining process. The major part of the fresh water removed would never be returned under present climatic conditions.

17. In order to obtain efficient and beneficial use of the groundwater, it will be imperative that strict emphasis be placed on management of water, soils and crops.

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1 US gallon = 3.79 litre
0.833 Imperial gallon

DETAILS OF BOREHOLES DRILLED BY CGWB DURING EARLIER PROJECTS

S. No.	Name borehole	Elevation above m.s.l. (ft.)	Depth drilled (ft.)	Depth to basement (ft.)	Depths of perforated sections (ft.)	Zones tapped	Static water level b.g.l. (ft.)
1	2	3	4	5	6	7	8
1.	AJASAR (*)	665.35	360	-	191-322	I, II	158.
2.	AKAL	764.36	729	-	427-480 624-717	I II	249.
3.	ASAYACH	752.52	816	-	687-708	III	260.
4.	BARDHNA	726.05	470	437	233-250 370-419	II III	219
5.	BARORAGAON	727.05	965	-	377-397 459-534 641-767 847-922	I II III	227
6.	BASINPIR	692.20	750	-	Abandoned	-	(I
7.	BHAGURAGAON	727.99	975	-	282-321 576-612 7[illegible]-809	I II III	23
8.	BHAIRWA	639.33	847	-	239-276 467-571 730-842	I II III	13
9.	BHILANI	932.79	555	542	387-517	I, II, III	39
10.	BHIYAR	792.71	952	-	276-357 487-525	I II	2
11.	BHOJAK	621.19	1005	-	620-660 720-925	II III	1
12.	CHACHRA	895	149	140	Abandoned		(1
13.	CHANDHAN I (old)	616.28	983	964	187-225 350-400 420-580 600-640 660-770 850-950	I II III	118.
14.	CHANDHAN II	-	946	-	273-412 428-585 678-728	I II	81.65
15.	CHHOR I (3 holes)	-	383	-	Abandoned	-	(Los

1	2	3	4	5	6	7	8	9	10	11	12	13	14	
16.	CHHOR II	-	298	-	Abandoned	-	(L[illegible] circulation)							
17.	DABHALA I (old)	751.97	722	-	555-653	II	239	402	20.99	22½	19	60,000	-	-
18.	DABHALA II	749.34	731	-	338-390 600-710	I II	234	499	22.97	20	22	85,600	-	-
19.	DABHALA III	758.90	720	-	322-401 564-656 679-699	I II	250	496	19.61	24	25	66,000	-	-
20.	DEVIKOTI	876.41	452	450	Abandoned	-	(Ina[illegible]uate thickness of granular zones)							
21.	DEVIKOT II	876.41	390	-	Abandoned	-	(Los[illegible] of circulation)							
22.	DEVIKOT III	876.41	445	-	314-434	III	363.[illegible]	88	26.94	3	3	15,600	70	223
23.	DHAISAR I(Old)	677.20	805	-	270-620	I,II	183.[illegible]	285	5.83	24	19	81,600	-	-
24.	DHAISAR II	652.17	807	-	365-511 618-802	I,II III	16[illegible]	460	9.48	6	48	2,06,000	-	-
25.	DHAISAR III	671.86	820	-	240-370 455-515 610-640 740-810	I II III	179	402	9.51	-	42	-	-	-
26.	DHOLIA	675.65	98	3	Abandoned	-	(Ina[illegible]uate thickness of granular zones)							
27.	DILASAR	737.65	310	288	Abandoned	-	(Ina[illegible]uate thickness of granular zones)							
28.	FATEHGARH	838.25	991	-	287-304 346-367 388-447 468-509 546-586 625-656	II III	308.	402	10.30	24	39	70,400	-	-
29.	JAVANDH	662.46	840	-	287-346 411-493 647-826	I II III	161.	338	8.56	6	39	1,23,700	-	-
30.	JERAT	708.57	365	-	210-360	I	19[illegible]	237	14.04	4	17	9,500	-	-
31.	JESURANA	663.65	936	-	398-457 497-598 659-772	I II III	167	402	12.63	9	32	80,800	-	-
32.	JETHA	578.73	921	-	565-712 845-905	II III	83	697	22.05	3½	32	1,16,000	-	-
33.	KAJOI	-	81	15	-	-	([illegible]uate thickness of granular zones)							

3		4	5	6	7	8	9	10	11	12	13	14	15
34. KAHASAR (Southern area)	757.25	254	252	187-247	-	173.39	[illegible]	56	3	16	12,200	60	204
35. KAMERI	645.80	889	889	261-400 552-602 } 621-658 } 811-870	I II III	151.41	4[illegible]	44	6	28	1,96,900	400	492
36. KASULAPANA	759.53	475	470	280-300 320-352 413-423	-	193.34	1[illegible]	.43	6	3	7,100	62	115
37. KITA	910.40	495	-	294-488	III	413.00	2[illegible]	.39	3	11	21,000	-	-
38. LATHI I (Old)	651.48	644	635	317-457 479-[illegible] } 52[illegible] }	I II	157.72	60	.86	24	40	1,52,400	232	657
39. LATHI II	653.80	620	-	363-578	I,II	161.90	46	71	6	40	1,53,900	-	-
40. LATHI (N.N.W.)	626.73	816	807	-	-	139.10	Abandoned (Poor quality water)						
41. LOHARKI	830.90	360	208	Abandoned	-	(Inadequate thickness of granular zones)							
42. MULANA	842.13	701	699	395-475 506-690	II III	327.23	29[illegible]	.63	3	28	-	300	-
43. RAJWAI (*)	800.22	947	-	Abandoned	-	(Inadequate thickness of granular zones)							
44. RASLA	891.41	330	-	Abandoned	-	(Inadequate thickness of granular zones)							
45. SAGONA KI DHANI	856.04	810	-	223-283 302-322 684-773	I II III	357.18	30[illegible] (Co[illegible]sor)		-	-	-	-	-
[illegible]. SAGRA	574.40	790	-	366-424 } 445-467 } 665-717	I II	82.00	78	2.80	6	24	1,02,400	-	-
[illegible]. SANAWARA	875.00	35	25	Abandoned	-	(Inadequate thickness of granular zones)							
[illegible]. SANGAR	877.93	680	-	347-409 } 420-500 }	III	346.34	16[illegible]	.58	1	29	-	-	-

1	2	3	4	5	6	7	8		11	12	13	14	15
49.	SANWALA	632.00	985	-	405-451 696-798	I II	141.10	17.55	8	25	1,14,100	-	-
					816-835 ⟩ 908-927 ⟩	III							
50.	Site No.7	623.13	837	831	340-520 640-760	I II	129	[illegible].97	-	37	1,20,800	500	241
51.	Site No.13	629.85	804	773	390-492 590-743	I II	135.3[illegible]	[illegible]1.50	-	43	1,56,000	500	312
52.	SODAKOR	651.78	818	803	250-350 ⟩ 470-520 ⟩	I	158.[illegible]	18.93	-	29	1,66,800	520	321
					620-720	II							
53.	SRIBHADRIA	686.78	749	-	423-470 610-719	I II	179.0	8.24	6	23	69,100	-	-
54.	SUJIO	611.59	700	-	345-375 ⟩ 449-468 ⟩ 479-510 ⟩	I	121.[illegible]	[illegible]7.51	8½	28	39,300	-	-
55.	SUNARGAON	579.45	606	420	Abandoned -		(Inackness of granular zones)						
56.	UNDU	759.90	937	422	264-394	I	177.[illegible]	.13	12½	12	42,400	230	184

(*) Drilled through Jaissone into Lathi formation.

