

**WATER TABLE BEHAVIOUR AT TAWA COMMAND  
AREA - A CASE STUDY OF POWARKHEDA**

**THESIS**

**Submitted in Partial fulfilment of  
the requirements for the Degree of**

**MASTER OF TECHNOLOGY**

**IN**

**AGRICULTURAL ENGINEERING  
(Soil and Water Engineering)**



**By**

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*Dedicated*  
to  
*My Parents*

CERTIFICATE I



This is to certify that the thesis entitled "WATER TABLE BEHAVIOUR AT TAWA COMMAND AREA - A CASE STUDY OF POWERKHEDA" submitted in partial fulfilment of the requirements for the degree "MASTER OF TECHNOLOGY IN AGRICULTURAL ENGINEERING" of Jawaharlal Nehru Agricultural University, Jabalpur, is a record of the bonafide research work carried out by Mr. SYED NAVED NAQVI under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

  
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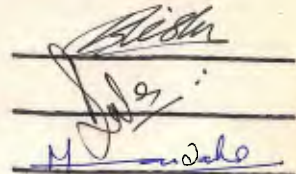
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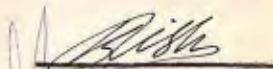
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EXTERNAL EXAMINER

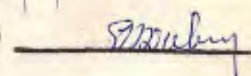
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*Naved*

( SYED NAVED NAQVI )

Jabalpur

July, 1987.

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## LIST OF ABBREVIATIONS

Agric.	- Agricultural
ASAE	- American Society of Agricultural Engineers
ASCE	- American Society of Civil Engineers
ABIP	- Central Board of Irrigation and Power
CHAP	- Chapter
cm.	- Centimetre
Colo.	- Colorado
Div.	- Division
Drain	- Drainage
Engng.	- Engineering
Eqn.	- Equation
Fig.	- Figure
ha.	- Hectare
Hydraul.	- Hydraulics
Hydrol.	- Hydrology
I.I.T.	- Indian Institute of Technology
Inc.	- Incorporated
Irrig.	- Irrigation
ISAE	- Indian Society of Agricultural Engineers
J.	- Journal
J.N.K.V.V.	- Jawaharlal Nehru Krishi Vishwa Vidyalaya
Km.	- Kilometre

LBC	- Left Bank canal
m.	- Metre
MCM	- Million Cubic Metre
mm.	- Millimetre
M.P.	- Madhya Pradesh
M.S.L.	- Mean Sea Level
R.B.C.	- Right Bank Canal
Res.	- Research
Resour.	- Resources
SMW	- Standard Meteorological Week.
Sq.	- Square
U.S.A.	- United States of America
Vol.	- Volume
W.B.	- West Bengal
ZARS	- Zonal Agricultural Research Station.

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CHAPTER - (I)

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INTRODUCTION

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I N T R O D U C T I O N :  
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The world is full of natural resources. The nature has provided so many things for the benefit of human beings. Now, it depends upon the users, the way in which they utilize it. Out of all natural resources, land, water, air and sunshine are so important that no life can exist without these. The proper utilization of water and land can economically make the country very rich. The land resources are fixed and therefore it is important to emphasize on the proper utilization of water for the development of nation. The downfall of the great nations coincided with deterioration of soil and water management and conservation practices. Even in our own country, unwise exploitation and misuse has badly damaged some soils and has called our attention to the need for stringent measures to conserve and improve this valuable resource.

We have been harvesting water through big reservoirs in one watershed and conveying it to another watershed through canals. Transportation of water beyond natural boundaries has created imbalances in natural drainage. Local disturbances have also been caused through physical structures obstructing

existing waterways. Therefore, our post harvest technology of water use needs a review in view of problems created through negligent or bad management of water and land. The mismanagement of post-harvest operations of agricultural produce results in certain temporary losses. The mismanagement of land and water resources in irrigated areas in causing several permanent problems including degradation of environment. The most serious is the rise of the water table, which might result in rendering the land permanently unsuited for agriculture. It is, therefore, important that we devote more attention to the efficient use of irrigation water already available and possibly less on harvesting more water. It takes about ten years to make an irrigation project operational. It would be naturally justified to spend another few years on better utilization of irrigation water and exploitation of full potential efficiently.

The problem of water logging has arisen mainly wherever, either canal irrigation exists or excessive irrigation has been given to the area.

Rainfall is one of the most important natural hydrologic event. It is an essential input in many hydrologic processes. Among the various natural or artificial input-output components of hydrologic cycle, the ground water

levels are directly influenced by the total amount of rainfall received during the year. The ground water levels, whether it be the water table of an unconfined aquifer or the piezometric surface of a confined aquifer, indicates the elevation of atmospheric pressure of the aquifer.

With the view to identify the reasons responsible for water table rise and the problems created thereafter, the study was conducted at Powarkheda, Z.A.R.S., J.N.K.V.V., Jabalpur with the following specific objectives:

- 1/ To study the effect of rainfall on water table behaviour.
- 2/ To study the effect of canal introduction on water table.
- 3/ Prediction of rate of rise of water table to indicate the requirements for preventive measures.

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CHAPTER - (II)

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REVIEW OF LITERATURE

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REVIEW OF LITERATURE :  
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The curiosity of research workers and hydrologists in the natural and stochastic phenomenon led them through different studies on it. This chapter deals with some critical comments, analysis and results obtained by several investigators on some such natural hydrologic events. These are on rainfall, water table fluctuation in open wells and observation wells, the effect of canal flow on rise of water table and the proper use of these resources to meet water needs of crop.

## 2.1 WATER TABLE BEHAVIOUR :-

Water table is a continuous random variable. It varies not only with time but also with the external environmental influences. The various research workers studied the water table behaviour and presented their comments as below:

Russel (1945) presented the methodology to predict the water table behaviour. He utilized the analogy of pore

spaces capable of holding water and resulting into saturation. The method suggests the laboratory determination of pore space of the soil rock from the same locality to a depth of 90 cm. The laboratory experiments of adding water to this soil will be a true representative of what is likely to happen in the field.

Hore and Kidder (1954) found that water levels in small perforated cased wells lagged behind those in larger diameter wells. They used 2 in, and 3/8 - in. diameter wells in their study at Michigan.

Todd (1959) found that the change in ground water levels can be due to natural or artificial means. The changes in external loads induce variations in ground water levels.

- (i) **Secular and seasonal effect:-** Secular variations are those extending over periods of several years or more. These are commonly produced by alternating series of wet, dry years in which rainfall is above or below the mean.
- (ii) **Stream flow effects:-** These effects are observed where a stream channel is in contact with an unconfined aquifer. Water may flow from the stream into the ground or the reverse, depending upon the relative water level. An influent stream supplies water to aquifers; an effluent stream receives

water from the aquifer.

- (iii) Evaporation effect:- Unconfined aquifers with water table near ground surface frequently exhibit fluctuations which can be ascribed to evaporation and/or transpiration. Both processes cause the release of ground water into the atmosphere and both are highly correlated with temperature. Results show that evaporation is significant for water table one meter or more below the ground surface.
- (iv) Atmospheric Pressure Effect:- Changes in atmospheric pressure have no effect on water tables but do produce sizable fluctuations in wells penetrating confined aquifers. Decrease in atmospheric pressure causes increase in water level and conversely.
- (v) Tidal effects:- In coastal aquifers in contact with the ocean, sinusoidal fluctuations of ground water levels occur in response to tides.

Benz et al. (1963) conducted a study to evaluate the comparative sensitivity and cost of large and small diameter wells. They found that small wells in fine textured soils gave a better estimate of water table and were more responsive to influences causing fluctuations. Both small and large diameter wells have their own peculiar advantages and disadvantages depending upon the primary purposes of the well. However, it is more economical to install small diameter wells.

Orsborn (1966) showed that the net effect of all the factors affecting storage volume of a ground water reservoir can be evaluated in terms of the annual maximum and minimum levels of its piezometric surface. The maximums and minimums as well as their differences were found to exhibit normal probability distribution. He showed that co-relation between the maximum and minimum levels in a particular observation well can be applied to other observation wells in the same aquifer or to observation wells in other aquifers of similar physical characteristics and with annual piezometric declines of comparable magnitude.

Walten (1970) studied the water table fluctuations. According to him, the fluctuation ranges from few centimeters to few meters in a relatively small time. This depends upon the climate and the crop growing season.

Holbo, Harr and Hyde (1975) designed an electronic measuring and recording system to make periodic measurements of water levels simultaneously in the sixteen small diameter piezometers.

