CHAPTER VI

GROUNDWATER HYDROLOGY

HYDROLOGICAL CYCLE

The hydrological cycle is a fundamental concept of hydrology which points out that water continually evaporates from the ocean, moves over the land through the atmosphere, precipitates on the land and therefore follows one of three courses. Part of it infilterates into the ground; and part flows overland to stream channels, to lake, or to the sea. Part of the water that sinks into the ground and part of that in streams and lakes later also evaporates or is transpired by plants. Water that returns to the atmosphere in these ways is carried back to the ocean to fall again. These events may occur during shortly after, or long after the precipitation. Their occurrence and rates depend on many factors such as form of precipitation, amount and rate of precipitation, other weather conditions and nature of land-surface viz. bed rock or soil, bare or covered by vegetation, wet or dry, frozen or non frozen etc.

Part of the water that percolates in to the ground reaches the saturated zone and moves downward and laterally to sites of discharge as seeps and springs. In regions of perennial streams, this groundwater discharge provides the dry-weather flow (base flow) of streams. Surface run off during and shortly after a storm provides the flood discharge of streams.

Climate, soils, rocks, topography and vegetation are the environmental controls on the infiltration and run off of precipitation and on the movement of water below the land surface.

GROUNDWATER OCCURRENCE

In the Heran river basin groundwater occurs in various forms. The factors which are responsible for the diverse modes of groundwater occurrences are the lithological variation, structural and tectonic pattern and of course, their interaction have given rise to different geomorphic controls.

The groundwater occurrence encountered in the study area can be grouped into three categories:-

(i) Aquifers,

(ii) Springs and

(iii) Stream channels.

The distribution and occurrence of these categories vary from place to place. Of course by and large all the three categories are interrelated such as in the upper reaches of the basin when precipiration falls on the ground, a large part goes as run-off, water which infiltrates in the ground charges the aquifers, but under the influence of surface gradient, structural discontinuities this water flows and emerges in the form of spring which ultimately meets stream channels in the middle part of the basin. In the lower reaches the river and streams again lose their discharge by virtue of their influent nature and hence the water which was intially of the nature of surface run-off became groundwater in the lower reaches.

AQUIFERS

In a broad sense, these are natural zones below the surface that yield water in sufficiently large amounts to be economically important. In the study area the encountered aquifers are of non indurated porous and permeable sedimentary deposits, fracture zones in dense trap rocks, weathered zones of basalts and metacrystallines, semi-porous sandstones, and other geologic features.

Based on the identified lithologic composition and groundwater regimes, these water bodies are grouped into two classes of aquifers, (1) Phreatic and (ii) Semi-confined.

Phreatic Aquifers

These subsurface water bodies cover a vast expanse of the upper and middle parts of the basin area. These are the structures where water only fills a permeable bed, the upper surfaces of the saturated zone where water table is free to rise and fall, their extent and position is controlled by structure or stratigraphy.

As alluded in Chapter II, the upper and middle parts of the basin dominantly comprise consolidated formations of Deccan Trap lava flows, compact Bagh sedimentaries and Precambrian crystallines.

The Precambrian crystallines being dense in nature, lack inherent primary porosity. It is the secondary porosity which has generated water bearing capacity in these rocks. The groundwater in this part of the basin is limited to weathered zones only.

So far the trap rock is concerned field observations have shown that the occurrence of phreatic aquifers in this hard rock terrain is dominantly controlled by geological and structural set up. These water bodies are either limited to the veneer of the rocks or to the depth and extent of the discontinuity surfaces together with topographic controls viz. landforms and relief. The area around village Dungragam, Pipaldi, Chaktala, Amalwant, Bhumaswada is highly undulatory (Plate VI.1) and has developed numerous local depressions. As the precipitation percolates downwards it starts migrating towards the general gradient of the area and gets accumulated in these surficial lows which ultimately develop into phreatic aquifers. Those which are governed by the discontinuities viz. masterjoints, fracture zones have very less overburden and soil cover and they intermittently discharge their resources in the form of springs at the location where the discontinuities get exposed at the surface or in stream channels. The area around village Bildha, Kasarvav, Galesar, Hathikhan, Bakhatgarh and other parts which are dominantly hilly shows such aquifer conditions.

In the terrain of Precambrian rocks i.e. north of Panvad, Ghantoli and Nandpur villages these aquifers shows very conspicuous relationship with the depth and extent of weathered zone. As, these rocks by their nature and composition do not permit water to seep in or to allow to migrate, it is the only weathered zone which has a limited capacity to hold the groundwater, just meet the demand of the local population.

Plate VI.1 Field photograph showing undulatory terrain with surficial depression, provides an adequate site for the development of phreatic aquifers. (Loc. Village Pipaldi)

The influence of dykes on these aquifers is also significant. They control subsurface flow and form local groundwater storages. These structures either act as barrier, or regulate the groundwater flow. The dyke barriers develops a local shallow aquifer on one side, while other side subsits on a meagre supply. Such aquifer conditions are witnessed in the area north of Panvad and south of Wanta villages. It has been observed that the dyke controlled aquifers are elongated in shape i.e. their elongation is parallel to the trend of dykes and are of limited width.

The nature and composition of Bagh sandstones has governed the development of phreatic aquifers. As the sandstones is quartzitic and compact it bears very low primary porosity. The presence of intercalated shaly layers also reduce its water bearing capacity. The only source of input is discontinuity surfaces, but these are also tight and filled with siliceous and ferrugenous materials. As it has been witnessed around Ghantoli, Kalediya, Wanmala, Kothiya and Navi Vasahat near Sinhadra, these aquifers provide a very low yield.

The aquifers identified in the non-indurated sedimentary deposits produce high yields. Their input is completely depend on the supply through stream channels, and flow derived from the elevated rocky terrain. Being highly porous, and permeable in nature these aquifers remain flowing till the input is diminish from the upper reaches or unless the flow is checked by dykes or impermeable beds. The occurrence of these aquifers is dominantly confined to the river valley's, flood plains and in terrace deposits, The conditions discussed above are very common in the middle segment of the study area around Wijali, Mankodi, Narukot, Ucheda, Bagaliya, Lalpur, Nava Timberva, Chalamali, Rajwasana, Kosindra, Wasana and Lachchras. The extent of aquifers is governed by the depositional pattern of these sedimentary deposits. By and large their lateral and vertical extent is much higher as compared to the aquifers in consolidated rocks. Based on the field observations and well section studies, the phreatic aquifer's characteristics are summarised in (Table 6.1).

Semi-Confined Aquifers

These are the deep aquifers comprises semi-permeable material, and on the basis of the nature of permeability belongs to two categories. In category (i) the material which forms the aquifers is non-indurated and in the category (ii) the presence of fracture zones to large depths have provided subsurface conduits for transmitting groundwater, particularly in the area of consolidated formations.