*****

CHAWLA

DETAILS OF BORE HOLES DRILLED DURING ... P PROJECT, LATHI AREA

No.	Name of borehole	Land surface elevation above m.s.l. (ft.)	Depth drilled (ft.)	Depth to basement (ft.)	Depths of perforated sections (ft.)	Zones tapped	Saturated thickness of aquifer (ft.)	Static water level b.g.l. (ft.)	Tested discharge USgpm	Drawdown (ft.)	Sp. cit. USg. dra.
1	2	3	4	5	6	7	8	9	10	11	12
1.	AJASAR T.W. (Tota) with 4 O.W.	712.27	583	581	240-290 335-390 455-550	I II III	260	204	495	17.08	29
2.	AKAL S.H.	756.26	1232	1220	262-472 511-682 871-1158	I II III	700	246	-	-	-
3.	BHAIRWA T.W. with 5 O.W.	647.51	814	850 (in O.W.)	250-320 340-420 460-500 520-550 665-790	I II III	500	145	560	17.89	31
4.	BHIYAR S.H.	833.02	1667	-	Drilled into rocks younger than Lathi, did not encounter Lathi formation.						
5.	BHOPA S.H.	933.66	408	404	-	-	14	390	-	-	-
6.	CHHOR T.W. with 1 O.W.	853.98	801	900 (in O.W.)	380-675	I	350	351	302	16.30	19
7.	DUWARA S.H.	719.19	694	[illegible]	-	-	250	222	-	-	-
8.	FATEHGARH S.H.	841.97	1168	1154	-		550	313	-	-	-
9.	HARBA S.H.	797.57	1993	-	-	Drilled into rocks younger than Lathi, did not encounter Lathi formation.					
10.	JETHA S.H.	588.44	1234	1129	-		550	82	-	-	-
11.	KANAJI KI DHANI (S.H.)	803.13	484	475	-		250	224	-	-	-
12.	KANASAR S.H. (Northern area)	673.12	770	708	-		[illegible]	170	-	-	-
13.	MOKLAT S.H.	714.47	1467	1396	-		750	177	-	-	-

	2	3	4	5	6	7	8	9	10	11	
14.	RAJWAI T.W. with 1 O.W.	770.02	1667	1547	500-560 620-720 930-1260 } 1300-1370 }	I II III	815	260	510	19.68	
15.	RAMA T.W.	881.04	838	753	480-720	III	350	395	300	19.33	1
16.	SIHAR S.H.	773.05	527	-	Drilled in-to Vindyan rocks exclusively						
17.	SIRWA S.H.	920.45	450	434	-	-	0	Water level below bottom of Lathi formation.			
18.	SUJIO S.H.	577.29	1267	1230	148-220 487-546 994-1211	I II III	748	93	-	-	-

T.W. Test well

S.H. Stratigraphic bore hole

O.W. Observation well.

CHAWLA

1	2	3	4	5	6	7	8	9	10	11
14.	RAJWAI T.W. with 1 O.W.	770.02	1667	1547	500-560 620-720 930-1260 } 1300-1370 }	I II I…	815	260	510	19.68
15.	RAMA T.W.	881.04	838	753	480-720	III	350	395	300	19.33
16.	SIHAR S.H.	773.05	527	-	Drilled in-57 … to Vindyan rocks exclusively					
17.	SIRWA S.H.	920.45	450	434	-	-	0	Water level below bottom of Lathi formation.		
18.	SUJIO S.H.	577.29	1267	1230	148-220 487-546 994-1211	I II III	748	93	-	-

T.W. Test well

S.H. Stratigraphic bore hole

O.W. Observation well.

DATA ON SELECTED PUMPING TESTS ON LATHI AQUIFER

[illegible]	Pumping test stage	Duration (Hrs)	Discharge (USgpm)	Test well W.L. during pumping (ft. b.g.l.)	D.D. (ft)	Ob. Well 1 W.L. during pumping (ft. b.g.l.)	D.D. (ft)	Ob. Well 2 W.L. during pumping (ft. bg.l.)	D.D. (ft)	Ob. Well 3 W.L. during pumping (ft. b.g.l.)	D.D. (ft)	Ob. Well 4 W.L. during pumping (ft. b.g.l.)	D.D. (ft)	Ob. Well 5 W.L. during pumping (ft. b.g.l.)	D.D. (ft)	Distance between T.W. & O.W. (ft.) Dia of filter (inches) and zones tapped (ft.)	
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
[illegible]SAR (Tota) T.W.	I	3	372	215.32	10.99	206.46	2.06	210.35	5.59	-	-	206.11	2.04			T.W.-(240'-290') (335'-390') (455'-550')	14"/6" dia
	II	3	430	217.58	13.25	206.79	2.39	211.30	6.54	-	-	206.74	2.67				
	III	3	503	220.34	16.01	207.27	2.87	212.66	7.90	-	-	207.30	3.23			O.W.1.-(255'-300') (340'-395') (460'-555')	252' 4" dia
	IV	3	560	223.08	18.75	207.77	3.37	213.88	9.12	-	-	207.89	3.82				
	LDT *	72	495	221.41	17.08	207.66	3.26	213.11	8.45	207.37	3.42	209.08	5.01			O.W.2.- 250'-290'	100' 8" dia
																O.W.3.- 335'-390'	108' 8" dia
																O.W.4.- 455'-550'	238' 8" dia
[illegible]SAR (Tota) 3rd zone well.	LDT *	19.5	140	205.08	0.75	204.48	0.08	205.27	0.51	-	-	217.53	13.46			Distance from O.W.4 to O.W.1 -354' O.W.4 to O.W.2 -266' O.W.4 to O.W.3 -344'	
[illegible]ORA-[illegible]ON	LDT *	24	320	244.23	17.06											T.W.(377'-397') (459'-534') (641'-767') (847'-922')	O.W.1-70'
[illegible]AIHNA T.W.	I	2.5	350	154.30	9.38	147.[illegible]9	0.61	147.90	2.40	147.43	1.39	147.45	[illegible]	144.25	0.70	T.W.(250'-320') (340'-420')	
	II	2.5	490	156.83	11.91	147.43	0.75	148.52	3.02	147.88	1.84	147.97	2.36	144.50	0.95	(460'-500') (520'-550')	14"/6"dia
	III	2.5	510	160.48	15.06	147.59	0.91	149.23	3.73	148.30	2.26	148.54	2.95	144.75	1.20	(665'-790') C.W.1 (240'-275')	
	IV	2.5	590	163.70	18.78	147.81	1.13	150.09	4.59	-	-	149.21	3.62	145.05	1.50	(330'-350') (370'-390')	
	V	2.0	650	166.24	21.32	147.97	1.29	150.68	5.18	-	-	149.66	4.07	145.23	1.68	(470'-490') (510'-530')	453' 4"dia
	L.T.D. *	136	550	162.81	17.89	148.02	1.35	150.10	4.60	149.19	3.15	149.37	3.78	145.39	1.84	(650'-670') (690'-730')	
																O.W.2 (240'-300') (340'-420')	151' 4"dia