Mishra (1982) found that the fourth harmonic of the Fourier's series can represent the water table variation during different months of the year. The equation is of the form,



Ghosh et al. (1984) conducted a water table survey in tea estates located in Brahmaputra valley with a view to obtain information on the behaviour of water table in the monsoon months, collecting other diagnostic informations and suggesting suitable field drain spacing to control water table. The water table fluctuations in the tea areas are governed by the channel levels whether it is a main drain or valley through which drain discharges are carried to recipient river or stream.

Sharma et al. (1987) studied the water table fluctuations in Nainital Tarai and at Bhabar (U.P.). They observed that water table is rising in most of Tarai belt. While during 1975 to 1982 it has lowering trend in Bhabar belt. The maximum rise of water table of 1.5 to 2 m. occurred in Kashipur area, in pre-monsoon period. In other areas of Tarai belt, the rise has been in the range of 0.5 to 1.5 m. In Gularbhoj and Nanakmatta area, fall upto a maximum of 0.5 m. was noted. They have also proposed a water table prediction model which is found to be quite suitable for field application.

## 2.2 RAINFALL AND WATER TABLE :-

Rainfall is one of the most important input in several hydrologic processes. It varies not only with time but with space also. Based on the heterogeneous nature of

the soil, the water table changes are different in different area even if the magnitude of rainfall is constant. Several investigators studied the response of rainfall events on the water table and presented their critical comments in the following paragraphs.

Fischel (1956) has studied the variation (short and long term) in water table at San Bernardino Valley, California and found that these fluctuations are the results of recharge from the rainfall, irrigation and discharge from pumping. The magnitude of fluctuation depends on quantities of water recharged or discharged.

Todd (1956) discussed the factors causing fluctuations in ground water levels. Apart from rainfall, irrigation and pumping, the evaporation, tides, tides, atmospheric pressure and earthquake are borne in part by the ground water and confined aquifer which affect the piezometric levels.

Van Schilfhaarde (1965) presented an approach that attempts to take into account the probability distribution of precipitation. Daily water table heights can be calculated from the daily input of meteorological data and soil moisture status. The equation derived from a steady state solution based on potential theory, can be stated

as follows -

$$Y_N = (Y_{N-1} + (A/f) (e^{1/A} - 1) P_N) e^{-1/A}$$

$$A = fFC/SK$$

Where,

$Y_N$  = Water table height above the tile axis mid-way between tile lines at the end of the  $N^{\text{th}}$  time period.

$f$  = drainable pore space.

$P_N$  = net accretion during the  $N^{\text{th}}$  time period.

$F$  = an infinite series defined by Toksoz and Kirkham (1961), which is a function of drain diameter, spacing and depth of an impermeable layer below the drain axis.

$C$  = the ratio of the average flow between the drains to the flux mid way between the drains.

$S$  = drain spacing.

$K$  = hydraulic conductivity.

Boersma (1967) analysed the water table data so as to derive the information for the prediction of water table fluctuations, when only the amount of rainfall is known. The position of the water table is expressed by an equation when surface run off and lateral flow are not taking place -

$$h_n = h_{n-1} + 100 \frac{qr}{r} - 100 \frac{P}{S}$$

Where, 'h' is the position of the water table (inches), n is the day number, r is the pore space drained during a decline of Water table (per-cent), q is the deep seepage rate (in per day) and S is the pore space available for storage (per cent). The deep seepage rates can be determined from the rate of decline of water table during periods when the rainfall does not affect these elevations by using following equation -

$$q = \frac{d \times r}{100}$$

Where, q is the seepage rate, d is the rate of water table decline (in per day).

Rennolls (1980) used first order autoregressive model to describe the response of the Water level in a bore hole to a series of rainfall events. The parameter of the model were obtained by maximum likelihood estimates, and by ordinary least square method.

Mishra (1982) studied the effect of rainfall on water table of open wells. He found that the water table does not rise suddenly with the rainfall but these can be correlated by some time lag of 2 to 3 weeks.

### 2.3 EFFECT OF RAINFALL AND CANAL WATER LEVEL ON THE WATER TABLE OF OPEN WELLS :-

In addition to rainfall events, water table also varies with the recharge obtained from the canal water level and other surface water sources namely streams and rivers. The most important cause for the rise in water level is the artificial application of water to the soil by means of irrigation. The problem is easily intensified, yielding water logging and drainage problems, particularly in the areas where the canal irrigation exists.

Agrawal and Malik (1984) studied the water table behaviour of Haryana State by dividing it into two zones- one the north-eastern part having good quality ground water and the other in central and south-western region with brackish ground water. They found that the average annual rise of water table ranged from 8 to 68 cm. after the introduction of canal in the central and south-western region while it declines from 10 to 15 cm. per year in the good water quality region. The rise in water table of central south-western region was mainly due to the very limited exploitation of ground water and due to rainfall and canal water levels.

Samantrai, S.K. et al. (1987) conducted research on the determination of different sources and their extent

of contribution to rise in ground water table in Hirakund command area of Orissa. Their study involved determining and analysing the fluctuation of ground water level at four places, i.e. near canal, irrigated area, uncultivated area and dry farming area during the year. They found that ground water remains within the safe limit for field crops in areas neaby canal, dry farming areas and uncultivated area except the irrigated tract. Therefore, pre\_gence of high water table in irrigated area may cause failure of crops like mustard and til during the Rabi season. However, the ground water in irrigated area can safely be used for irrigating the Rabi crops.

Sondhi, S.K. et al. (1987) assessed the ground water resources of a canal command area at Mahi Right Bank Canal (MRBC) for the period 1976-77 to 1977-80. They have quantified the different components of ground water recharge using ground water recharge equation and water balance equation. The study revealed that the average annual recharge to ground water basin during the above period was of the order of 1260 MCM. Out of this, a quantity of 500 MCM contribute towards the increase of the ground water storage. The quivalent rise in the water table over the gross command areas amounts to 1.14 m. In addition, about 47 per cent of the recharge goes as subsurface out-flow from the area.

#### 2.4 WATER LOGGING PROBLEMS AND REMEDIAL MEASURES :-

The air, water, nutrients and other factors influencing the soil health must be in balanced state. The excess of water in the area creates unfavourable conditions for plant growth. The preventive measures must be based on the sound soil i.e. the sound with regards to its capacity to pass on to animals and men with essential nutrients. The British Medical Association has realised the vital correlation in the soil and health of any living system, plants or animals (Justine Glass 1964).

The poor health of the soil is reflected in terms of not only the plant growth but also with the health of the human beings of the affected area. The plant health depends upon the light, mechanical support, heat, air, water and nutrients. With the exception of light, the soil is an agent in supplying either wholly or in part all of the above. The plant growth is dependent on the favourable conditions of these factors and if any one of them is out of balance with others, can reduce or even entirely prevent the growth of plants (Buckman and Brady 1971).

The following investigators have discussed about the problems which arise due to excess of water in the area and their remedial measures to check the problem.

Anjaneyulu (1972) carried out a study on the reclamation of water logged soils in Rajasthan by way of drainage improvements and found that the soils reclaimed in this way ensure good returns from the first year. He observed that the saline-alkali soils responded very well to suit surface drainage, soil improvement with addition to gypsum through bores and spreading of mulches and sand combined with organic matter at 50 Kg/ha.

Dhruv narayana and Gupta (1972) suggested surface drainage to control the problem of saline-alkali soils. They stressed on 3 tier system of surface drainage along with dug out ponds to control the quality of stored water. The system creates the conditions for better plant growth.

Gulati and Agrawal (1972) presented a case study of drainage project planning in Ludhiana (Punjab). The paper discusses about the investigations and offers a procedural approach of planning under varying problems of water logging, alkalinity, and salinity.

Kumar and Arya (1972) presented a comprehensive study on research needs for combating water logging. The paper points out the needs for determining the causes of water logging, the degree of relief, management, and reclamation of water logged lands.

Lanka and Padhi (1972) have suggested the rational approach of canal operation to reduce water logging through gradual recession of water table and suggested that multiple cropping should be practised in order to attain the highest project efficiency, and optimum production. They have compared normal irrigation with the traditional crops and the rational irrigation through multiple cropping. They opined that such practice not only improves the project efficiency but also the nutritional requirements of the community.

Mehta et al (1972) studied the effect of pumping and surface drainage to control water table, waterlogging, and salinity conditions for deep black cotton soils. The studies were carried out at college of Agriculture, Navsari, Gujarat on 192 ha. of lowlying area through a system of surface drains and pumping of wells.

The above system helped the cultivation of crops like cotton, castor, bajra, soybean, sunflowers, mustered and vegetables. The treatment also helps the farmers of command area to take the crops all the year round.