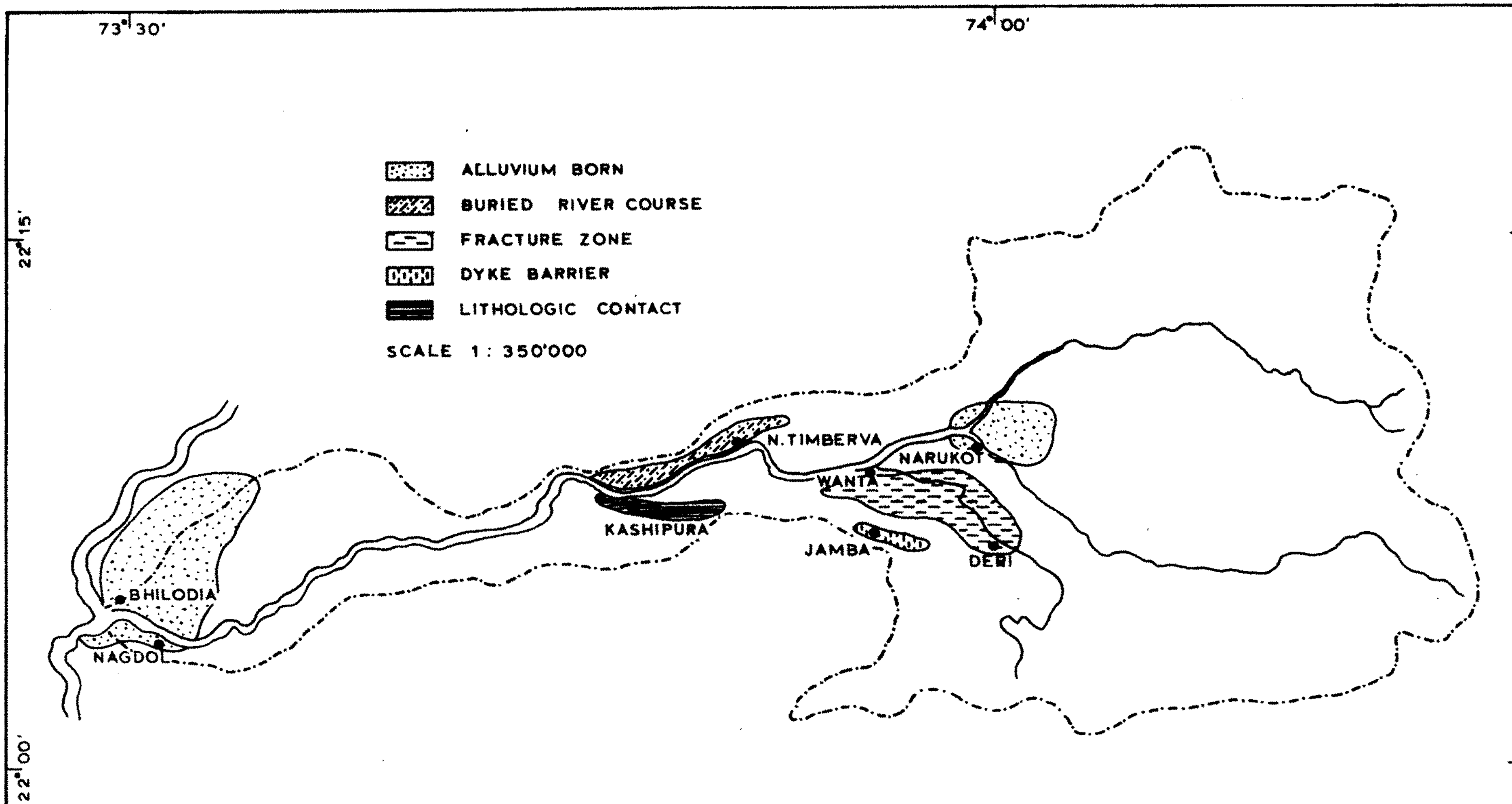
The occurrence of semi-confined nature of aquifers is dominantly identified in the middle and lower segments of the Heran basin (Fig.6.1).

The category which comprises non-indurated sediments forming such aquifers is mainly controlled by the geomorphic processes viz. landforms, palaeochannels, nature of river bed and overall relief of the terrain . The cases belong to this category are potential sources of groundwater. The area between Bagaliya and Chalamali where the right bank of river Heran has accumulated a thick levee deposit has been identified as a palaeochannel of Heran and this has given rise to one of the largest semiconfined aquifers of the study area. The extent of this aquifer is 6 km in length, 2 km width of high yield.

The other aquifer is been located between village Narukot and Mankodi; here the detritus dumped by the rivers Heran, Kara and Rami during flash floods, provide high yield.

In the lower segment of the basin villages Bhilodiya, Jalodara, Nagdol, Bihora, Tankhala, Kotali, Mobhiya etc. are the areas of high potential aquifers. Here the mixed fluvial materials brought by the rivers Heran, Orsang provides ideal conditions for developing semiconfined aquifers of higher depth. The influent nature of the river bed in the lower basin, downstream of Ghantoli has augmented to the potential of these aquifers.