Pumping well (site)	Pumping test stage	Duration (Hrs)	Discharge (US gpm)	Test well W.L. during pumping (ft. b.g.l.)	Test well D.D. (ft)	Ob. Well 1 W.L. during pumping (ft b.g.l.)	Ob. Well 1 D.D. (ft)	Ob. Well 2 W.L. during pumping (ft. b.g.l.)	Ob. Well 2 D.D. (ft)	Ob. Well 3 W.L. during pumping (ft.b.g.l.)	Ob. Well 3 D.D. (ft)	Ob. Well 4 W.L. during pumping (ft.bgl)	Ob. Well 4 D.D. (ft)	Ob. Well 5 W.L. during pumping (ft.b.g.l.)	Ob. Well 5 D.D. (ft)	Distance between T.W. & O.W. (ft) Dia of filter (inches) and zones tapped (ft)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
																O.W.3-(415'-545') 292' 8"/4"dia O.W.4-(250'-300') (340'-425') 200' 4" dia (460'-560') O.W.5-(670'-850') 148' 8"/4"dia
5)BHAIRWA O.W.3 (tapping 2nd zone only)	LDT *	24	160	145.75	0.83	146.99	0.31	146.01	0.51	157.70	11.66	147.45	1.86	143.71	0.16	Distance from O.W.3 to O.W.1-159' O.W.3 to O.W.2-212' O.W.3 to O.W.4-201' O.W.3 to O.W.5-432'
6)BHAIRWA O.W.5 (tapping 3rd zone only)	LDT *	24	160	145.47	0.55	146.74	0.06	145.60	0.10	146.19	0.15	145.75	0.16	151.88	8.33	Distance from O.W.5 to O.W.1-592' O.W.5 to O.W.2-256' O.W.5 to O.W.4-332'
7)CHHOR T.W.	I II III LDT *	3 3 3 72	200 275 350 302	359.81 364.57 368.25 365.55	10.56 15.32 19.50 16.30											T.W.-380'-675' 14"/6" dia
8)DABHALA	II.LDT *	20	499	258.87	22.97	252.79	2.62									T.W.-(338'-390') (600'-710') O.W.1-(332'-401') (564'-656') 2200' (679'-699')
9)RAJWAI T.W.	I II III IV V LDT *	3 3 3 3 3 72	330 421 405 572 650 510	271.69 273.98 276.75 279.87 284.27 280.59	10.78 13.07 15.84 18.96 23.36 19.68	262.71 263.24 263.69 264.53 265.30 266.44	3.12 3.65 4.10 4.94 5.71 6.85									T.W.-(500'-560') (620'-720') 12"/6" dia. (930'-1260') (1300'-1370') O.W.1-(500'-550') (620'-720') 100' 6" dia (900'-1270')
10) RAMA T.W	I II LDT *	3 3 40	225 275 300	408.70 412.83 414.72	13.51 17.64 19.53											T.W.-480'-720' - 14"/6" dia

* LONG DURATION TEST

COEFFICIENTS OF TRANSMISSIBILITY, STORAGE AND PERMEABILITY FROM SELECTED PUMPING TESTS IN LATHI AQUIFER

TABLE: 4

No.	Test well	Coefficient of Transmissbility(T)USgpd/ft. Test (pumping) well Jacob modified non-equilibrium equations: Time-draw down	Time-recovery	Residual draw down t/t[1] plot adjusted time-residual draw-down	Observation well: Jacob modified non-equilibrium equation (time-draw-down/ recovery)	Non-equilibrium equations: Theis method (time-draw-down)	Cow method (time-draw-down)	Coefficient of storage(S) dimensionless, Observation well: Modified non-equilibrium equation (time-draw-down) Jacob method	Non-equilibrum equations: Theis method (time-draw-down)	Chow method (time-draw-down)	Saturated thickness of aquifer (ft)	Average coefficient of field permeability USgpd/ft[2]
1	2	3	4	5	6	7	[illegible]	9	10	11	12	13
1.	AJASAR(Tota) 1/	81,680	81,680	-	93,350	88,630	8,040	4.280×10^{-4}	4.147×10^{-4}	5.03×10^{-4}	260	338
2.	BANORAGAON 2/	-	-	46,400	-	-	-	-	-	1.795×10^{-4}	-	-
3.	BHAIRWA 1/	134,000	134,000	-	-	130,980	-	-	9.614×10^{-4}	-	500	264
4.	DABHALA II 2/	-	-	85,600	-	-	-	-	-	1.504×10^{-4}	800 (estimated)	107
5.	CHHOR 1/	31,270	31,270	-	-	-	-	-	-	-	350	89
6.	RAJWAI 1/	104,000	75,000	61,200	104,000	95,500	.	1.300×10^{-4}	1.740×10^{-4}	-	815	110
7.	RAMA 1/	93,170	93,170	105,500	-	-	-	-	-	-	350	277

1/ From pumping test run during UNDP project

2/ From pumping test run during earlier Projects.

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TABLE : 5

CHEMICAL ANALYSES OF TUBEWELL WATER SAMPLES COLLECTED IN MAY, 1970 FROM LATHI AQUIFER.

No.	Location	EC micro-mhos at 25°C	TDS (ppm)	Cations in epm Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Anions in epm CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}	SSP %	SAR (Sodium adsorption ratio)	RSC eqm	pHd	pHc
				1	2	3	4	1	2	3	4					
1	2	3	4	5				6				7	8	9	10	11
1.	AJASAR	3062	1848	3.0	4.6	21.28	0.54	0.4	5.8	3.2	20.02	77.0	11.22	-1.4	8.15	7.35
2.	BARORAGAON	1601	880	1.8	1.2	12.70	0.88	Nil	5.8	2.6	8.18	76.6	10.32	2.8	7.10	7.51
3.	BHAGURAGAON	3570	2130	4.2	3.6	27.40	0.50	Nil	5.0	5.2	25.40	76.7	13.86	-2.8	7.80	7.51
4.	BHAIRWA	1408	816	1.4	1.2	12.16	0.13	Nil	6.2	2.2	6.49	81.1	10.66	3.6	7.90	7.59
5.	BHILANI	2048	1092	1.4	2.2	15.89	0.70	Nil	6.4	2.8	10.99	79.5	11.89	2.8	7.80	7.52
6.	BHOJAK	1015	866	1.6	2.8	12.06	0.20	Nil	6.0	2.2	8.46	72.4	8.04	1.6	7.75	7.40
7.	CHANDHAN	1720	934	1.8	1.0	12.60	0.26	Nil	6.0	1.2	8.46	80.4	10.65	3.2	8.00	7.59
8.	CHHOR	1140	722	5.8	2.5	1.79	0.70	Nil	4.4	1.6	4.79	16.6	0.62	-3.9	7.70	7.14
9.	DABHALA	1334	816	2.0	1.6	11.60	0.13	Nil	5.8	2.4	7.00	76.3	8.65	2.2	7.80	7.48
10.	DEVIKOT	1455	940	2.6	1.6	10.35	0.30	Nil	5.8	2.0	7.05	69.7	7.15	1.6	7.70	7.41
11.	DHAISAR	1173	740	0.8	1.0	9.20	0.25	Nil	6.4	0.6	4.25	80.3	9.71	4.6	8.10	7.68
12.	FATEHGARH	4817	2818	6.2	5.2	33.45	0.56	Nil	5.0	6.0	36.38	74.7	14.85	-6.4	7.50	7.52
13.	JERAT	778	516	1.8	1.4	[illegible].57	-	Nil	5.6	2.2	1.97	67.2	5.19	2.4	7.50	7.43
14.	JESURANA	3765	2168	3.4	3.4	29.83	0.27	Nil	5.4	6.4	25.10	80.6	16.21	-1.4	7.40	7.56
15.	KANASAR (Southern area)	1587	840	4.2	3.6	8.40	0.30	Nil	5.6	3.3	7.60	50.9	4.25	-2.2	7.60	7.18
16.	KARMERI	1114	660	1.8	1.4	8.96	0.15	Nil	6.0	1.2	4.51	72.8	6.89	2.8	7.50	7.45
17.	KITA	1930	1128	3.2	2.4	14.09	0.50	Nil	6.2	3.0	10.99	66.7	8.45	0.6	8.00	7.34
18.	LATHI	1670	860	1.4	0.8	13.87	0.16	Nil	6.6	1.6	8.03	85.5	13.23	4.4	8.00	7.66
19.	MULANA	880	450	2.2	1.6	4.73	4.25	Nil	4.4	1.0	3.38	55.8	3.43	0.6	7.40	7.40
20.	RAJMATHI (4 miles NE of Kana Ji Ki Dhani)	2200	1226	3.6	3.2	14.75	0.50	Nil	5.6	3.2	13.25	66.8	8.00	-1.2	7.80	7.33
21.	RAJWAI	2227	1286	2.8	2.2	16.20	1.07	Nil	5.6	3.0	13.67	73.5	10.24	0.6	7.50	7.46

1	2	3	4	5				6				7	8	9	10	11
				2	2	3	4	1	2	3	4					
22.	RAMA	2780	1564	3.8	2.4	[illegible]	0.22	Nil	5.4	3.6	18.05	72.7	11.92	-0.8	7.25	7.46
23.	SAGRA	2780	1734	3.8	2.6	23.80	Tr.	0.4	4.0	3.4	22.40	78.8	13.30	-2.0	8.40	7.59
24.	SITE NO.7	1760	944	1.8	1.0	14.59	0.16	Nil	7.2	2.4	7.75	84.1	12.80	4.6	8.00	7.55
25.	SRIBHADRIA	7757	5042	10.4	7.0	68.38	1.10	Nil	4.8	14.4	67.68	78.7	23.18	-12 .6	7.20	7.50
26.	UNDU	3207	1928	4.6	3.8	24.0	0.70	Nil	7.2	4.4	21.50	72.5	11.71	-1.2	8.10	7.28

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TABLE 6

CHEMICAL ANALYSES OF DUGWELL WATER SAMPLES COLLECTED IN MAY, 1970
FROM LATHI AQUIFER, LATHI PERCHED WATER ZONES AND OTHER RESERVOIRS.