Morchan and Rathinam (1972) have suggested seepage control measures and water management to improve efficiency of irrigation and surface drainage for controlling

ground water in Tamil Nadu. They indicated benefits of drainage. They stressed on the combined efforts of agronomists, engineers and soil scientists to solve the problem.

Nagrajan (1972) presented an approach to solve the drainage problem of Cauvery delta of Tamil Nadu. He suggested diversion of upland drainage to relieve drainage conjection in the lower regions. A detailed master plan developed by him deals with the drainage problems which takes into account the several alternatives.

Pandya (1972) carried out studies on 523 open wells and 700 piezometers to analyse the cause of water logging in Chambal command of Madhya Pradesh. He presented a method to identify water logged areas alongwith some remedial measures to overcome the problem.

Paul and Pandey (1972) focussed on the measures to check water logging through underground water conveyance system. They suggested that the high initial cost system can be easily justified by the amount of water and the area saved. The system also offers the safe movement of machinery and equipment in the area.

Raj and Bapat (1972) investigated the problems of water logging and suggested the measures to be adopted

where the canal irrigation is to be introduced. The drainage scheme discussed in this paper was implemented before canal inception, the first of its kind in Gujrat, proved to be a boon to the cultivators in the area. The scheme improved the waterlogging during pre-irrigation period. The efforts could bring the sizable area under command which otherwise would have been deprived of cultivation.

Singh and Singh (1972) presented a detailed study on the causes and remedies of water logging in Punjab. According to them water logging problem first appeared in 1850 in the state. The realignment of canal and improvement of drainage in the ten years period from 1870 to 1880 brought about a marked lowering of the water table. They also discussed the efficiency of antiwater logging measures like surface drains, canal lining, sub-surface drains, and tube-well pumping for the various parts in Punjab.

Uppal (1972) has discussed the problems of water logging in Punjab and Hariyana. He stressed on water logging and salinity problems in command areas of Punjab. During the period of 20 years i.e. from 1942 to 1962, an area of 16 lakhs ha was affected from the water-logging. He suggested the anti water logging measures like drainage, flood and choe control and showed their effectiveness within

5 years of period. The full control is reported to be achieved within 10 years of time. He recommended the maintenance of water table level below 4 m.

Shakya, et al. (1987) suggested multiple well point system for water logged areas of the south-west Punjab severely affected by sub-surface water logging, and sodicity. In their study, three rows of parallel multiple well point systems, each comprising of eight wells of 6 m. deep and 90 mm. diameter, connected to a 350 m. long suction pipe line of 90 mm. and 110 mm. diameter, had been installed at 70 cm. below ground level in a 12 hectare area of large water logged tract of Punjab. Lower 3 m. portion of each 6 m. deep well consisted of strainers wrapped with nylon wiremesh with 30 mm. thick gravel pack around. Row to row and well to well spacing was kept 100 m. and 50 m. respectively. The well point system had been tested by pumping water continuously for 48 hours. Method of superposition principle was used for computation of draw down at different points which agrees well with the observed values.

## 2.5 HYDROLOGIC MODELS AND ANALYSIS:-

Hydrologic models are mathematical information to simulate natural hydrologic phenomena (Chow, 1964), which are considered as process or as system.

The relationship between different inputs and outputs of environmental and hydrologic variables can be represented by numerical models derived theoretically or by regression methods using statistical techniques.

Standardization should be the rule to as great an extent as is possible, of data, of units, of isolines, scales and other factors which will make the data comparable and eliminate the risks of confusion in the minds of the users. Most data networks and the data themselves have imperfections because of space and time variabilities of elements as well as instrumental and procedural inadequacies. The analyst, is, therefore, required to resort to statistical procedures and conceptual models (Rodda, 1976).

Hydrologic uncertainties can be classified into three types (Tung and Mays, 1981).

- (i) The inherent uncertainty due to the stochastic nature of hydrologic process;
- (ii) The model uncertainty resulting from a limited amount of data available for assessing the true random mechanism of the hydrologic process; and
- (iii) The parameter uncertainty due to an insufficient amount of data from which the parameters in an assumed model are estimated.

The last two types of uncertainties can be definitely avoided by using long term data. Some of the most commonly used hydrological models are presented below:

Wisler and Brater (1959) observed that the length of record of a limited period offers a false picture for long term planning. They quoted the work of Alexandar and Binnies who established that any record falling shorter than 10 years may not be useful for long term planning. They presented a curve giving the average percentage deviation from the true mean with respect to number of years of record (Fig. 2.1). They have shown that the use of 10 years data will yield the mean value which will be having an error more than 10% from the true mean.

Jones et al. (1972) developed a weather model. Weather model consisting of the combined rainfall, temperature, and evaporation models was used to generate 10 years of daily data for comparing the model data with observed data. The data sets were compared by examining averages, lengths of certain sequences and certain individual observations. They used Markov-chain model for calculating the conditional probabilities of any day being wet or dry given that the previous day was either dry or wet. They developed the equations for the conditional probabilities

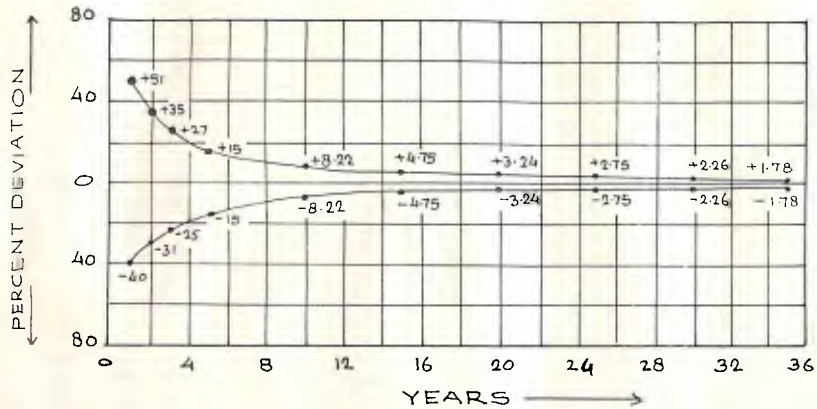


Fig. 2.1 RELATIONSHIP BETWEEN THE NUMBER OF YEARS OF RECORD AND AVERAGE PERCENTAGE OF DEVIATION FROM TRUE MEAN

SOURCE: WISLER, C.O. AND E.F. BRATER (1959) HYDROLOGY FIG.32,P91.  
JOHN WILEY AND SONS

of the day being wet or dry based on the weather of the previous day. The equations are as follows:-

$$P_n(i) = 0.194 + 0.042 W - (6.89) 10^{-3} W^2 \\ + (4.43) 10^{-4} W^3 - (1.35) 10^{-5} W^4 \\ + (1.94) 10^{-7} W^5 - (1.03) 10^{-9} W^6$$

$$P_m(i) = 0.419 + 0.042 W - (8.37) 10^{-3} W^2 \\ + (6.07) 10^{-4} W^3 - (2.02) 10^{-5} W^4 \\ + (3.13) 10^{-7} W^5 + (1.84) 10^{-9} W^6$$

$$P_{nm}(42) = P_n(42) \cdot P_m(42)$$

Where,  $i = W =$  week number of the year.

$P_n(i)$  is the conditional probability that, any day during the  $i^{\text{th}}$  week will be wet; and

$P_m(i)$  is the conditional probability that, any day during the  $i^{\text{th}}$  week will be wet, given that the previous day was dry.

$P_{nm}(42)$  is the probability of a wet-wet sequence occurring during week 42.

Gupta (1972) found that the several processes in hydrology and water resources demonstrate the persistence. For instance, storage in the basin is a measure of the carry over effect which is indicative of persistence

in the stream flow regime. This carry over effect repeats information already obtained from previous measurements.

A statistical measure of the carry over effect is the autocovariance function. If  $X(t)$  is the value of the observed variable at time  $t$ , the sample autocovariance function of lag  $\tau$  is defined by

$$C(\tau) = 1/T \int_0^T [X(t+\tau) - \bar{X}] [X(t) - \bar{X}] dt. \quad \dots(1)$$

in which  $T$  = the length of record;

and  $\bar{X}$  = the computed sample mean.

Equation (1) is general formulation applicable to continuous series. In water resource data systems, discrete time series are a general rule rather than the exception. Accordingly equation (1) can be rearranged as;

$$C(K) = \frac{1}{N-K} \sum_{t=1}^{N-K} [X(t+K) - \bar{X}] [X(t) - \bar{X}] \quad \dots(2)$$

in which  $N$  = number of items which make up the time series; and  $C(K)$  is indicative of how measurements  $K$  time units apart, are correlated. In practice, a normalized equivalent of  $C(K)$  is used which is known as the autocorrelation coefficient and is given by -

$$r(K) = \frac{C(K)}{C(0)} \quad \dots(3)$$

Values of  $r(K)$  near unity are indicative of high persistence effect whereas statistical independence can be inferred by near zero values. Optimal sampling interval should be such that the auto correlation coefficient at the corresponding lag must be statistically indistinguishable from zero.