FIG 6.1



DISTRIBUTION OF SEMI-CONFINED AQUIFERS IN THE STUDY AREA

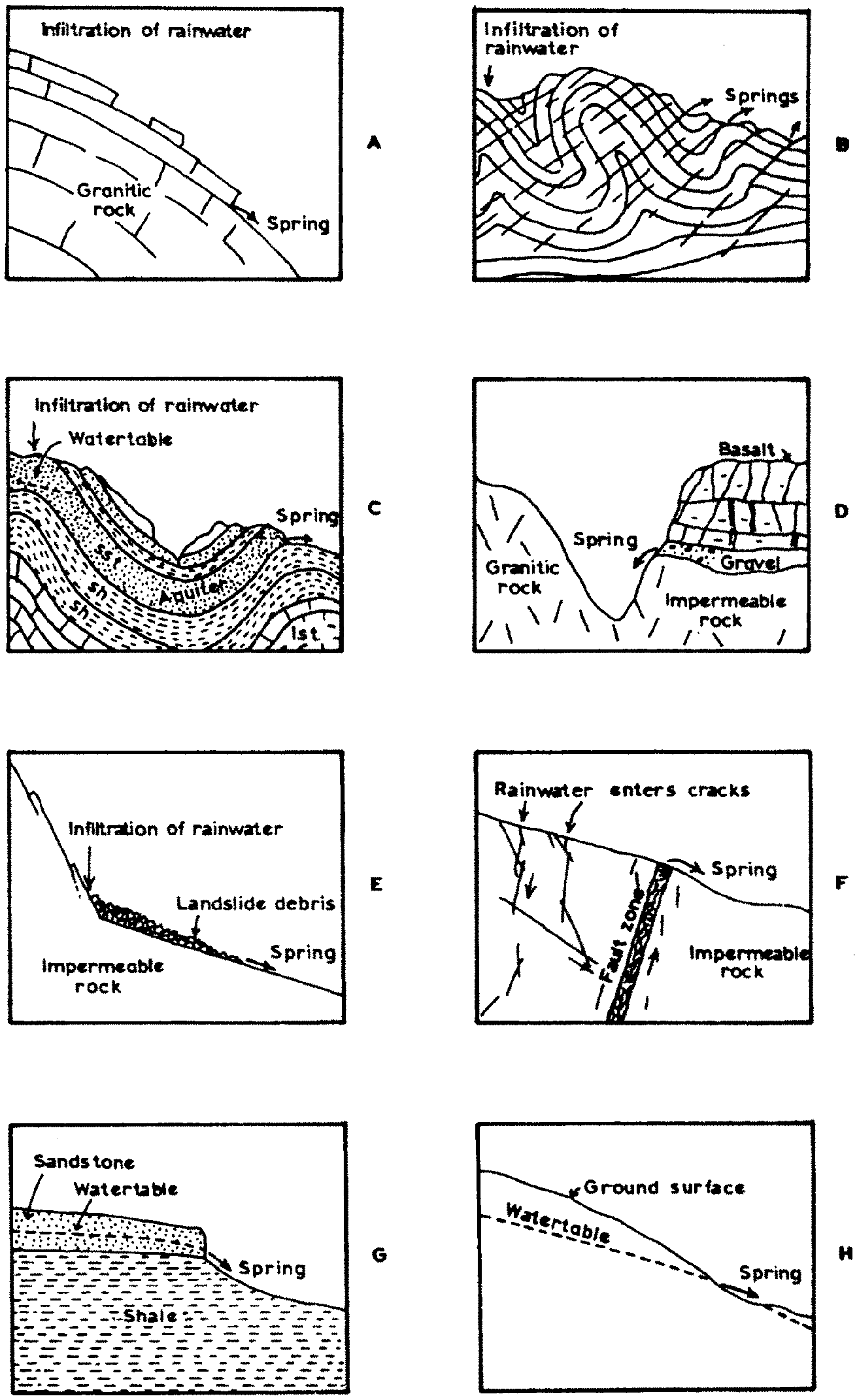
SPRINGS

Any natural discharge of water large enough to flow in a small rivulet can be called a spring. Davis & DeWiest (1970) has classified springs in a number of ways viz; on magnitude of discharge, type of aquifer, chemical characteristics, water temperature, direction of water migration, relation to topography and geologic structure. The three principal variables that determine springs are aquifer permeability, area contributing recharge to the aquifer and quantity of recharge.

The study area of which 70% is comprised of consolidated formations, exhibits spring conditions at several places. As the permeability of hard rocks is low, the water is forced to the surface over a large area. At several places in the upper and middle parts of the basin, the banks of entire stream systems are lined with small individual seeps and springs with aggregate discharges of several hundred cubic metre per minute. Such conditions has been observed on the left bank of Heran between Wanta,Jharoli and Sodhvad, and in Kara's left bank near Bakhatgarh, Renda etc. Such conditions are of the fact that the homogenity in lithology plays an important role for providing spring conditions. All over the hilly areas around Siriwasan, Bildha, Artiya, Mathwad, Chipan and Karipani which is dominantly occupied by Deccan Traps; under favourable topographic conditions, the landsurfaces intersect the water table and springs originate.

Most of the springs are localised. A vertical or horizontal variation of permeability cause the localization of springs. (Fig.6.2). Sliderock deposits, soil horizons and landslides help to localize the flow of springs. The presence of discontinuity surfaces, structural variability in rocks by tectonic movements produce many changes in permeability and thereby localize springs. The southeastern part of the middle basin is highly dissected by faults and shear zones, the water table which has downgrading trends in the hilly area, intersects these structures and emerges in the form of springs. Exfoliations in granitic terrain around Siyada, Vejaliya and Pipariya has also given rise to small springs.

Although, Bagh beds cover about 25% basin area, no significant spring conditions have been identified. Perhaps the factors of low altitude, horizontal deposition and very low permeability have been responsible for the failure to produce springs. However, the limestone beds in the area between Kawant, Hathikhan and Karipani do exhibit some limited development of springs which originate on account of solution caverns.



OCCURRENCES OF SPRING CONDITIONS IN THE STUDY AREA

(After Davis and DeWiest, 1970)

GROUNDWATER LEVEL AND ITS FLUCTUATIONS

SCOPE

The Heran river basin has not been given full attention by any government agency yet. Though various studies have been conducted by different departments of state Government undertakings for various project purposes. Central Groundwater Board (CGWB) has only a single observation well for the entire basin area and that too has been established recently (1983) at Thadgoan village. No exclusive study on its ground water potential has been undertaken. However considerable information of value is available from the Soil Survey Department of the Government of Gujarat. This department has carried out long term groundwater level fluctuation studies for the period 1976-1982 in connection with the command area development for the proposed Heran dam project near Lalpur. The Soil Survey department has established more than 300 observation wells for monitoring seasonal groundwater level fluctuations, out of these, 91 observation wells fall within the middle and lower parts of the basin area. Gujarat Water Resources Development Corporation (GWRDC) has selected lower segment of the basin to monitor seasonal groundwater level fluctuations for the command area development programme for Narmada dam project. GWRDC is carrying out these studies blockwise, viz. Aswan-Heran block and Heran-Orsang block. A total of 23 observation wells of GWRDC fall within and in adjointing parts of the study area. GWRDC is also carrying out hydrogeological studies under Agriculture Refinance and Development Corporation (ARDC) programme for talukawise groundwater development.

Unfortunately, the upper segment of the Heran river basin which has partly in Gujarat and partly Madhya Pradesh, has remained unattended, except for some bore hole records drilled by Public Health Engineering Department, under UNESCO's 'No Source Scheme', so far no significant work has been done.

The present author has made an attempt to study the groundwater conditions of the upper part of the basin, but on account of limited facilities and adverse terrain conditions, he could not do full justice. Difficult terrain conditions, the scope of and limitations of the present study, sparse population, lack of communication network and in accessibility of the area, author had to restrict his studies only upto Kawant area. Further east he took only approach traverses along Kawant - Bakhatgarh, Bhakhatgarh-Chaktala-Kawant and visited a few interior villages.

To study the seasonal and longterm groundwater level fluctuations and aquifer characteristics author has collected all the relevant informations from various agencies and systematically compiled and analysed for hydrogeological appraisal.

OBSERVATION WELLS

To study the groundwater level fluctuation in Heran river basin by covering as much area of the basin, as possible 68 observation wells were selected, 50 on the basis of information gathered from various government agencies and the remaining 18 identified by the author himself. These wells have been identified in the field for seasonal checks. All these wells were inventoried and located on the Survey of India topographic maps (Fig.6.3). The distance between the observation wells has been kept at about 3 km so that each well could cover about 10 sq.km. area. The details of seasonal water level observations are given in Appendix 6.1.

Due to limitations of the resources and the large scope of the work, author has collected himself (i.e. 1983-85) only three years' seasonal observations and has supplimented his observations with the data available from other sources. The Reduced Water Levels (RWL) with respect to the MSL have been calculated and analysed. Though due care has been taken, in recording the levels, the author does not rule out the possibility of the influence of the pumping effect of neighbouring wells, on the measured levels of some wells.

Water Table

The watertable is the surface in unconfined material along which the hydrostatic pressure is equal to the atmospheric pressure.

The general conditions of groundwater table and its fluctuations in study area are dominantly controlled by the lithology and geomorphic features. The area identified as a zones of phreatic aquifers shows very wide seasonal variation in their levels. Groundwater level in phreatic aquifers of consolidated formations are almost very near to ground level during monsoon and post monsoon periods, and which progressively depleted day by day, so much so that large percentage of wells becomes dry by the end of April (premonsoon season). Those wells which are located in unconsolidated formations, the range of fluctuations in groundwater level is smaller though, the depth of groundwater table is more. The aquifers of semi-confined nature show very little seasonal variations in groundwater levels.