1	2	3	4	5	6				7				8	9	10
Sl. No.	Location	pH	EC micro-mhos at 25°C	T.D.S. (ppm)	Cations in epm				Anions in epm				SSP %	SAR	RSC (epm)
					Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}			
					1	2	3	4	1	2	3	4			
1.	AJASAR	7.40	3372	1920	6.8	4.6	23.00	0.40	Nil	8.0	4.8	21.99	66.0	9.58	-3.4
2.	TOTA	7.60	2826	[illegible]	4.9	4.3	21.15	0.45	–	7.8	4.4	18.60	68.2	9.44	-1.4
3.	BARDHNA	8.05	3500	1996	3.6	4.2	26.49	0.70	–	9.0	5.4	20.59	75.7	13.24	1.2
4.	NAVATALA(5 miles E of Sribhadria)	7.20	4347	2800	5.4	5.2	31.63	0.53	–	6.4	7.8	28.76	74.0	13.84	-4.2
5.	SRIBHADRIA(1 mile E of village)	7.00	4625	2816	7.8	6.0	33.40	0.70	–	6.0	10.6	31.30	69.7	12.87	-7.8
6.	LATHI(Village well south of road)	7.20	1813	1082	4.6	2.4	5.80	3.40	–	3.8	3.1	9.31	35.8	3.10	-3.2
7.	SUJIO	8.20	4328	2492	3.8	3.6	35.10	1.5	0.8	7.6	7.8	27.35	86.8	18.28	1.0
8.	SODAKOR	7.40	2027	1080	2.2	2.0	14.00	0.86	Nil	8.0	2.6	8.46	73.6	9.65	3.8
9.	THAYOT(2 miles NE of Moklat	7.50	891	494	1.6	1.0	5.10	0.36	–	5.8	Tr.	2.26	63.8	4.47	3.2
10.	BHAGURAGAON	7.70	1502	912	1.2	1.4	11.99	0.19	–	8.2	0.8	5.78	81.2	10.52	5.6
11.	BASINPIR	7.40	553	352	2.8	1.4	1.52	0.33	–	4.3	0.4	0.85	25.1	1.05	0.6
12.	BARORAGAON	7.80	889	566	1.4	0.8	7.50	–	–	6.2	Tr.	3.50	77.3	7.14	4.0
13.	ASAYACH	7.20	1730	918	1.0	1.0	13.45	0.33	–	5.6	2.0	8.18	80.7	13.45	3.6
14.	SAGONA-KI-DHANI	7.20	614	[illegible]	3.6	2.0	2.95	0.14	–	6.0	1.0	21.69	33.8	1.74	0.4
15.	CHHOR	7.70	960	[illegible]	3.0	2.6	3.75	0.23	–	5.0	1.2	3.38	39.1	2.22	-0.6
16.	CHANDHAN	7.20	2561	1320	1.8	1.4	21.23	0.43	Nil	7.2	3.0	14.66	85.4	16.85	4.0
17.	KARMERI	7.50	2116	1290	4.6	4.4	10.00	2.28	–	11.4	8.4	6.48	46.8	2.12	2.4
18.	CHANDHAN	7.40	533	312	2.0	1.8	2.30	0.34	–	3.6	2.0	0.84	35.7	1.68	-0.2
19.	DILASAR	7.30	1622	1000	3.0	2.2	11.01	1.60	–	7.0	3.2	7.61	61.8	6.83	1.8
20.	DHAISAR	7.60	1978	1300	4.6	6.4	11.51	0.70	–	9.6	6.0	7.61	49.6	3.48	-1.4

JAVANDH	7.40	960	520	3.6	2.8	2.27	2.00	–	7.6	1.2	1.87	22.2	1.32	1.2
MULANA	8.30	1445	896	2.4	2.4	9.50	–	.2	5.8	0.6	7.70	66.4	6.13	1.2
NIRAUN(10 miles E of Mulana)	7.30	3064	1836	2.6	3.2	23.50	1.34	Nil	13.0	5.8	11.84	76.7	13.80	7.2
KITA	7.90	1402	902	4.6	2.8	6.31	0.18	–	5.0	1.0	7.89	45.4	3.28	-2.4
DEVIKOT	8.40	1779	1140	5.8	3.8	11.40	–	1.2	6.4	3.6	9.80	54.3	5.20	-2.0
BHAKHRANI(2½ miles SW of Sirwa)	7.50	1590	940	3.8	2.2	9.42	0.57	Nil	5.8	1.8	8.46	56.5	5.44	-0.2
SITORAI(4 miles NNW of Rama)	7.20	3258	1790	4.4	2.4	25.05	0.63	–	5.6	4.0	22.88	77.3	13.58	-1.2
KATHORA(1½ miles N of Rama)	7.50	2766	1628	4.6	2.8	21.55	0.63	–	6.4	4.0	19.18	72.8	11.20	-1.0
RAMA	7.30	1406	728	2.2	2.8	9.47	0.70	–	6.8	1.6	6.77	62.3	5.98	1.8
KAUDA(2½ miles E of Rama)	7.50	3583	2130	5.2	2.8	27.30	0.60	–	5.4	4.6	25.90	76.0	13.66	-2.6
BHILANI	8.00	1556	1001	2.6	2.4	11.00		–	5.6	2.0	8.40	68.8	6.95	0.6
SANGAR	7.30	920	510	4.0	2.0	3.00	[illegible]	–	5.6	1.3	2.54	31.8	0.57	-0.4
LAKHASAR(5½ miles E of Rasla)	7.90	2952	1730	5.4	5.2	18.05	0.40	Nil	4.2	5.4	19.45	62.1	7.84	-6,4
RASLA	7.15	670	306	4.2	1.0	1.54	0.6	–	5.4	Tr.	1.97	20.9	0.95	0.2
MERA JOT(6 miles ESE of Rasla)	7.80	3872	2384	6.0	7.4	24.61	0.8	–	9.8	4.2	24.82	63.4	9.51	-3.6
BHAINSAR(12 miles SE of Rasla)	8.35	1729	1000	2.8	2.8	11.20	0.40	0.4	9.0	1.6	6.20	65.1	6.69	3.8
RAJMATHAI(4 miles NE Of Kana Ji Ki Dhani)	7.70	1740	980	8.0	2.2	12.40	0.6	Nil	7.4	1.4	9.45	67.9	7.69	2.2
KANA JI KI DHANI	8.35	2977	2030	5.4	5.4	18.90	0.66	0.4	5.2	4.4	20.30	62.4	8.13	-5.2
ARANG(4 miles NE of Chachra)	7.50	1181	688	4.8	1.2	5.64	1.37	Nil	5.2	2.3	4.51	38.6	2.68	-0.8
KANASAR(Southern area)	8.10	1670	[illegible]	2.8	2.0	11.04	2.80	–	10.6	2.4	5.64	59.2	7.13	5.8
SARAN-KA-TALA (3 miles ESE of Bhiyar)	8.00	1584	912	2.2	3.8	9.65	0.36	–	7.4	3.0	5.61	60.3	5.72	1.4
DHANWA(4 miles W of Akal)	7.65	778	520	4.6	1.8	0.95	0.54	–	5.4	0.8	1.69	12.0	0.53	-1.0
BHU(7½ miles WSW of Akal)	7.60	1000	688	3.6	2.8	3.77	0.45	–	4.6	3.2	2.82	35.5	2.11	-1.8
BOPA(6 miles W of Kita)	8.40	2113	1174	2.8	5.8	17.10	–	.2	19.6	1.9	4.90	66.5	8.25	11.2
KOTRI(11 miles WSW of Kita)	8.00	1112	700	3.2	3.4	4.30	–	Nil	8.8	Nil	2.10	39.5	2.37	2.2