**Persistence Models :-** In recent years, advances have been made in the development of modeling techniques whose objectives include the simulation of the behaviour of water resource system. If stream flow is thought of as the sum of deterministic and stochastic component, a simple Markov model is formulated by Fiering (1967) can be stated as -

$$X_t = r_1 X_{t-1} + \epsilon_t \quad \dots(4)$$

in which  $X_t$  and  $X_{t-1}$  = the values taken by the variable at time steps of  $t$  and  $t-1$ , respectively; and  $\epsilon_t$  = an independently and identically distributed variable. A slightly more comprehensive model is the second order autoregressive scheme as suggested by Quimpo (1968) and Yevjevich (1971). In general terms the stochastic component of the second order scheme can be stipulated as -

$$X_t = a_1 X_{t-1} + a_2 X_{t-2} + \epsilon_t \quad \dots(5)$$

in which the  $x$  terms and  $\epsilon_t$  are as defined in equation (4) and  $a_1$   $a_2$  are analogous to regression coefficients. The task of formulation calibration and verification of the foregoing models have been the principal concern of Thomas and Fiering (1962), Beard (1967), Butcher, et al. (1969), Devries and Sveum (1970), Gupta and Fordhem (1972), and Qiumpo (1968).

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CHAPTER - (III)

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MATERIALS AND METHODS

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MATERIALS AND METHODS :  
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The rising trends and the rate of rise in water table can be studied with the help of historical data already available. However, the data base and interval between two successive observations will determine the amount of information and conclusions that can be drawn from the existing data.

The present chapter deals with the data collected on various parameters influencing the water table along with the methods used in analysis and interpretation to arrive at the causes of water logging.

### 3.1 Salient Features of the Area

Powarkheda is located in the Hoshangabad district. Archaeologically, historically, and culturally Hoshangabad is one of the most important districts of Madhya Pradesh. The mighty Naramada considered as one of the scared rivers of India, has been its life line since time immemorial. The district lies in the central Naramada valley

and on the north of Satpura plateau. It is between the latitudes of  $21^{\circ}51'$  and  $22^{\circ}38'$  N and the longitudes of  $76^{\circ}46'$  E and  $76^{\circ}42'$  E.

### 3.1.1 Topography

Topography of the district is marked by the plateau and hills of the Satpura in the south all along the length. The remaining half of the district upto the northern boundary is the low plain of the upper Narmada valley. This extends in a narrow strip of about 40 km. in width. The Narmada itself flows alongwith the northern boundary of Hoshangabad leaving to the upper half of the valley on the right bank that lies in Raisen, Sehore and Dewas.

### 3.1.2 River system and Water Resources

Nearly the whole of the district drains into Narmada. The exception is a very small area in the extreme south of Harda, near the village Ratamali its water flows into Tapti, the second major river. Floods area regular feature in the valley but Narmada being an entrenched stream crosses its banks not too frequently.

The Narmada rises from Amarkantak and merges in the Gulf of Combay. The total length of the river is 1290 km. The location of the district alongwith its water sources are shown in Fig.3.1.

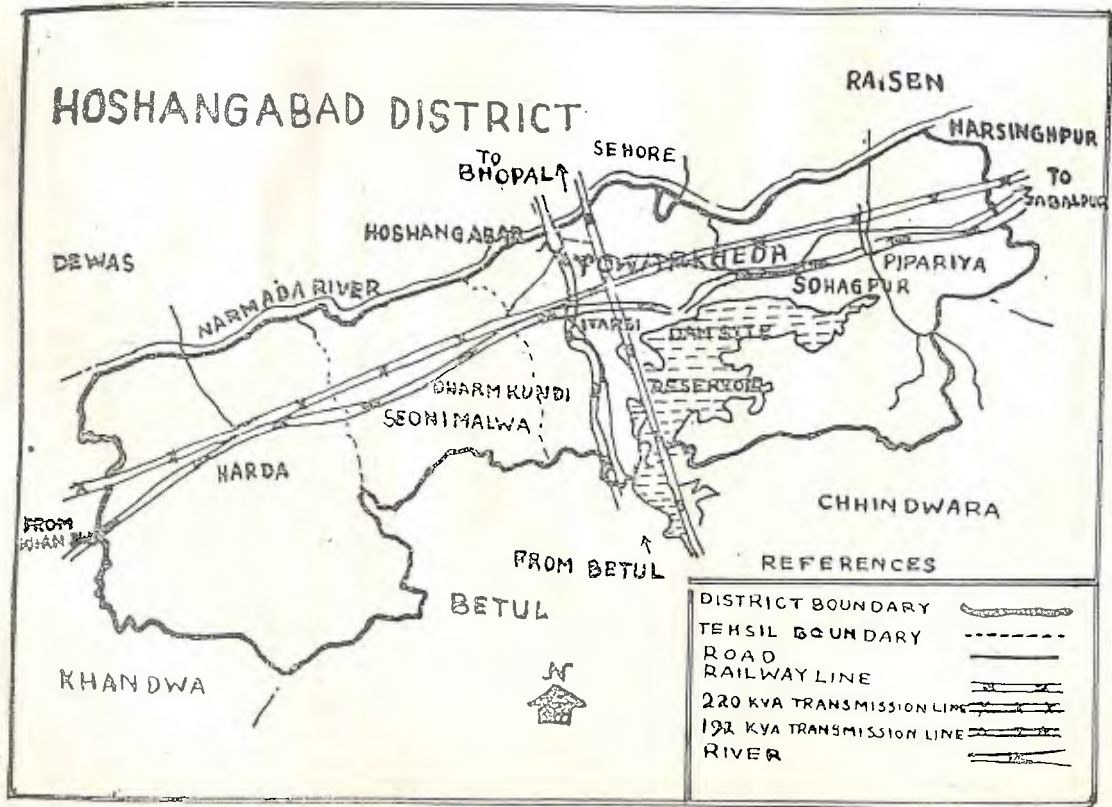


Fig-3.1 WATER RESOURCES AND LOCATION OF HOSHANGABAD DISTRICT

### 3.1.3 Climate

The district has dry climate except during the south-west monsoon season. The year may be divided into three periods. The cold period is from December to February, followed by the hot from March to June, and rain from mid June to mid September.

### 3.1.4 Temperature

May is the hottest month with mean daily maximum temperature  $41.9^{\circ}\text{C}$  and mean daily minimum temperature  $27.3^{\circ}\text{C}$ . December-January form the coldest part of the year with mean daily maximum  $26.5^{\circ}\text{C}$  and minimum  $12.2^{\circ}\text{C}$ . The highest maximum temperature recorded at Hoshangabad was  $46.1^{\circ}\text{C}$  on 4 days during 1954, while the lowest was  $3.3^{\circ}\text{C}$  recorded in 1935 on January 15.

### 3.1.5 Humidity

During the south-west monsoon the relative humidity is high, remarkably at Pachmarhi, which decreases in the post monsoon season, rest of the year atmosphere is very dry.

### 3.1.6 Rainfall

The annual normal rainfall is 1294.5 mm. except for the hilly area which get <sup>much</sup> ~~some~~ more. The rainfall generally increases from South-West towards the North-East. About 92%

annual rainfall is received during South-West monsoon, July being the wettest month. On an average there are 53 rainy days.

### 3.1.7 Winds

Winds are generally light during the South-West monsoon season, and are mainly from South-West or west. In the post monsoon and cold seasons, the winds are from North-East or East.

### 3.2 Location of the Site and its General Description

The study was carried out at Powarkheda village of Tawa command area. Powarkheda is located on the Itarsi-Hoshangabad road at a distance of about 11 Km. from Itarsi. It falls in the Hoshangabad district. The Tawa command is in operation since, 1976. The dam constructed on the river Tawa is a tributary of Narmada with the irrigation potential of 3.30 lakhs hectares. The dam is located about 33 km. from Itarsi railway station towards East. Tawa project lies in the Hoshangabad district between the Narmada river in the North and Machak river in the West, Dudhi river in the East and the main Tawa canal in the south and between two mountain ranges of the country, the Vindhya and Satpuras. The location map of Tawa Project area is shown in Fig.3.2.