Reduced Water Level (RWL) map with superimposed pre- and post-monsoon water level contours (with reference to mean sea level) for the year 1980 has been drawn to give an idea as to the dispositions and movement of groundwater within the basin area (Fig. 6.4). It could be seen from the Iso-RWL map that the depth to water level is maximum in the lower segment of the basin. In general a westerly gradient of the water table is observed.for determining maximum fluctuations in post and pre-monsoon periods, 1976-82 and 1979-85 year's lowest premonsoon and highest postmonsoon static water levels have been considered. The lithological variations and their significant controls on RWL contours are as under:

Lithology	Observation well Nos.	SWL (m) Pre	SWL (m) Post	Gradient m/m	Direction of Flow
Meta-sedimentaries	56,57,59,61,67	18.45	4.60	1:400	WSW
Bagh sandstone	42-54	15.0	2.45	1:400	WNW
Deccan Trap	18-31 34-36 42-44,65,66	14.25	2.15	1:200	WSW
Alluvium	58,60-64,68	22.10	12.00	1:600	WSW & SW

The SWL contours in the upper part of the basin i.e. upstream of Heran-Kara confluence could not be drawn, as it is not possible to do so, when the terrain configuration is highly rugged.

To study the effect of topography on water table, water level above the MSL was plotted against the corresponding ground level (Fig.6.5). It will be seen from the graph that the concentration of points more or less fall on a near straight line indicating that the water table varies directly with the ground level.

Groundwater Flow Direction and Gradient

Variations in groundwater flow direction and change in hydraulic gradient depend on two important controls (i) physiography and (ii) Structure.

(i) The physiographic control on groundwater flow direction and gradient is exhibited in the lower basin of unconsolidated material. The palaeo-topography over which the alluvium is deposited has been subjected to varied degree of consolidation; on account of it, the intercalated sequence of sand, gravel and clays has developed local physiographic subsurface lows and highs and their depositional pattern has given rise the changing trend in permeability directions. The combined effects of these phenomena have controlled the changing pattern of hydraulic gradient and flow directions.

(ii) The major E-W & NW-SE fracture patterns and dykes provide the structural control and govern the hydraulic gradient and flow direction. Since low primary porosity