HAWLA*

TABLE: 7

TUBEWELLS PUMPAGE DATA, LATHI AQUIFER

1968 – 1970

S.No.	Name of the tubewell	Pumping hours in 1968												Total pumping hours in 1968	Discharge of the well USGPM	Total pumpage in 1968 Acre ft.
		Jan	Feb	March	April	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.			
1.	AJASAR(Old)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2.	AKAL	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3.	BARDHNA	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4.	BARORAGAON	–	–	–	–	–	–	–	–	–	–	22	201	223	346	14.21
		–	–	–	51	52	62	37	19	42	49	27	23	362	320	21.32
5.	BHAIRWA(Old)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6.	BHILANI	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
7.	BHOJAK	–	–	–	134	53	38	2	218	79	181	252	226	1183	700	152.50
8.	CHANDHAN I	–	–	–	79	145	118	66	98	139	90	65	38	838	844	130.20
9.	CHANDHAN II	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10.	DABHALA II	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
11.	DABHALA III	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
12.	DEVIKOT III	–	–	–	–	–	–	–	–	–	–	46	23	69	44	0.56
13.	DHAISAR II	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
14.	DHAISAR III	–	–	–	–	333	217	47	98	157	91	159	86	1188	800	175.00
15.	FATEHGARH	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
16.	JERAT	–	–	2	53	75	121	22	10	116	86	39	30	554	60	6.12
17.	JETHA	–	–	–	43	42	33	6	270	334	343	191	–	1262	580	134.50
18.	JESURANA	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
19.	KARMERI	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
20.	KITA	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
21.	LATHI I	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
22.	LATHI II	–	–	–	–	–	–	–	–	–	–	5	18	23	365	1.97
23.	MULANA	–	–	–	–	–	–	–	–	–	–	–	48	48	220	1.94
24.	SAGRA	–	–	–	–	–	–	160	316	472	272	327	437	1986	120	43.83
25.	SANGAR	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
26.	SANWALA	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
27.	Site No.7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
28.	Site No.13	–	–	–	–	–	16	26	70	50	39	6	225	432	700	55.68
29.	SODAKOR	–	–	–	–	–	–	–	–	–	10	83	226	309	590	28.45
30.	SRIBHAMRIA	–	–	–	–	–	–	–	–	–	53	69	33	155	421	12.01
31.	RAJMATHI (4 miles NE of Kana Ji Ki Dhani)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
																678.64

HAWLA*

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TUBEWELLS PUMPAGE DATA, LATHI AQUIFER

1968-1970

Pumping Hours in 1969

S.No.	Name of the Tubewell	Jan	Feb	Merch	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total pumping hours in 1969	Discharge of the well U S G P M	Total pumpage in 1969 Acre ft.
1.	AJASAR(Old)	-	-	-	-	-	-	-	-	-	-	-	16	16	140	0.41
2.	AKAL	-	-	-	-	-	-	15	19	4	-	38	14	90	170	2.82
3.	BARBENA	135	219	210	65	-	-	-	-	-	-	-	-	629	346	40.07
4.	BARORAGAON	26	-	44	53	71	66	48	35	73	44	38	43	541	320	31.87
5.	BHAIRWA(Old)	-	-	-	-	-	-	-	-	-	-	8	-	8	700	1.03
6.	BHILANI	-	23	88	99	37	51	64	43	52	70	26	38	591	100	10.86
7.	BHOJAK	242	229	139	20	28	24	55	46	45	72	152	226	1278	700	163.60
8.	CHANDHAN I	54	120	108	81	190	159	120	136	212	187	175	182	1724	844	267.90
9.	CHANDHAN II	-	-	-	-	-	-	-	-	-	5	-	-	5	521	0.48
10.	DABHALA II	330	330	330	332	374	451	471	383	434	398	316	366	4515	499	414.90
11.	DABHALA III	310	310	310	312	317	248	206	231	252	339	297	310	3442	496	314.50
12.	DEVIKOT III	56	77	85	121	128	105	137	83	49	56	52	54	1003	44	8.13
13.	DHAISAR II	4	4	27	222	-	-	-	5	177	87	239	264	1029	460	87.14
14.	DHAISAR III	83	90	130	95	85	78	23	17	31	-	-	-	632	800	93.09
15.	FATEHGARH	-	-	-	-	-	-	-	31	15	38	17	19	120	402	8.88
16.	JERAT	26	29	34	38	31	22	55	43	90	82	61	31	542	60	5.99
17.	JETHA	-	-	-	-	-	-	-	-	-	-	267	369	636	580	67.92
18.	JESURANA	53	66	35	22	23	22	18	25	10	16	153	318	772	400	56.85
19.	KARMERI	1	85	506	427	348	270	5	219	435	-	335	381	3012	645	357.80
20.	KITA	-	-	45	41	30	48	27	24	32	32	29	28	336	100	6.18
21.	LATHI I	67	73	97	83	79	84	61	32	87	23	127	274	1085	600	119.90
22.	LATHI II	-	1	1	-	-	-	-	-	-	-	-	-	2	465	0.17
23.	MULANA	95	73	75	47	39	45	53	34	41	60	48	37	647	220	26.2[illegible]
24.	SAGRA	646	489	577	71	81	65	31	136	340	308	283	293	3320	786	480.10
25.	SANGAR	-	-	-	-	-	-	-	64	7	12	-	-	83	120	1.88
26.	SANWALA	-	56	127	297	282	219	113	184	247	105	236	270	2216	423	184.[illegible]
27.	Site No.7	28	202	236	141	268	177	126	160	191	120	103	276	2028	644	240.50
28.	Site No.13	27	-	9	-	-	-	-	-	-	-	-	-	36	700	4.84
29.	SODAKOR	-	-	206	272	157	-	-	-	-	-	-	-	635	500	58.46
30.	SRIBHADRIA	40	43	39	60	38	5[illegible]	50	26	41	35	27	26	475	421	36.82
31.	RAJMATHI (4 miles NE of Kana Ji Ki Dhani)	-	-	-	-	-	39	123	-	64	94	35	32	387	310	22.09
																4097.83