The altitude varies from 950 ft. to 1100 ft. from M.S.L. The Tawa command area has three agroclimatic zones (Table 3.1).

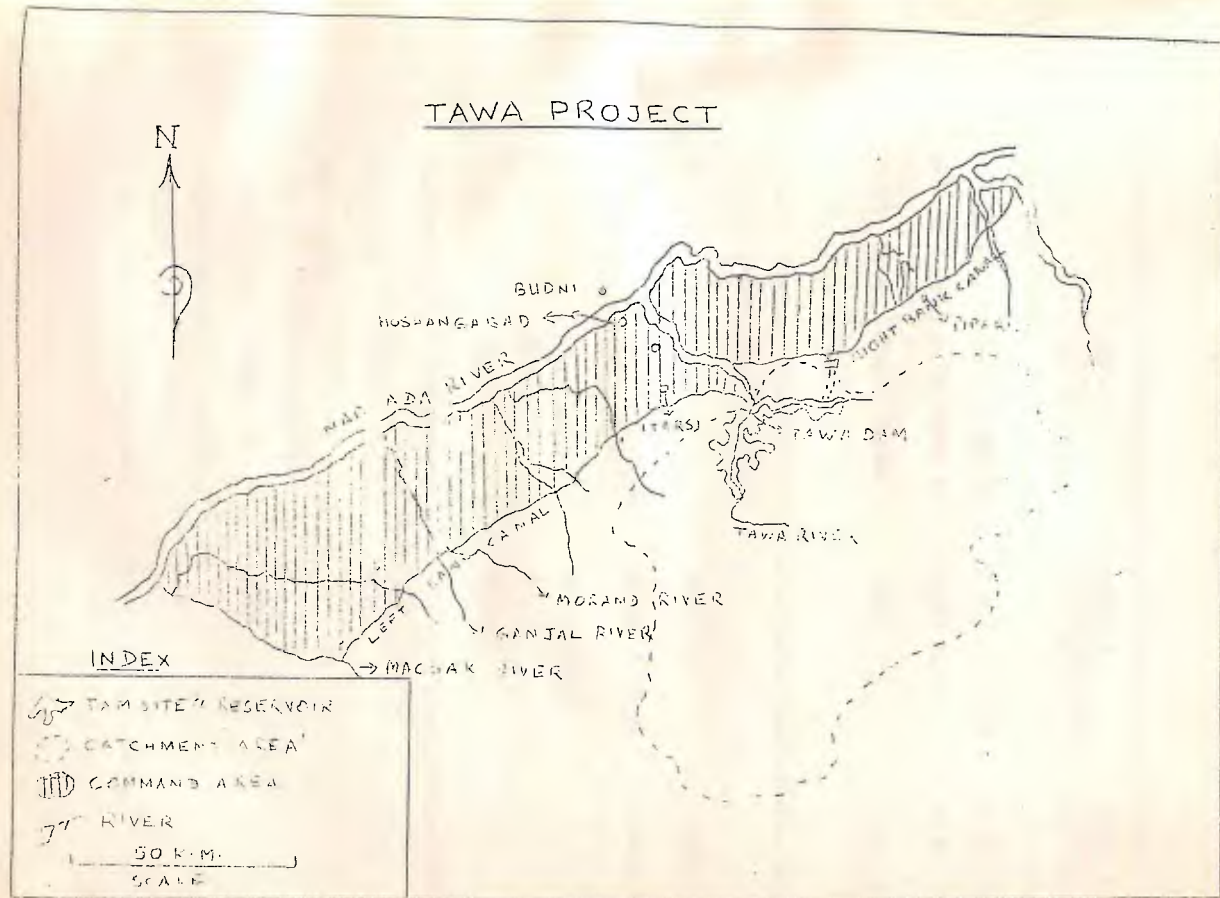


Fig 3.2 LOCATION MAP OF TAWA PROJECT AREA

TABLE 3.1 Agro-climatic zones of Tawa command area.

	Zone A (East of river Tawa)	Zone B (Between Tawa and Ganjal)	Zone C (Between Ganjal and Machak).
Total Area	0.65 Lakh ha	1.69 Lakh ha	1.27 Lakh ha
Command area	0.61 Lakh ha	0.98 Lakh ha	0.88 Lakh ha
Soil types	Sandy Loam Sandy clay	Clay	Clay Loam
Major crops	Horticulture		
Kharif	Soybean	Soybean	Soybean
Rabi	Wheat & Gram	Wheat & Gram	Wheat & Gram
Summer	Vegetables & Moong	Vegetables & Moong	Vegetables & Moong
Cropping intensity	139%	147%	135%
Irrigation Intensity	125%	138%	—

The topography of the area under Tawa command is varying and can be grouped as follows:

Slope grades	Percent area
3% and above	8%
0.5 - 3%	32%
Less than 0.5%	60%



The Tawa irrigation system has a composite masonry and earthen dam down stream under the influence of the rivers Tawa and Denwa.

There are two main canal system - Left Bank canal (LBC) system and Right Bank Canal (RBC) system. The canal net work of LBC is spread in B and C zones and RBC in zone -A. The Powarkheda is located in Zone B. The Z .A.R.S. Powarkheda is surrounded by different villages which have been considered for study purpose. The water table is rising at faster rate in these areas, especially in Pathodi, Kulhamadi, Chandrapura, Powarkheda Basti, Powarkheda farm, and Mimsodiya. All these villages are fed by Hoshangabad distributory. The sufficiently large amount of data available at Tawa pilot project, Powarkheda encouraged to carry out a case study. The Powerkheda farm encircles an area of about 180 ha and has a net work of ten dug wells. The location map of Powerkheda is shown in Fig.3.3. Generally the soils of the area are from deep to very deep, clay to

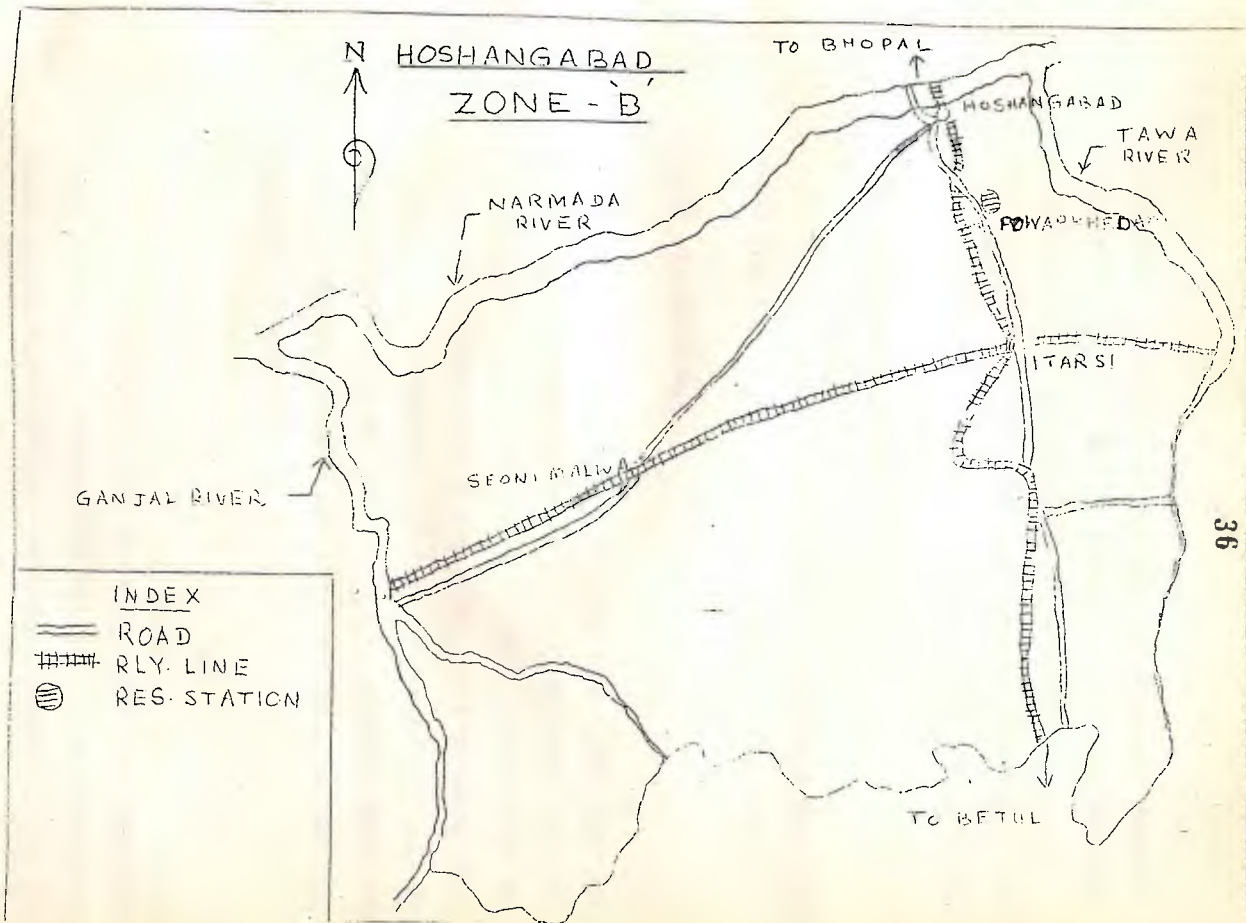


Fig. 3.3 LOCATION MAP OF POWARKHEDA

sandy loam in texture. Major part of the Tawa command area is occupied by the clay soil, with percentage clay varying from 40 to 65%. The clay content is nearly constant in upper horizon and increases with depth. The clay loam and loamy soils are also observed in some parts.