RELATION BETWEEN GROUND LEVEL & GROUNDWATER LEVEL

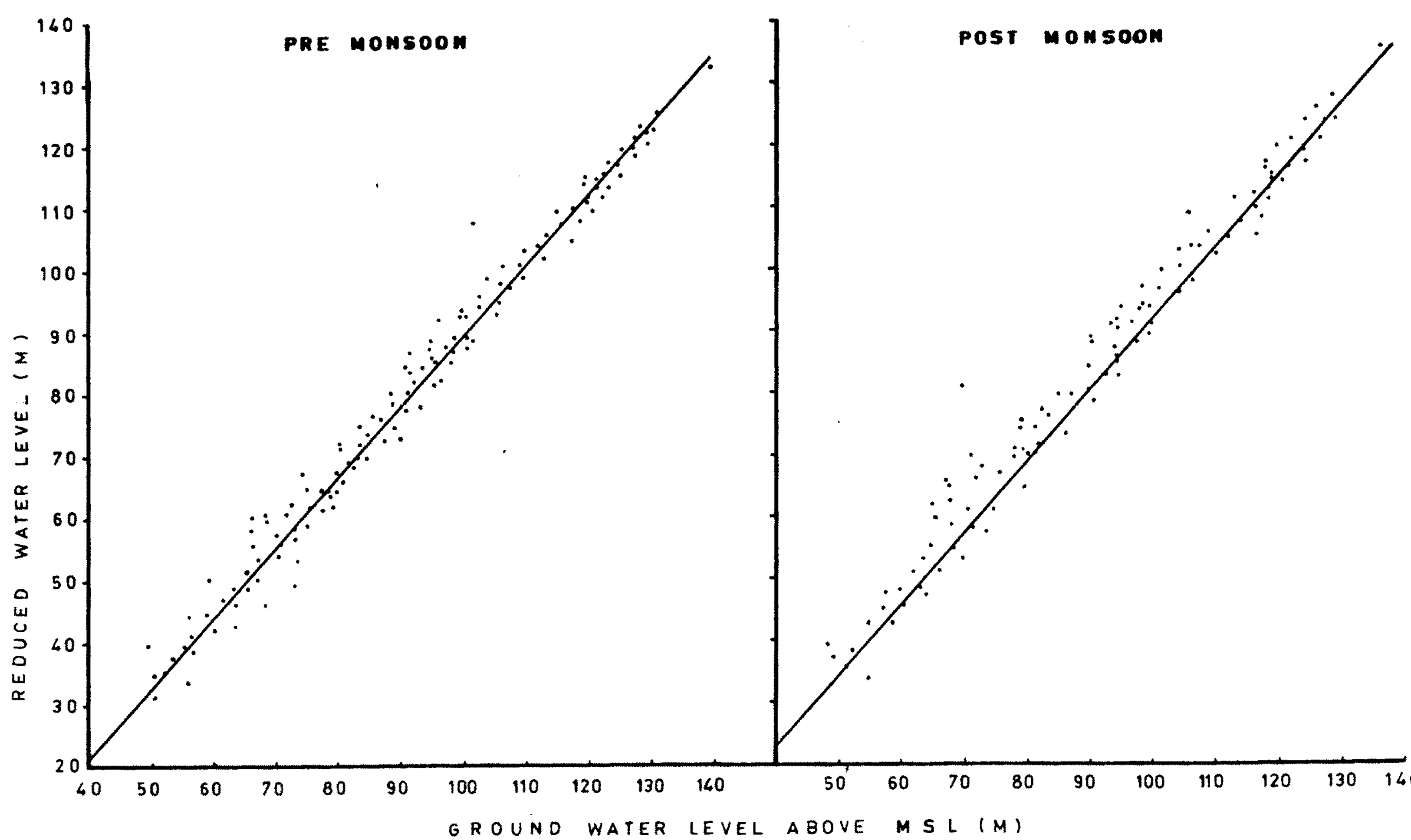


Fig.6.5

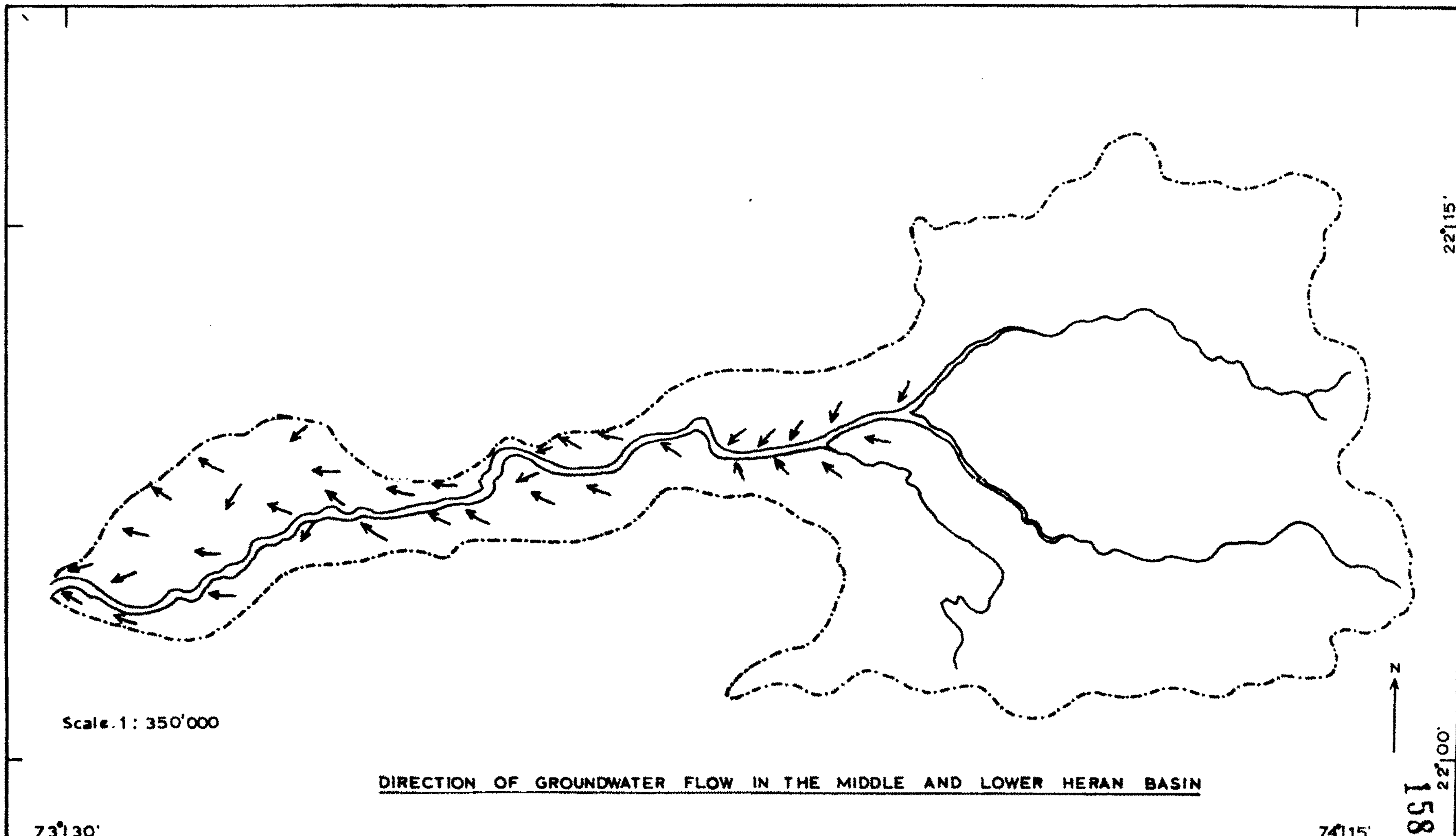
and permeability in hard rock is incapable to hold and transmit the groundwater, it is the fracture and joint pattern which control the flow direction and gradient (Fig.6.6).

Seasonal Water Level Fluctuations

The water levels all over the basin fluctuate with seasons. The amplitude of fluctuation varies from area to area and location of the observations well. To study the seasonal variations and average rise and fall in the water levels for estimation of recharge, records of 47 observation wells were scrutinised. Observation wells Nos 1 to 18 have not been considered for this purpose, as the data on these wells are scanty and for a limited period only. In observation wells N. 18 to 54 a total of six years (1976-1982) seasonal post monsson and pre monsoon water levels have been considered, observation wells No. 55 to 68 have been considered for the period 1979 to 1985.

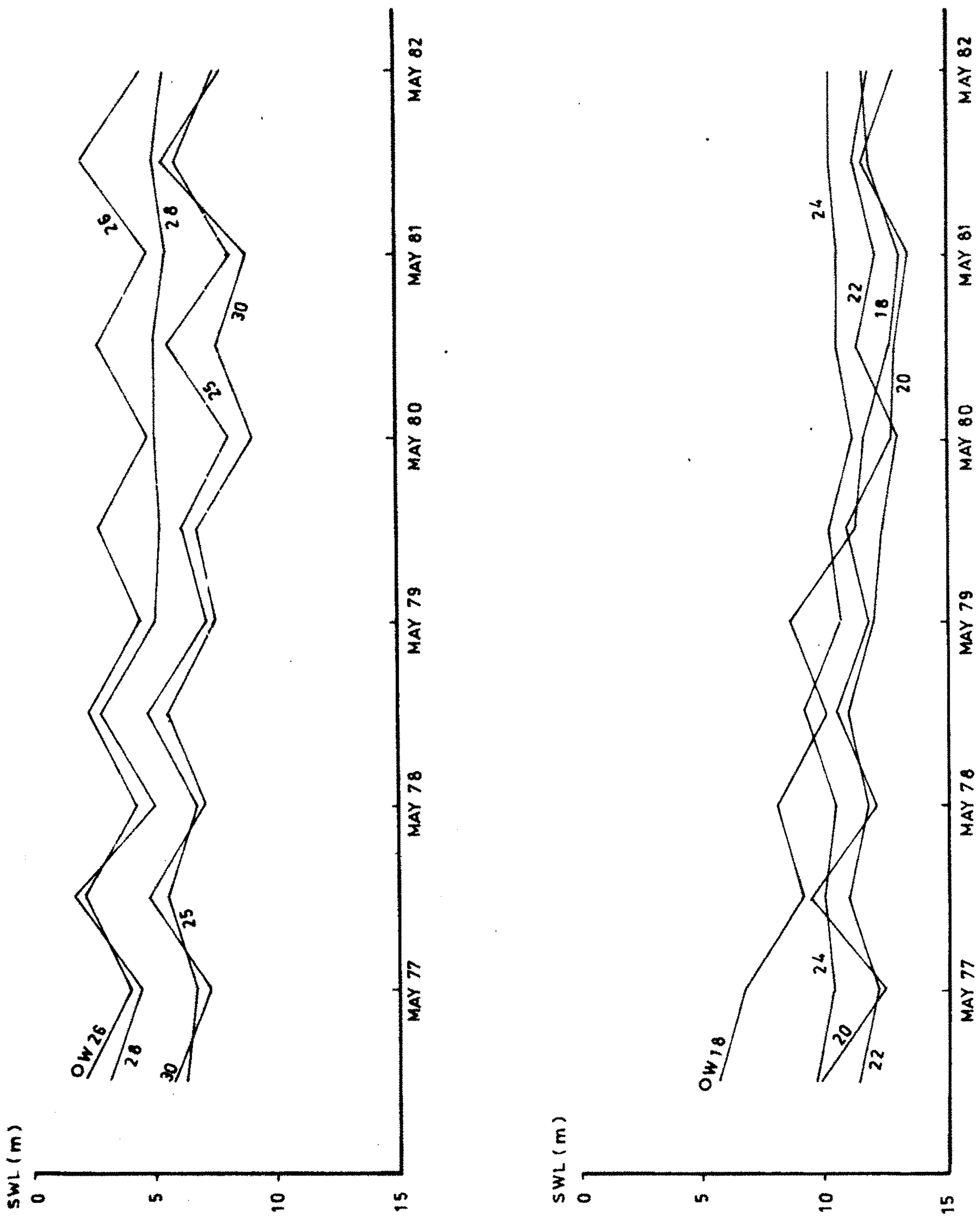
The deepest water level was recorded in well No.59 during May 1983 as 18.45 m, while well Nos.28 and 41 recorded shallowest 1.80 m during May 1977 and 81 respectively. As such the tubewells drilled by GWRDC in the lower reaches of the basin at Bhilodiya, Asodara, Nagdol, show water levels at higher depth of 28 m below ground level.