CHAWLA

TUBEWELL PUMPAGE DATA LATHI AQUIFER
1968-70

No.	Name of the Tubewell.	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct.	Nov	Dec.	Total pumping hours in 1970	Discharge of the well in U S G P M	Total pumpage in 1970 Acre ft.
		Pumping Hours in 1970														
	AJASAR (Old)	16	-	-	-	9	-	-	-	-	-	-	-	25	140	0.64
	AKAL	20	10	18	20	34	12	-	-	-	-	-	-	114	170	3.57
	BARDHNA	-	-	-	7	4	-	-	-	-	-	-	-	11	346	0.70
	BARORAGAON	40	40	59	64	92	97	12	-	-	-	-	-	404	320	23.80
	BHAIRWA(Old)	-	-	-	-	2	-	-	-	-	3	-	-	5	700	0.64
	BHILANI													500	100	9.21
	BHOJAK	202	273	208	29	38	13	3	-	-	1	123	150	1040	700	134.10
	CHANDHAN I	183	192	238	335	344	335	155	113	298	171	191	200	2755	844	428.10
	CHANDHAN II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DABHALA II	389	424	433	513	425	508	425	387	391	317	325	348	4885	491	117.90
	DAPHALA III	304	30	-	-	116	375	356	274	331	155	-	-	1941	496	177.20
	DEVIKOT III	53	67	80	68	70	75	5	-	-	-	-	-	418	44	3.39
	DHAISAR II	64	-	-	300	146	230	2	-	2	1	164	150	1059	460	89.69
	DHAISAR III	-	1	-	-	-	-	-	-	-	-	-	-	1	800	0.15
	FATEHGARH													240	402	17.76
	JERAT	37	23	41	35	40	28	4	-	-	-	-	-	208	60	2.30
	JETHA	225	360	290	31	12	18	-	21	145	91	135	150	1478	580	157.90
	JESURANA	258	264	72	-	-	-	-	-	-	-	-	-	594	400	43.74
	KARMERI	312	368	368	400	309	290	2	-	2	3	65	300	2419	645	287.20
	KITA	28	32	42	43	38	37	3	-	-	-	-	-	223	100	4.11
	LATHI I	160	240	52	241	95	-	-	-	2	-	-	-	790	600	87.28
	LATHI II	6	3	-	40	38	23	3	1	6	5	7	-	132	465	11.31
	MULANA	40	24	34	44	50	42	23	-	-	-	-	-	257	220	10.41
	SAGRA	392	328	288	112	24	15	16	108	143	90	298	300	2114	786	306.00
	SANGAR	-	-	-	-	-	15	-	-	-	-	-	-	15	120	0.33
	SANWALA	258	271	221	37	41	13	-	-	2	-	-	250	1093	403	81.12
	Site No.7	216	217	189	158	159	90	70	131	130	81	119	200	1760	644	208.50
	Site No.13	-	-	-	167	268	232	12	-	-	-	2	-	681	700	87.76
	SODAKOR	-	-	-	5	-	-	-	-	-	-	-	-	5	500	0.46
	SRIBHADRIA	24	13	19	23	47	40	15	-	-	-	-	-	181	421	14.03
	RAJMATHI (4 miles NE of Kana Ji Ki Dhani)	34	31	41	44	42	38	25	-	-	-	-	-	257	310	14.67

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
32.	BHAGURAGAON	10	12	15	35	38	28	7	-	-	-	-	-	145	68	1.82
33.	BHIYAR	90	90	90	90	90	90	90	90	90	-	-	-	810	200	29.83
34.	CHANDHAN RLY.	120	120	120	120	120	120	120	120	120	120	120	120	1440	100	26.52
35.	KANASAR (Southern area)	90	90	90	90	90	90	90	90	90	-	-	-	810	88	13.12
36.	KAJARI NADI (3Km. East of Karmeri)	84	176	144	220	200	172	1	-	-	1	186	150	1334	645	158.40
37.	LATHI RLY.	120	120	120	120	120	120	120	120	120	120	120	120	1440	100	26.52
38.	UNDU	90	90	90	90	90	90	90	90	90	-	-	-	810	187	27.89
																2465.96

CHAWLA

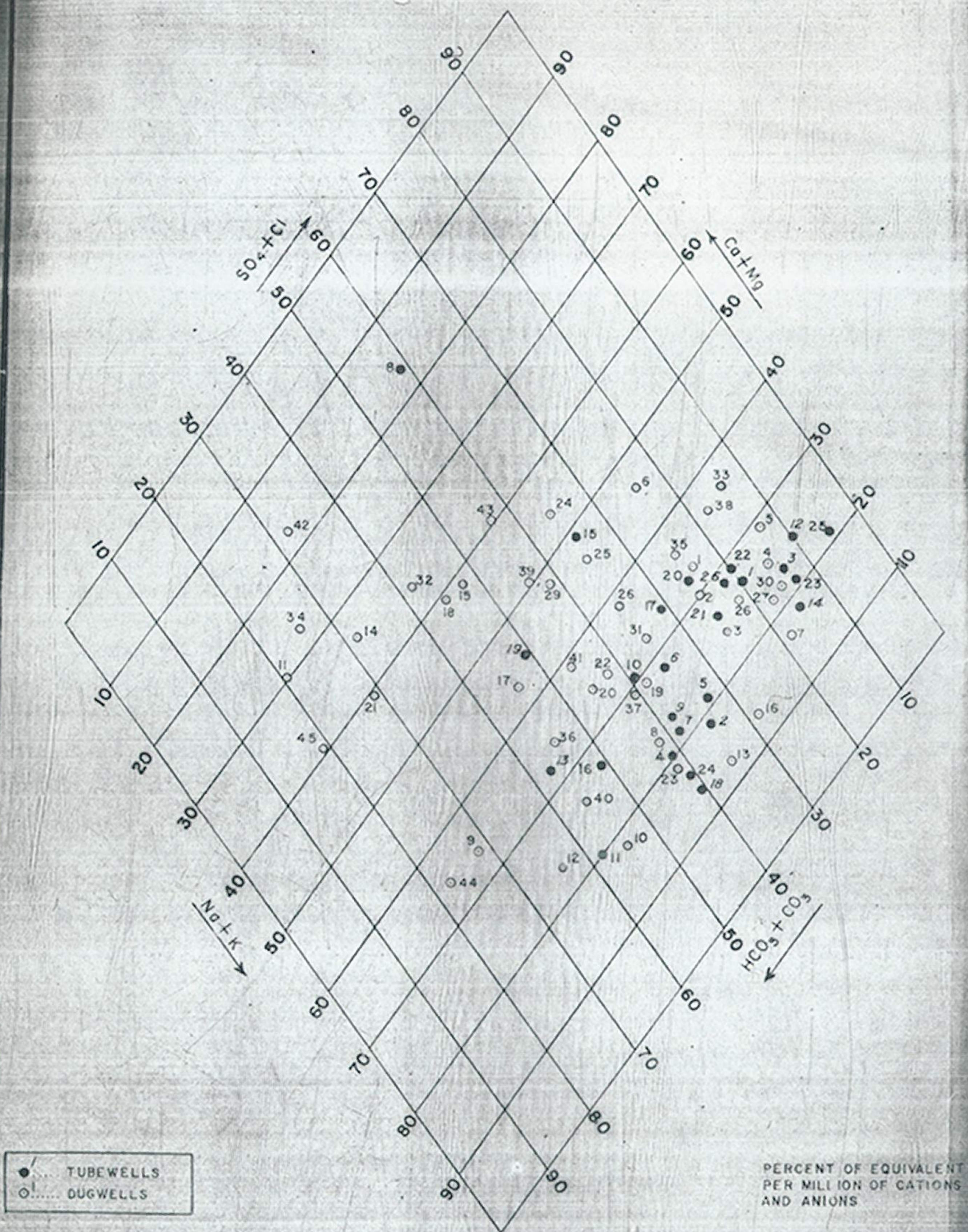
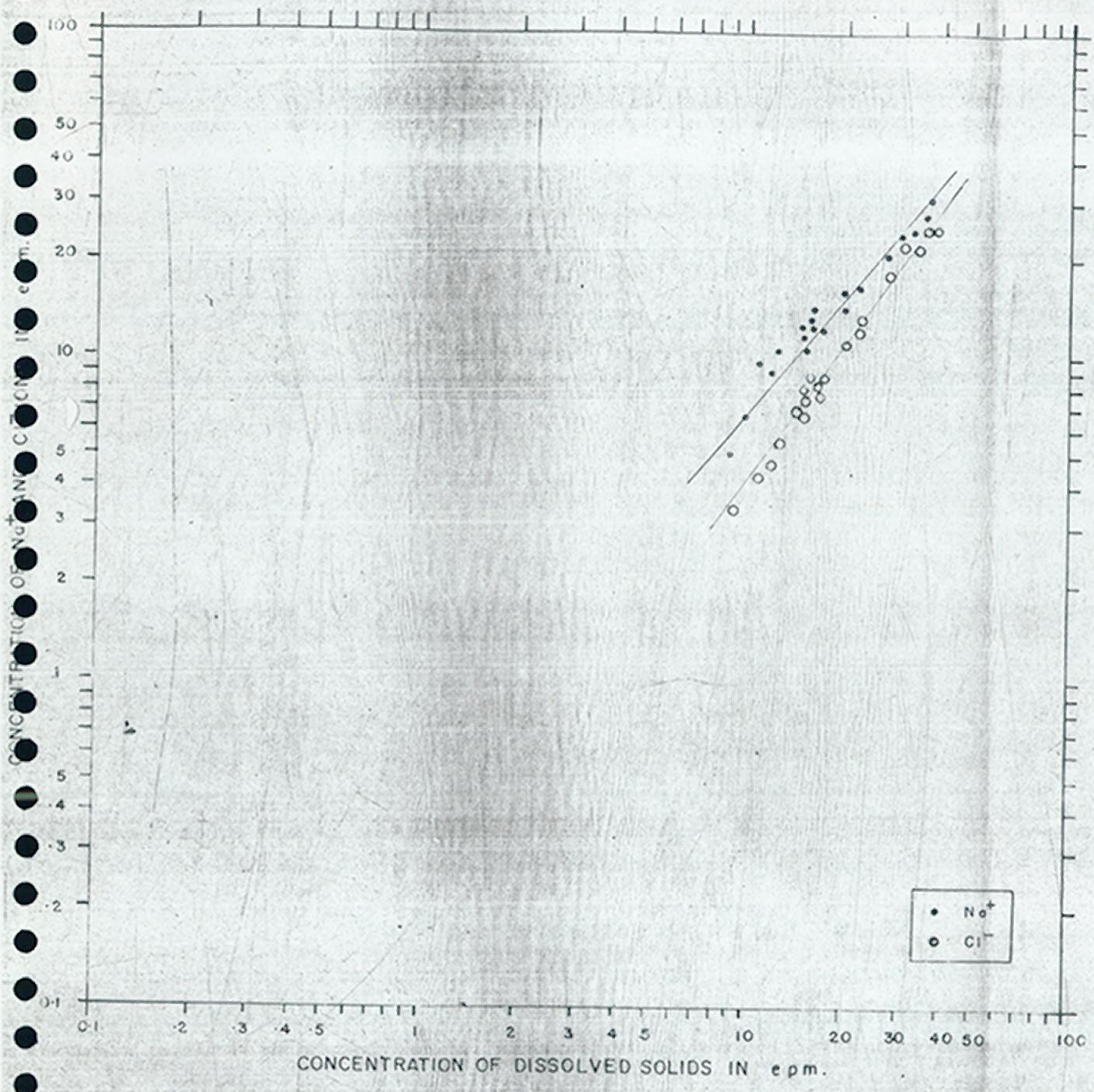