### 3.3 Collection of Data

The data regarding various parameters influencing water table were collected for the purpose of analysis.

#### 3.3.1 Rainfall data

The daily rainfall records were noted with the help of rain gages installed at Zonal Agricultural Research Station, Powarkheda. The daily rainfall records were lumped to form the weekly data for the period of 14 years (1972 to 1985). The cumulative rainfall at the end of each SMW were computed with the help of Weekly rainfall data. The weekly rainfall data for 14 years from 1972 to 1985 are presented in Appendix A.

#### 3.3.2 Water Table Data

The study of open wells was conducted under the ZARS, Powarkheda. Various open wells located at Powarkheda farm, and in the adjoining areas were considered for the study. Water table records were maintained on Weekly basis.

This included the water table records of the wells before and after the introduction of canal irrigation in the area.

The water table data for 4 years from 1972 to 1975 i.e. prior to canal introduction, and 10 years data from 1976 to 1985 after the introduction of canal, were available for the purpose of study. However, the record for 2 years in between these periods was not available.

### 3.3.3 Canal Delivery Schedule Data

The data regarding canal delivery schedule were obtained from the office of the Superintending Engineer, Department of Irrigation, Hoshangabad, Government of Madhya Pradesh. The data on canal delivery schedule were available for the period of 4 years from 1982 to 1985 and were utilized for the purpose of analysis.

### 3.4 Water Table Behaviour

The water table levels in the open wells are recorded at weekly interval. The water table records of the 14 years period from 1972 to 1985 were collected.

The water table behaviour of different open wells for 52 weeks of the year were analysed. The water table depth is plotted on Y axis and corresponding week on the X-axis. The study was done on the weekly water table beha-

viour and seasonal behaviour of water table before and after the introduction of canal.

### 3.5 Statistical Analysis of Water Table Data

The different values namely  $x_1$ ,  $x_n$ ,  $u_1$ ,  $u_n$  and R or A were noted for all the open wells for different years from the watertable fluctuation curves plotted above. A hypothetical picture showing these values is presented in Fig.3.4. The values of  $x_1$ ,  $x_n$ ,  $u_1$ ,  $u_n$  and R are shown in Appendix B.

#### 3.5.1 Statistical Parameters

The different statistical parameters such as mean ( $\bar{x}$ ), standard deviation ( $s$ ), and coefficient of variation ( $C_v$ ), corresponding to above values were determined as follows:-

Mean, ( $\bar{x}$ ) of the distribution is given by

$$\bar{x} = \frac{1}{N} \sum_{i=1}^N x_i \quad \dots(3.1)$$

The best estimate of the standard deviation of the population from which the sample has been drawn is denoted by  $S$ , and is given by

$$s = \sqrt{\frac{1}{N-1} \sum (x_i - \bar{x})^2} \quad \dots(3.2)$$

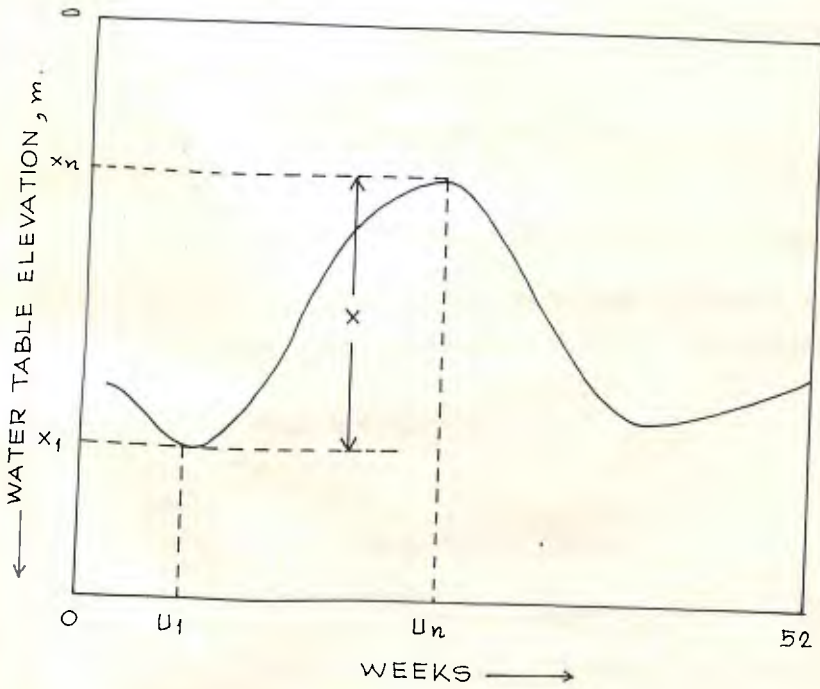


Fig. 3.4 HYPOTHETICAL PICTURE SHOWING WATER TABLE FLUCTUATION

Standard deviation divided by the mean is called coefficient of variation ( $C_v$ ),

$$C_v = \frac{S}{\bar{x}}$$

Coefficient of variation is also expressed in percentage

$$\text{i.e. } C_v = \frac{S}{\bar{x}} \times 100 \quad \dots(3.3)$$

$X_i$  are the values of variable,  $i = 1, 2, \dots, N$ .

Range (R) is defined as the difference between the largest and the smallest value of observations,

$$\text{i.e. } R = X_n - X_1 \quad \dots(3.4)$$

Where,

$X_n$  is the largest value.

$X_1$  is the lowest value.

Thus, the mean ( $\bar{x}$ ), standard deviation (S), Coefficient of variation ( $C_v$ ) and Range R were carefully evaluated using equations 3.1, 3.2, 3.3, and 3.4 respectively.

### 3.5.2 Polynomial Regression

Curvilinear data that do not approach linear

relationship under either a log or  $\log$ -semilog transformations can be fitted to a polynomial of the form:

$$Y = a + bx + cx^2 + dx^3 + \dots + X mx^{n-1} \quad \dots(3.5)$$

using as many terms as necessary to obtain a satisfactory fit.

The unknown coefficients  $a, b, c, d$ , etc. can be determined by solving the normal equations,

$$\begin{aligned} an + b \sum x + c \sum x^2 + d \sum x^3 + \dots &= \sum Y \\ a \sum x + b \sum x^2 + c \sum x^3 + d \sum x^4 + \dots &= \sum x Y \\ a \sum x^2 + b \sum x^3 + c \sum x^4 + d \sum x^5 + \dots &= \sum x^2 Y \\ a \sum x^3 + b \sum x^4 + c \sum x^5 + d \sum x^6 + \dots &= \sum x^3 Y \\ &\dots(3.6) \end{aligned}$$

The above equations can be solved easily by numerical methods such as Gauss elimination or Gauss Jordan elimination methods.



The number of equations and the number of terms to the left of the equal sign must each be equal to the number of coefficients needed, or one more than the degree of the regression equation.

Thus, the polynomials of any degree can be fitted by solving the above normal equations.

It can be easily seen that the linear equation is a special case of polynomial equation.

Putting  $c$  and  $d$  equal to zero, in equation 3.5, we have

$$Y = a + bx \quad \dots(3.7)$$

Which is a well known linear equation.

If only  $d$  is equal to zero, the equation 3.5 reduces to

$$Y = a + bx + cx^2 \quad \dots(3.8)$$

Which is a second degree polynomial.

The corresponding normal equations to be solved can be determined from equation 3.6 by putting  $c$  and  $d$  both equal to zero or only  $d$  equal to zero, as the case may be.