FIG. 6.6

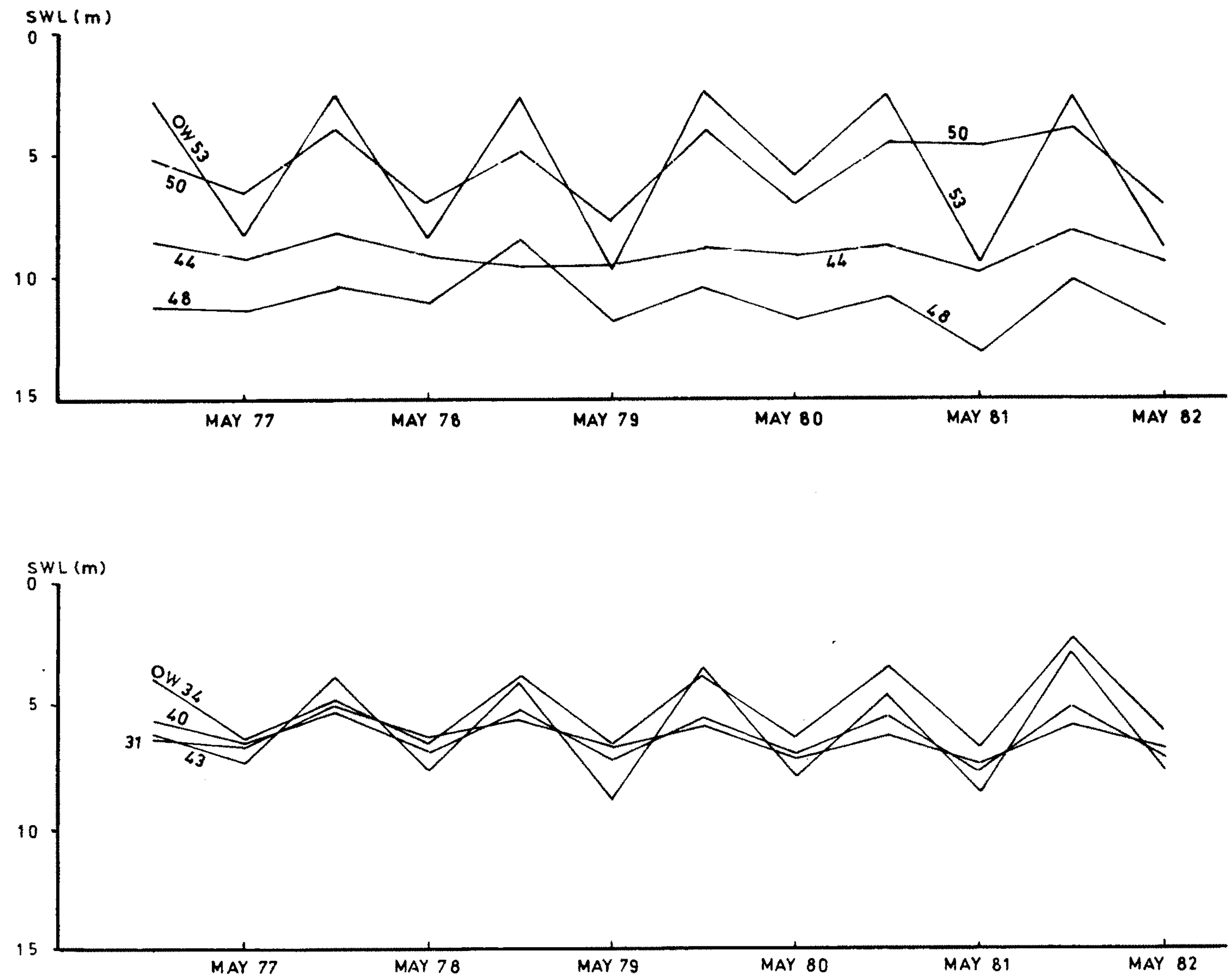


DIRECTION OF GROUNDWATER FLOW IN THE MIDDLE AND LOWER HERAN BASIN

FIG. 6.7.A



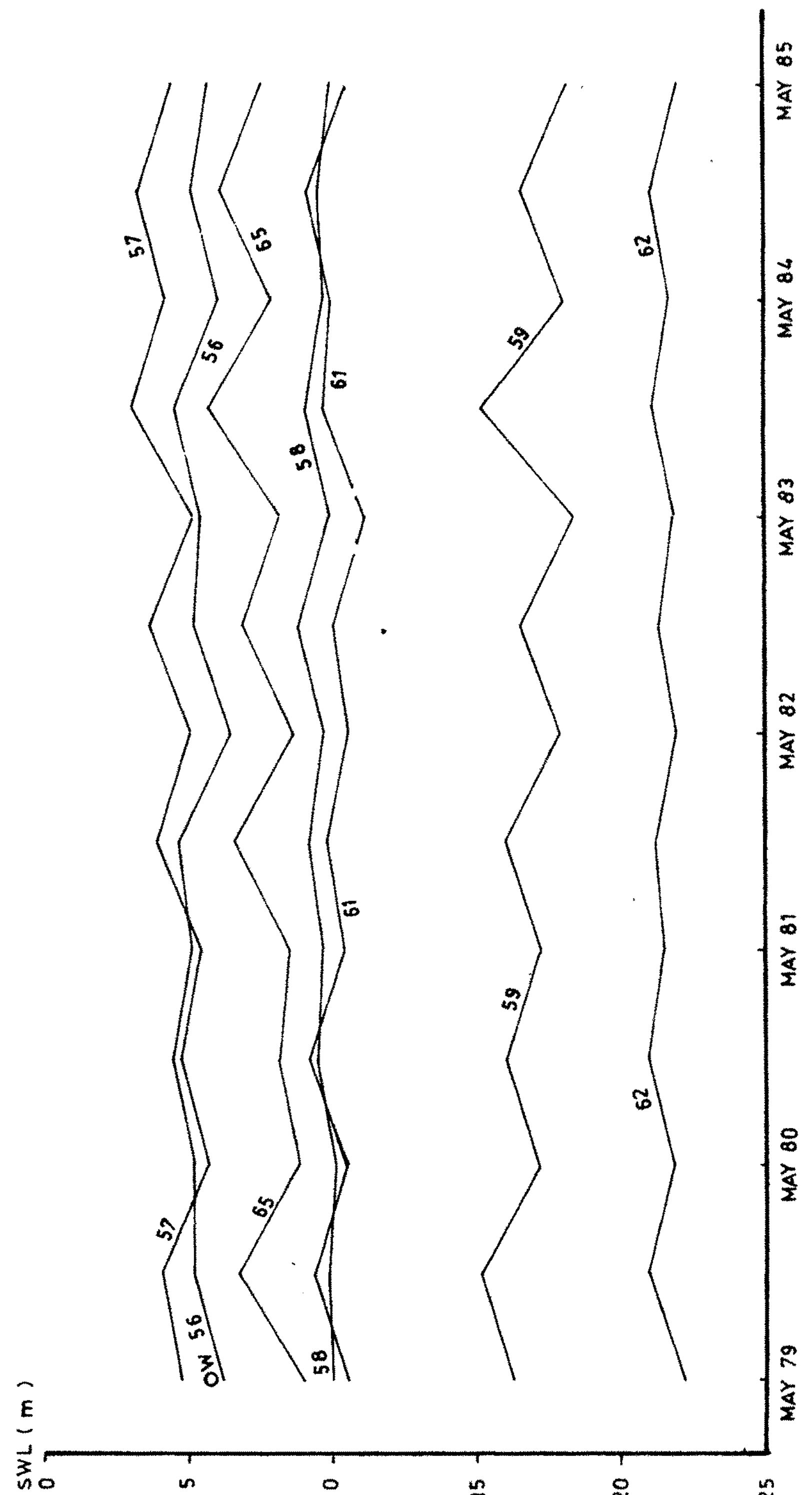
SEASONAL WATER LEVEL FLUCTUATIONS



SEASONAL WATER LEVEL FLUCTUATIONS

FIG. 6.7.B

FIG. 6.7.C



SEASONAL WATER LEVEL FLUCTUATIONS

level baseline i.e. October 1976 (well no.18-53) and October 1979 (well no.54-68). The trend in the fluctuation varies depending on the factors like the degree of weathering, intensity of fractures, joints, water bearing formation etc. apart from the effect of rainfall. Occasionally, considerable similarity in water level fluctuation all over the basin, irrespective of factors described above have been recorded. There was a general fall in water level during 1981 premonsoon period i.e. before the heavy rains, shortly afterwards the general water level rose considerably all over the basin.