DIAGRAM SHOWING THE CHEMICAL CHARACTERISTICS OF TUBEWELL AND DUGWELL WATERS IN LATHI AREA

DRG. No.:- UNDP-276

Ex. 7



RELATIONSHIP BETWEEN THE DISSOLVED SOLIDS AND Na^+ AND Cl^- IONS IN EQUIVALENTS PER MILLION.

DRG. No. — UNDP — 237/AUG — 1970

Ex. 8

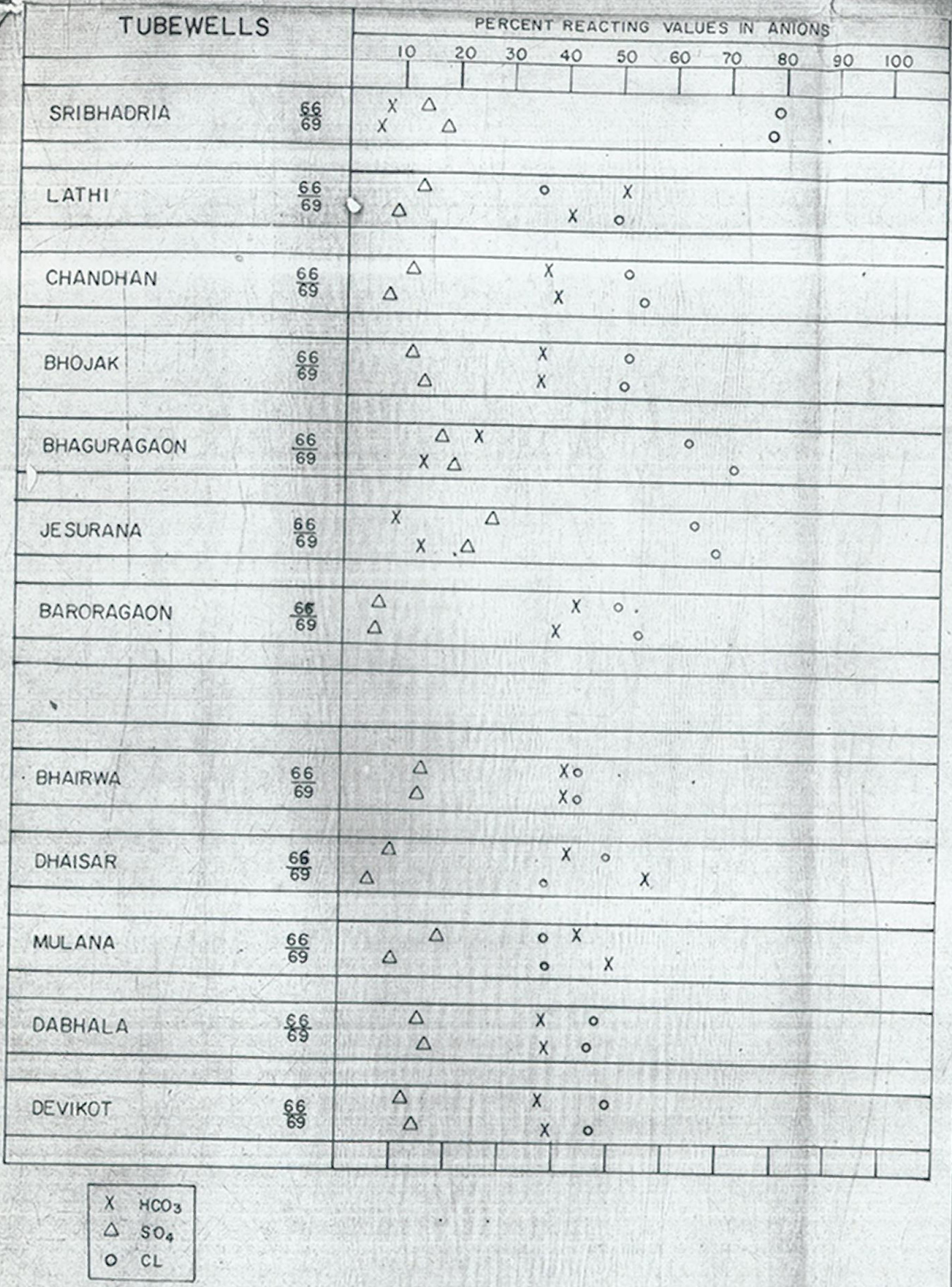
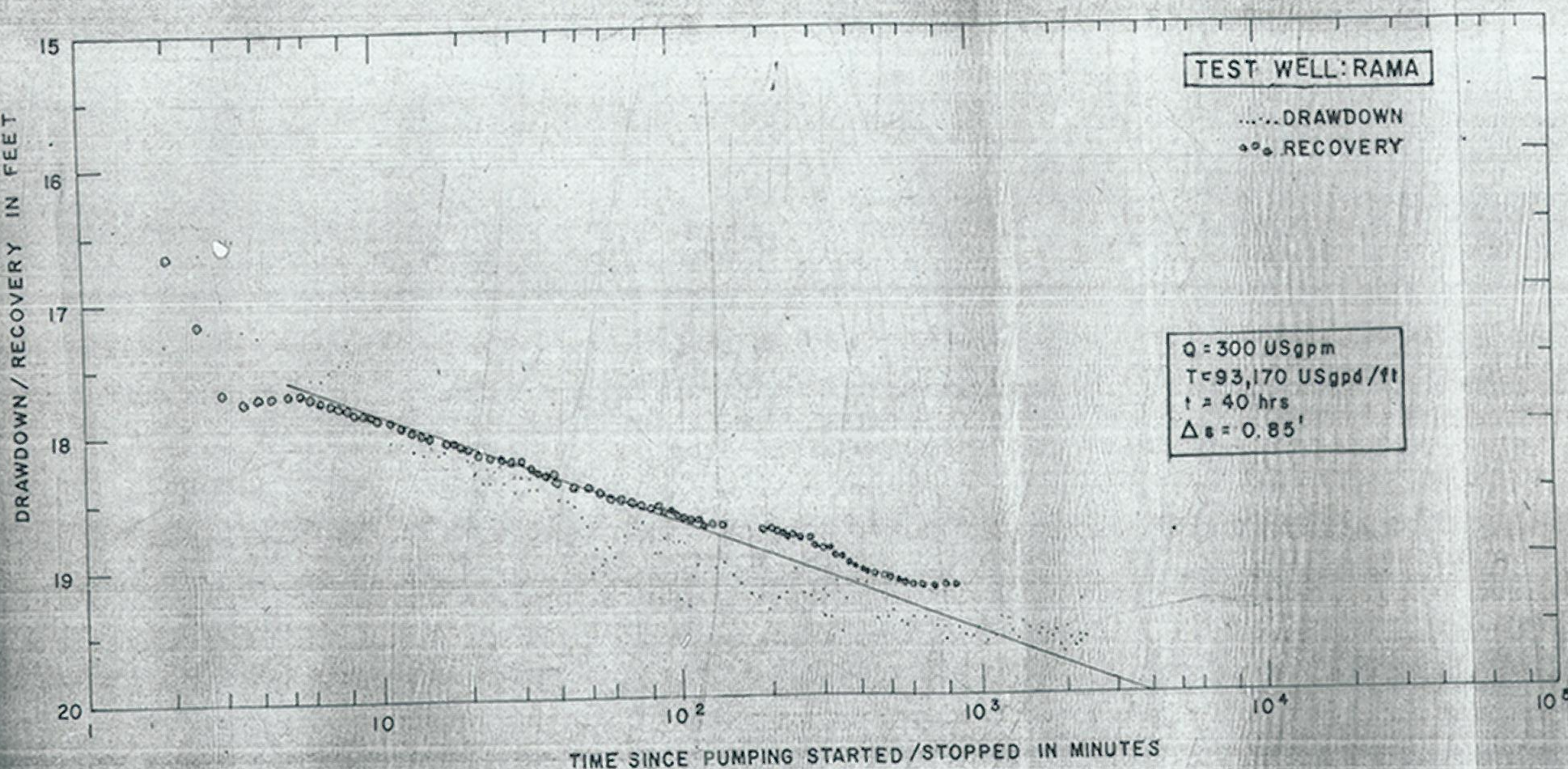