### 3.5.3 Criteria for best fit curve

The best fit curve is decided using the principle of least squares. It states that

- (i) Sum of deviation between observed and estimated value of variable is zero.

$$\text{i.e. } \sum(Y - \hat{Y}) = 0 \quad \dots(3.9)$$

Where,  $Y$  = observed value of the variable and  $\hat{Y}$  is the estimated value of  $y$  from the equation which has been used



to fit the given data i.e. for linear equation  $Y = a + bx$ .

- (ii) Sum of the squares of deviation between observed and estimated value is minimum

$$\text{i.e. } (Y - \hat{Y})^2 \text{ is minimum.} \quad \dots(4.0)$$

Out of several equations fitted to the given observed data, the best fit equation was decided with the help of equation (3.9) and (4.0) with special emphasis on the residual sum squares to be minimum.

### 3.5.4 Measures of Association

Two statistical parameters namely correlation coefficient ( $r$ ) and correlation ratio ( $\tau$ ) are used to determine the degree of association between the variables.

#### 3.5.4.1 Correlation coefficient

It is the measure of association between the two variables which are linearly related. It is mathematically, defined as

$$= \frac{\frac{1}{N} \sum f_1 (x_1 - \bar{x}) (y_1 - \bar{y})}{\sqrt{\frac{1}{N} \sum f_1 (x_1 - \bar{x})^2} \sqrt{\frac{1}{N} \sum f_1 (y_1 - \bar{y})^2}} \quad \dots(4.1)$$

The term in the numerator is known as covariance and is denoted as statistically. The terms in denominator are the standard deviations of variable  $x_1$  ( $\sigma_x$ ) and

$Y_1$  ( $\sigma_y$ ) respectively.  $\bar{X}$  and  $\bar{Y}$  are the means of variable  $x_1$  and  $Y_1$  and  $N$  is the total number of observations.

Thus equation (4.1) can also be written as

$$r = \frac{\mu_{11}}{\sigma_x \cdot \sigma_y}$$

The sign of correlation coefficient is same as that of the covariance term  $\mu_{11}$ . Thus, if the regression coefficients are positive, 'r' is positive and if the regression coefficients are negative r is negative. If  $\mu_{11} = 0$ , the variables are not related by linear relationship. However, they may be related by some curve-linear relation r varies between -1 and +1.

$r = -1$  indicates that the variables are inversely proportional to each other while  $r = +1$  indicates that the variables are directly proportional to each other.

#### 3.5.4.2 Correlation Ratio

Correlation ratio ' $\eta$ ' is the appropriate measure of curve-linear relationship between the two variables.  $\eta$  measures the concentration of points about the curve of best fit.

If regression is linear  $n = r$  otherwise  $n > r$ .  
The correlation ratio of Y on X is given by

$$r_{yx}^2 = 1 - \frac{\sigma_{ey}^2}{\sigma_y^2}$$

Where  $\sigma_{ey}$  is the standard deviation of the residuals i.e. of  $(Y - \hat{Y})$ .

$\sigma_y$  is the standard deviation of Y.

$$\therefore r_{yx} = \sqrt{1 - \frac{\sigma_{ey}^2}{\sigma_y^2}} \quad \dots(4.2)$$

Similarly, for regression curve of x on y

$$r_{xy} = \sqrt{1 - \frac{\sigma_{ex}^2}{\sigma_x^2}} \quad \dots(4.3)$$

The correlation coefficients ( $r$ ), and correlation ratio ( $\eta$ ), for the equations developed were determined using equation (4.1) and equation (4.2) respectively. The years were standardised to a new datum. The year 1972 was considered the base and was assigned zero value. The other years were also denoted by numbers with reference to 1972. Thus  $x = 0$  for 1972,  $x = 1$  for 1973,  $x = 2$  for 1974.....and  $x = 12$  for 1984 and so on and so forth. The relationship between the mean range of water table and the standardised years was developed using in 3.5.2 and 3.5.3.

### 3.5.5 Long Term Variation of Water Table

The long term variation of water table was studied with the help of water table data of four wells  $W_3$ ,  $W_{12}$ ,  $W_{16}$  and  $W_{10}$  using procedure 3.5. The range and coefficient

of variation were evaluated using equation 3.4 and 3.3 respectively.

The behaviour of maxima was studied with the help of water table records of three sample wells namely  $W_{12}$ ,  $W_{14A}$  and  $W_3$  for the 10 years records from 1972 to 1981. The deviation of water table for different wells were obtained for different years with reference to maxima of water table for the preceding year starting from 1972. The deviations were then added without ignoring the signs to know whether the net deviation is positive or negative.

### 3.6 Effect of Rainfall on Water Table

For studying the effect of rainfall on water table fluctuations, the cumulative rainfall at Fowerkheda for the years, 1972 and 1974 and the water table for different open wells namely  $W_3$ ,  $W_{12}$ ,  $W_{14}$  and  $W_{15}$  are plotted against the weeks in the years on X-axis and Y-axis to suitable scales. The years 1972 and 1974 were selected for the study because the complete water table record of  $W_3$ ,  $W_{12}$ ,  $W_{14}$  and  $W_{15}$  were available for this period. These water table records before 1976 indicate the water table mainly effected by rainfall as the canal was not introduced in the area before this period.

The above plot was then divided into different zones based on the steepness of the cumulative rainfall

curve and the corresponding magnitudes of rise in water table were determined for the rainfall occurring in that interval. The study was then conducted with the help of figures and tables so prepared for different rainfall curve zones.

### 3.7 Effect of Rainfall and Canal Water Level on Water Table

The effect of rainfall and canal water level on the water table of open wells at Powarkheda was studied from the water table records of  $W_3$ ,  $W_{12}$ ,  $W_{14}$  and  $W_{15}$  after the canal was introduced in the area. The procedure similar to 3.6 was adopted here also.

In addition, the water table behaviour due to rainfall and canal water level was also studied for some nearby village namely Kulhamadi, Chandrapura, Pathori and Beora with the help of water table records of  $W_8$ ,  $W_9$ ,  $W_{10}$ ,  $W_{11}$ ,  $W_{13}$ ,  $W_{14}$ ,  $W_{29}$ ,  $W_{30}$  for the period of 3 years from 1982 to 1984.

### 3.8 Effect of Canal Levels on the Water Table of Open Wells

The effect of canal water level on the water table of open well was studied with the help of water table data of  $W_{16}$  for which maximum continuous record was available.

The effect of canal water level on water table of open wells can be determined by subtracting the effect of rainfall on water table from the combined effect of rainfall and canal water level on water of open wells. The available water table for 3 years period before introduction of canal and four years data after introduction of canal was used for this purpose. The procedures as described in 3.6 was then adopted for determining the period and magnitude of rainfall in which water table rises. The total rainfall was divided by the interval in which it occurs to know the intensity of rainfall. Similarly, the rate of rise of water table was also determined during the interval for both the records before and after introduction of canal. Since the water table was mainly effected by rainfall before the canal introduction and hence a mathematical relationship was developed between the intensity of rainfall and the rate of water table rise, using the principle of least square (3.5.3) and curve fitting technique (3.5.2). The correlation coefficient (  $r$  ) or correlation ratio (  $\eta$  ) pertaining to the relationship was calculated using equation 4.1 and 4.3.

The period during which the canal operated was also noted and the canal operation was denoted by 1 otherwise 0. Thus, zero indicates that the canal does not

run during that specified period. The data was critically examined to see, if there was any rainfall in the period in which canal runs.

The rise in water level was thus divided into three section,

- (i) Rise due to rainfall,
- (ii) Rise due to canal level, &
- (iii) Rise due to both rainfall and canal level.

The effect due to the above three were separated and a relationship between intensity of rainfall and rate of water table rise was developed, as explained above for the data after canal introduction.

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## CHAPTER - (IV)

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### RESULTS AND DISCUSSION

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RESULTS AND DISCUSSION :  
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The present chapter deals with the results obtained from the studies carried out at Research farm, Powarkheda. The attempt has been made to present the results in the graphical form so as to offer the visual image of the ground water. Instead of quantification the efforts are confined to determine the extent of problem, its duration, and area where it exists. The results obtained from the study of water table before and after the introduction of canal with respect to the rainfall and canal water level are presented under various heads.

#### 4.1 Water Table Behaviour

The water table is a continuous random variable. It varies in a periodic fashion and attains each and every value, howsoever small, within the interval before attaining any positive integral values. Thus, the water table attained by a well will be from 0 to  $d$ , where  $d$  is the depth of the well. The water level above the well surface

will naturally be overflow.

The water table is governed by several factors such as water used in irrigation pumping, domestic purposes, outflow from the area, inflow into the well from some other areas, rainfall, seepage from the canals. The evaporation does not affect the water table as long as it is below 3 m depth. The evaporation becomes an important factor when the water table is less than or equal to 3 m.