The variation range of water level computed from the seven years' record in different geological formations is as under:-

Location	Geological Formation	Water table Max. (m)	Water table Min. (m)	Fluctuation (m)
Bortalav	Metamorphics	18.45	15.21	03.24
Chota Udepur		07.35	01.15	06.24
Ghantoli	Bagh sand-stone	09.80	02.45	07.35
		09.80	04.00	03.80
Kawant	Deccan Trap	11.35	03.17	08.18
Rampura	Alluvium	15.60	12.00	03.60

Groundwater Flow Rate

From Darcy's law it follows that the rate of groundwater movement is governed by the hydraulic conductivity of an aquifer and the hydraulic gradient. The relation between hydraulic conductivity and magnifude of natural velocity can be expressed as -

$$v = K.i \qquad \text{...... .... (Todd, Eq.3.42, pp.81)}$$

Where v, represents velocity or flow rate in m/day, K, the hydraulic conductivity of the aquifer in m/day and i, a hydraulic gradient in m/m. Groundwater velocities vary widely depending on local hydrogeological conditions. Usually velocities of groundwater flow tend to change with different formations as well as with depth and can range from negligible to those of turbulent in underground openings in basalts and cavernous limestones. Based on the above equation groundwater flow rate in different media i.e. lithologies for the study area have been computed which shows following trends.

Formation	Hydraulic Gradient (m/m) i	Permeability (m/day) K	Flow Rate (m/day) v
Metamorphics	1:400	0.78 - 61.15	1.95×10^{-3} to 0.15
Bagh sandstone	1:400	1.25 - 11.75	3.12×10^{-3} to 0.03
Deccan Trap (Basalt)	1:200	4.89 - 12.60	0.02 to 0.06
Alluvium	1:600	15.58 -277.47	0.02 to 0.46

AQUIFER CHARACTERISTICS

Parameters of groundwater flow to wells are of prime importance. Quantitative data on hydraulic characteristics of aquifers including transmissivity, storativity, and boundary conditions are essential for the understanding and solution of aquifer problems and the proper evaluation and utilization of groundwater resources. Field tests (pump test) provide the most reliable method of obtaining these parameters.

PUMP TEST

For determining the hydraulic properties of the various aquifer systems of study area selection of appropriate test wells were made. As such pumps tests have to be carried out for a long duration and require team efforts. Wherever it was possible 180 minutes' durations pumping out and recuperation tests were carried out.

Due to several constraints in conducting these test, the author could conduct only 11 pump tests in openwells. Few tubewell records and pumping out test results (for both step drawdown test and Aquifer Performance Test) conducted by GWRDC have been collected, evaluated for the purposes of augmentation.

In all 28 pump test results have been evaluated, out of it 15 pump test results are from tube wells and rest 13 belong to open wells. 8 numbers of test results have been collected from the villages bordering the study area in the lower reaches of the basin (Fig.6.8).

The pump test conducted in openwells in hard rock area are influenced by delayed yield i.e. during pumping test as the water table is lowered, gravity drainage of water from the unsaturated zone proceeds at a variable rate. (Fig.6. 9). Therefore the observed drawdown may give erroneous results. Wherever it is noticed that the observed drawdown exceeds 25% of the saturated thickness it has been duly corrected by applying correction factor derived by Jacob (1940)

$$S' = s - \frac{s^2}{2M} \text{ .... (For unconfined aquifer)}$$

where :

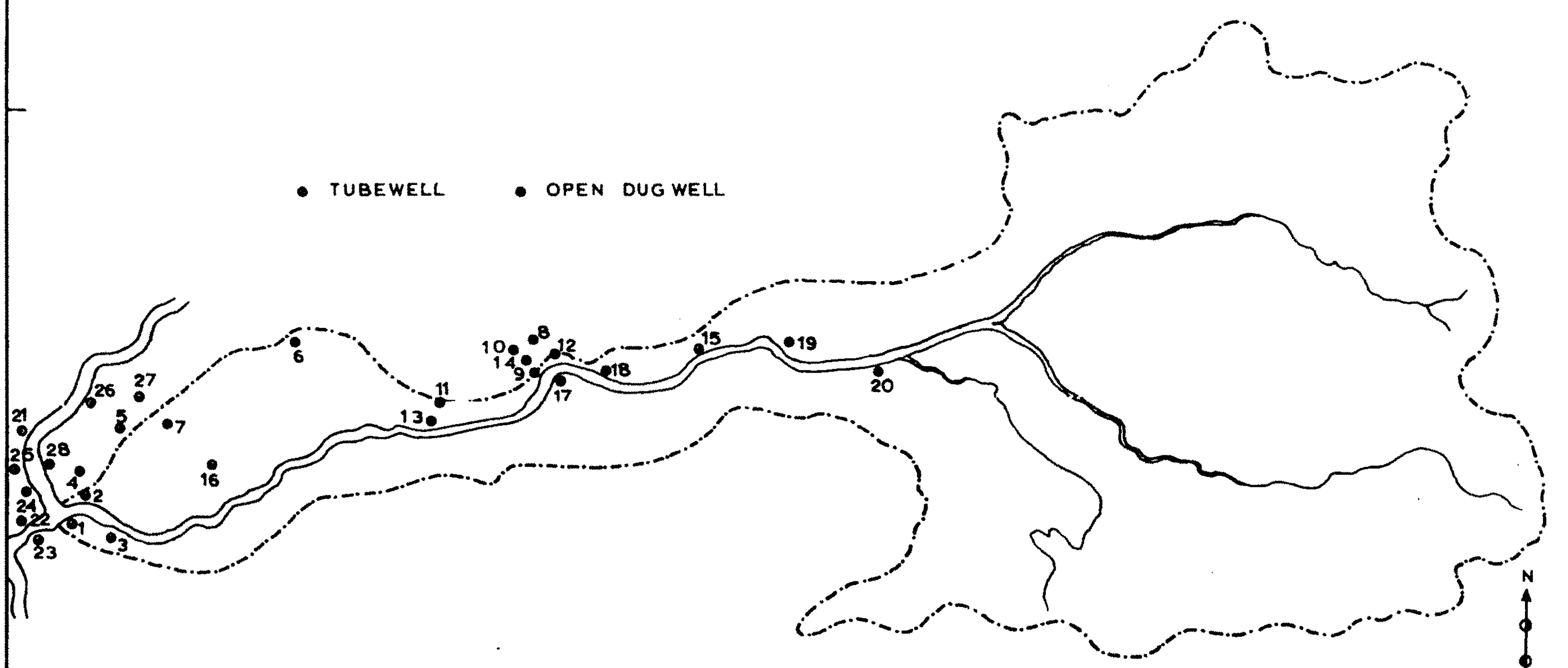
s = measured drawdown

M = Saturated thickness of the aquifer prior to pumping, and

S' = corrected drawdown

The drawdown (S') versus time curves have been plotted and interpretated with the help of Theis-Boulton's type curves for delayed yield. A match point is selected on the best fitted curve. Well function's W (Uay, $^r/_M$) and $^1/U_a$ are