DIAGRAM SHOWING PERCENT REACTING VALUES OF HCO_3^-, SO_4^{--}, Cl^-, IN 12 TUBEWELL SAMPLES COLLECTED IN 1966 & 1969 IN LATHI AREA

DRG. No – UNDP – 280/SEPT – 1970

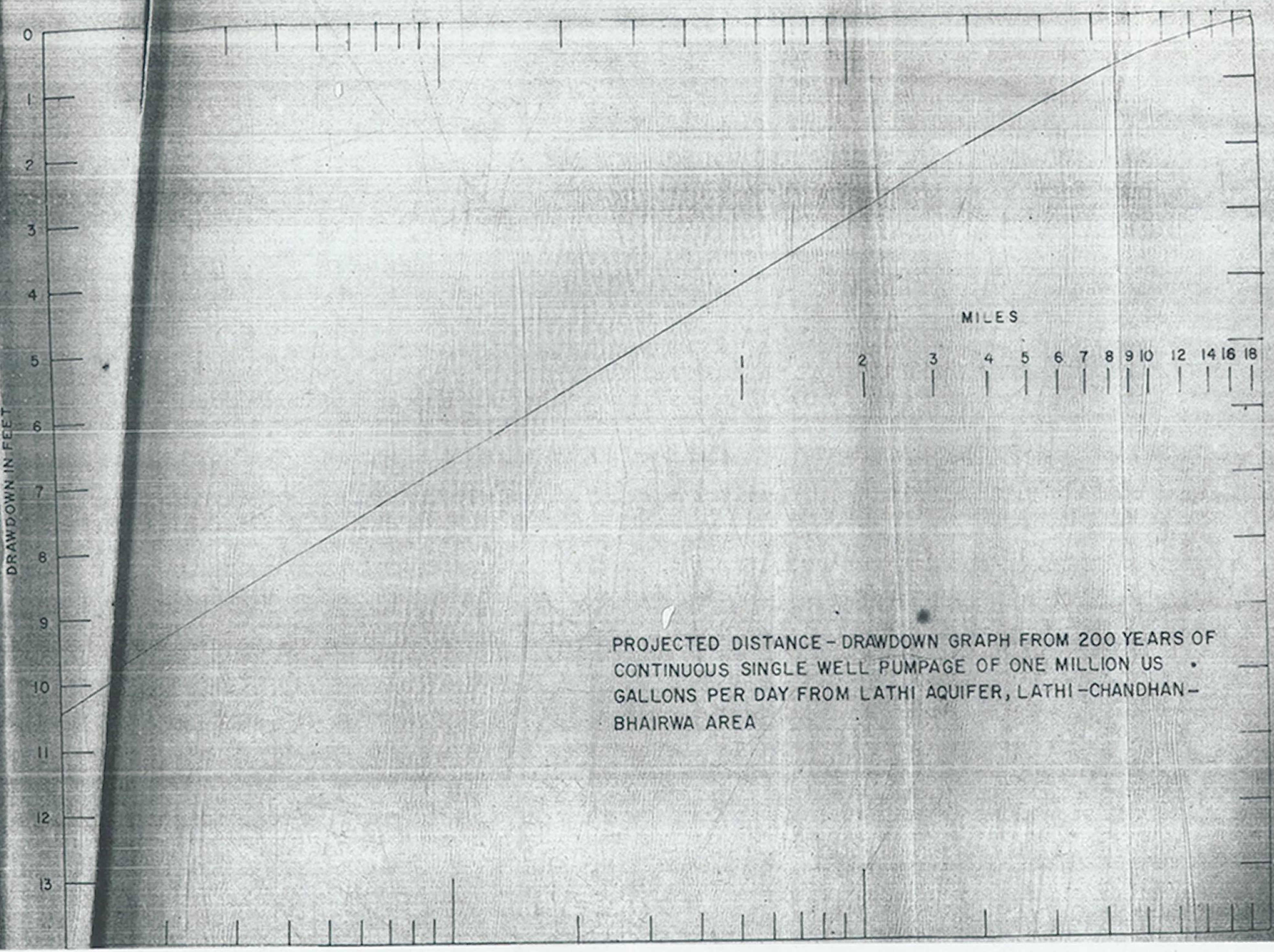
Ex. 9

TIME-DRAWDOWN / RECOVERY PLOT- RAMA



DRG. NO. 273/AUG. 70

Ex. 20



PROJECTED DISTANCE - DRAWDOWN GRAPH FROM 200 YEARS OF CONTINUOUS SINGLE WELL PUMPAGE OF ONE MILLION US GALLONS PER DAY FROM LATHI AQUIFER, LATHI - CHANDHAN - BHAIRWA AREA