FIG. 6.8



PUMP TEST LOCATIONS IN THE STUDY AREA

SCALE 1 : 350'000

73°30' (For village name refer Table 6.1) 74°15'

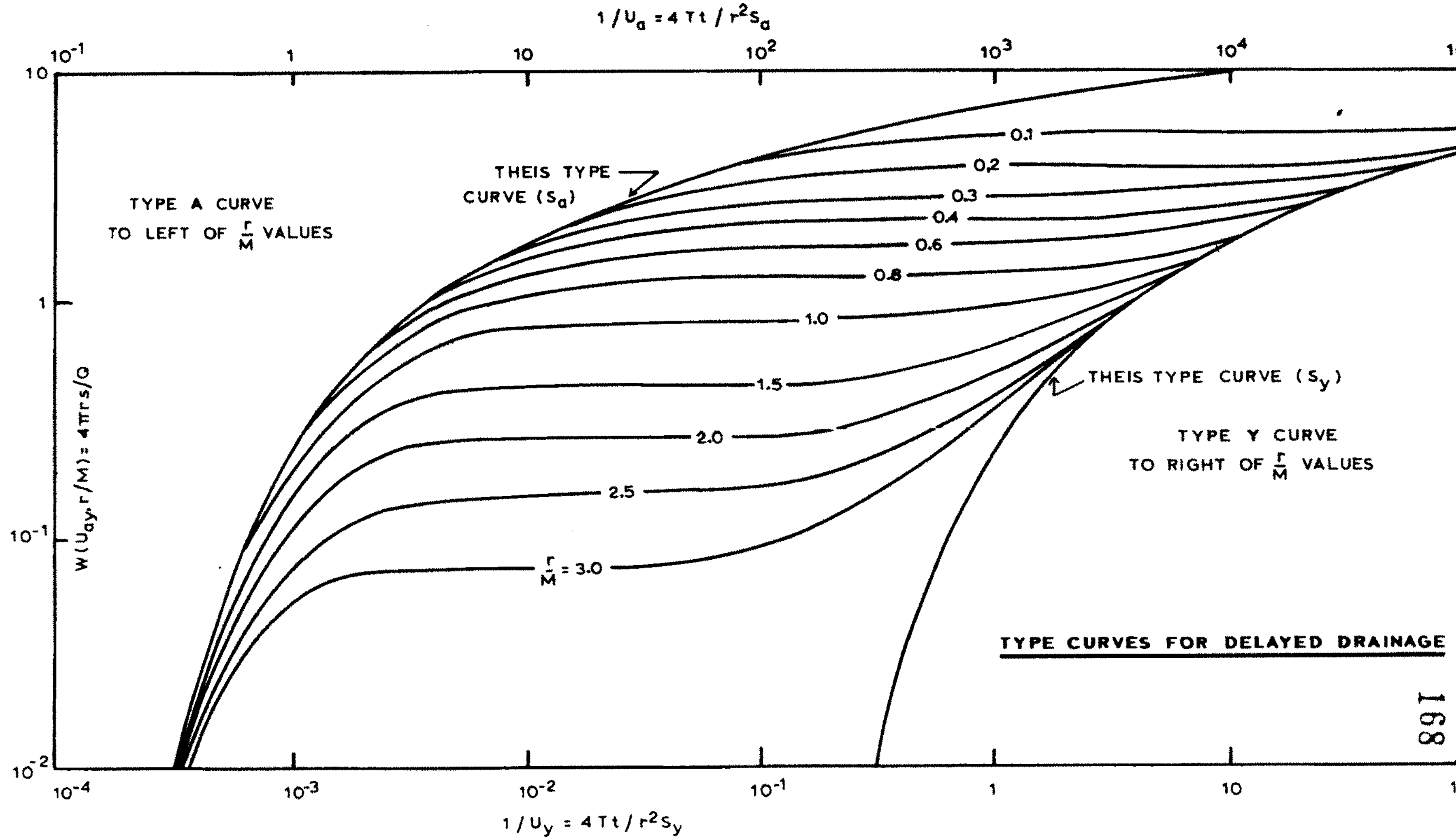

1 / U_a = 4 T t / r^2 S_a
10^-1
1
10
10^2
10^3
10^4
10^5
10
1
10^-1
10^-2
W(U_ay, r/M) = 4πTs/Q
TYPE A CURVE
TO LEFT OF r/M VALUES
THEIS TYPE
CURVE (S_a)
0.1
0.2
0.3
0.4
0.6
0.8
1.0
1.5
2.0
2.5
r/M = 3.0
THEIS TYPE CURVE (S_y)
TYPE Y CURVE
TO RIGHT OF r/M VALUES
TYPE CURVES FOR DELAYED DRAINAGE
10^-4
10^-3
10^-2
10^-1
1
10
10^2
1 / U_y = 4 T t / r^2 S_y

FIG. 6.9

noted for calculating the transmissivity (T)and storage co-efficient (S) by these formulae

$$T = \frac{Q}{U.\pi.s} \times W\ (U_{ay},\ r/M)$$

$$S = \frac{4.T.t.}{r^2} \times \frac{1}{Ua}$$

The computed results of Transmissivity and Storage Co-efficient range in different formations of the study area are as follow.

Formation	Coefficient of Transmissivity (T) m^2/day	Storage Co-efficient (S)	Permeability Coefficient (K) m/day
Alluvium	189 - 4716	0.0463 to 4.54×10^{-4}	15.58 to 277.47
Basalt	42 - 78	0.1337 to 0.2860	04.89 to 12.60
Sandstone	13 - 50	0.1237 to 0.1347	01.25 to 11.75
Metamorphics	07 - 121	0.0484 to 0.4472	00.78 to 61.00

Details of the aquifer parameters are given in the table 6.3.

The drawdown v/s time curves with their respective match points are annexed as (Annexure VI.1).

GWRDC's conducted pump test in alluvium area of lower basin the left out parameter i.e. storage coefficient (s), author has calculated the values by adopting the equation

$$S = 3 \times 10^{-6}.b \quad .....(\text{Todd, eq.2.10,pp.46})$$

States that the storage coefficient normally varies directly with aquifer thickness, which enables the rule-of-thumb relationship where 'b' is the saturated thickness in metres.

EVALUATION

Analysis of aquifer parameters viz. Coefficients of transmissivity permeability and specific capacity reveal that these parameters shows increasing trend from east to west i.e. upper segment of the basin to lower. The lithology and geomorphology have played a significant role in controlling these parameters. The wells located in hard rock area especially in basalt shows highest range of fluctuation while the wells located in alluvium is relatively low. Water level fluctuations are directly related with the annual variations in the rainfall.

Lithologically sandstones proved as the poorest aquifer and alluvium most potential one.