Thus, water table varies not only with time but also with different input and output factors.

The water table generally depletes in the dry season from January to May and September onwards, provided it is not being recharged from surface sources such as rivers, ponds and canals etc. This point is more clear when figures 4.1 and 4.2 are viewed critically. It is also clear that the water tables for most of the wells have attained the peak in 35th and 34th week respectively during 1972 and 1974.

With the introduction of canal in 1976, the water table behaviour changed considerably. Instead of single well defined peaks, more than one peaks were observed (Fig.4.3 and 4.4).

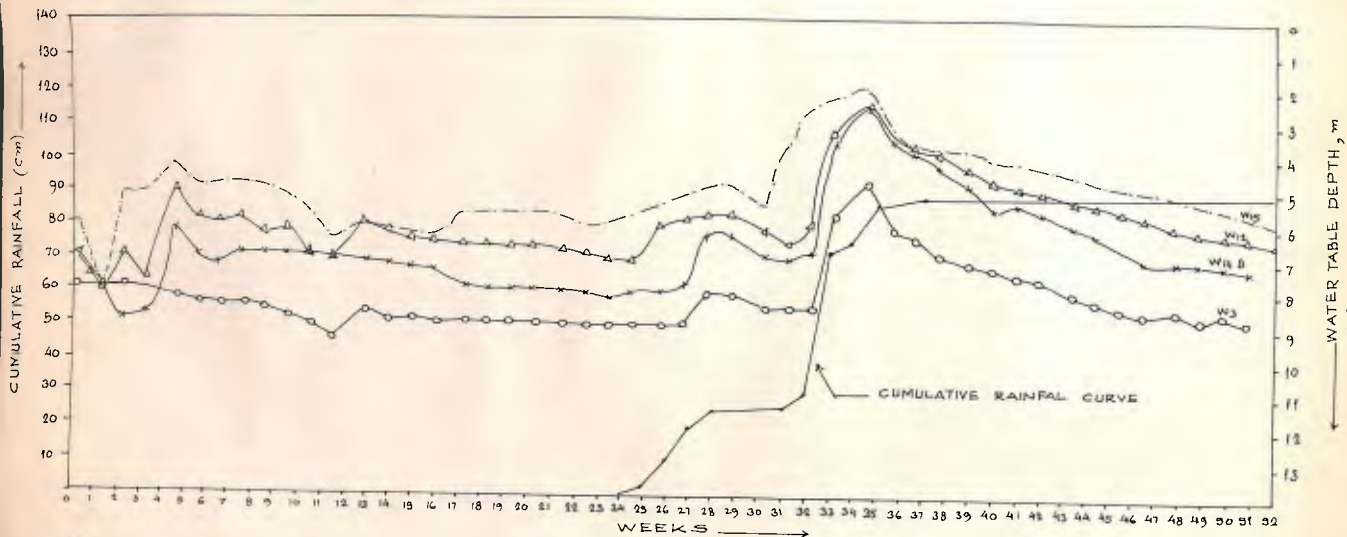


Fig 4.1 EFFECT OF RAINFALL ON WATER TABLE OF DIFFERENT OPEN WELLS DURING 1972 AT POWARKHEDA

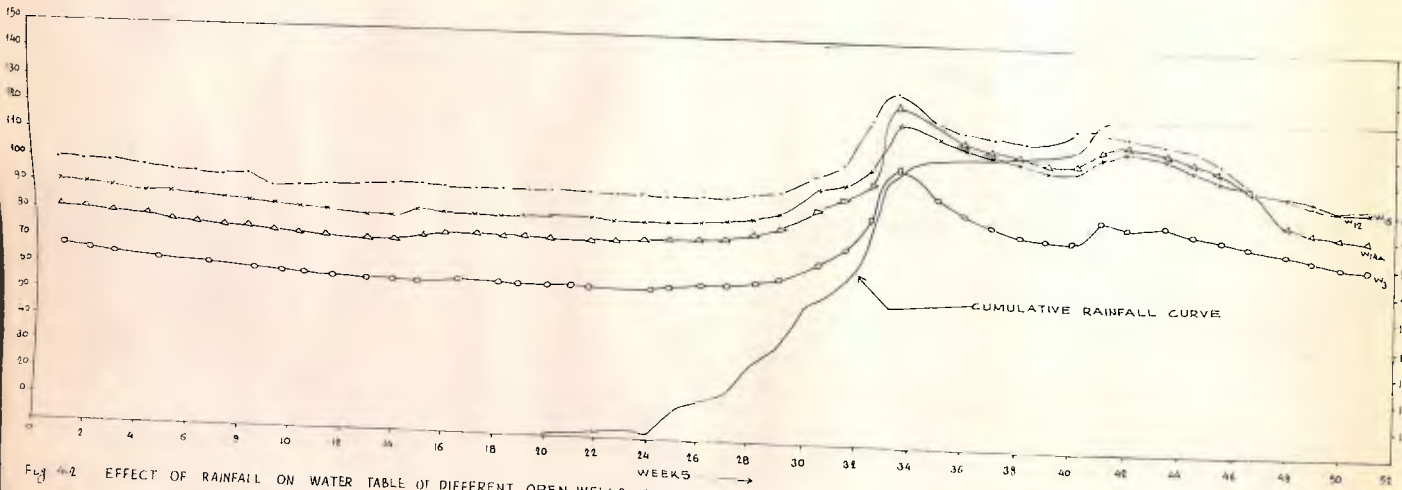


Fig. 4-2 EFFECT OF RAINFALL ON WATER TABLE OF DIFFERENT OPEN WELLS DURING 1974 AT POWARKHEDA

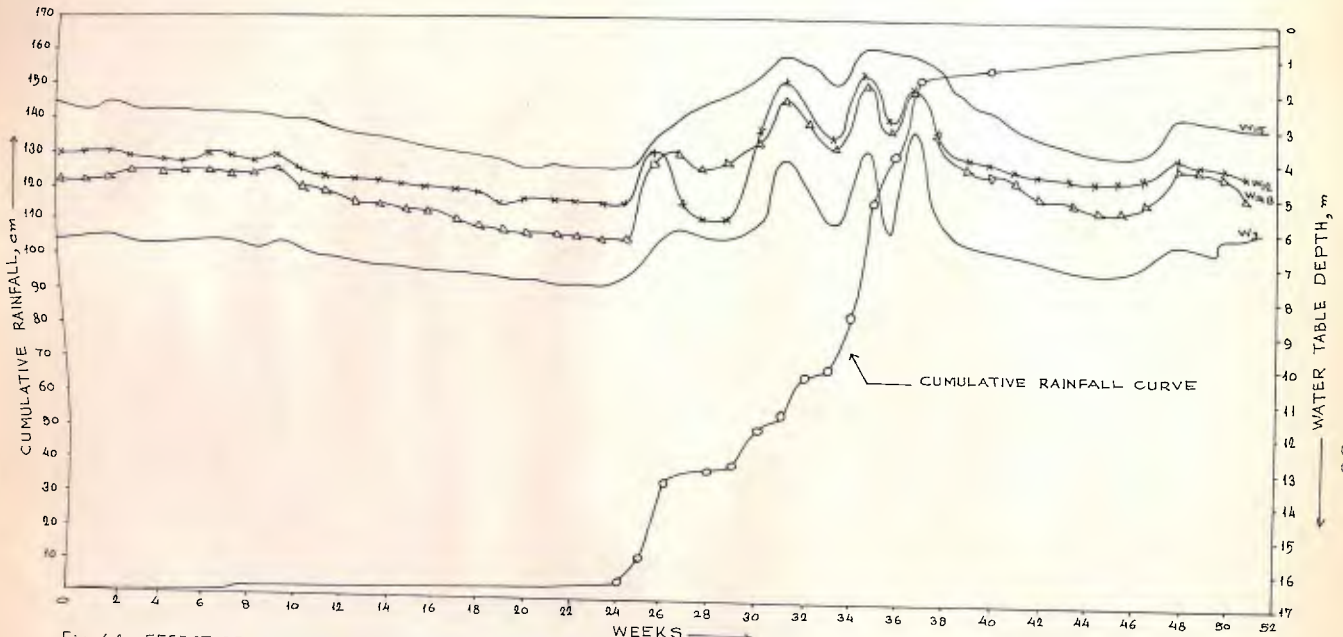


Fig. 4.8 EFFECT OF RAINFALL AND CANAL WATER ON THE WATER TABLE OF OPEN WELLS FOR THE YEAR 1977 AT POWARKHEDA

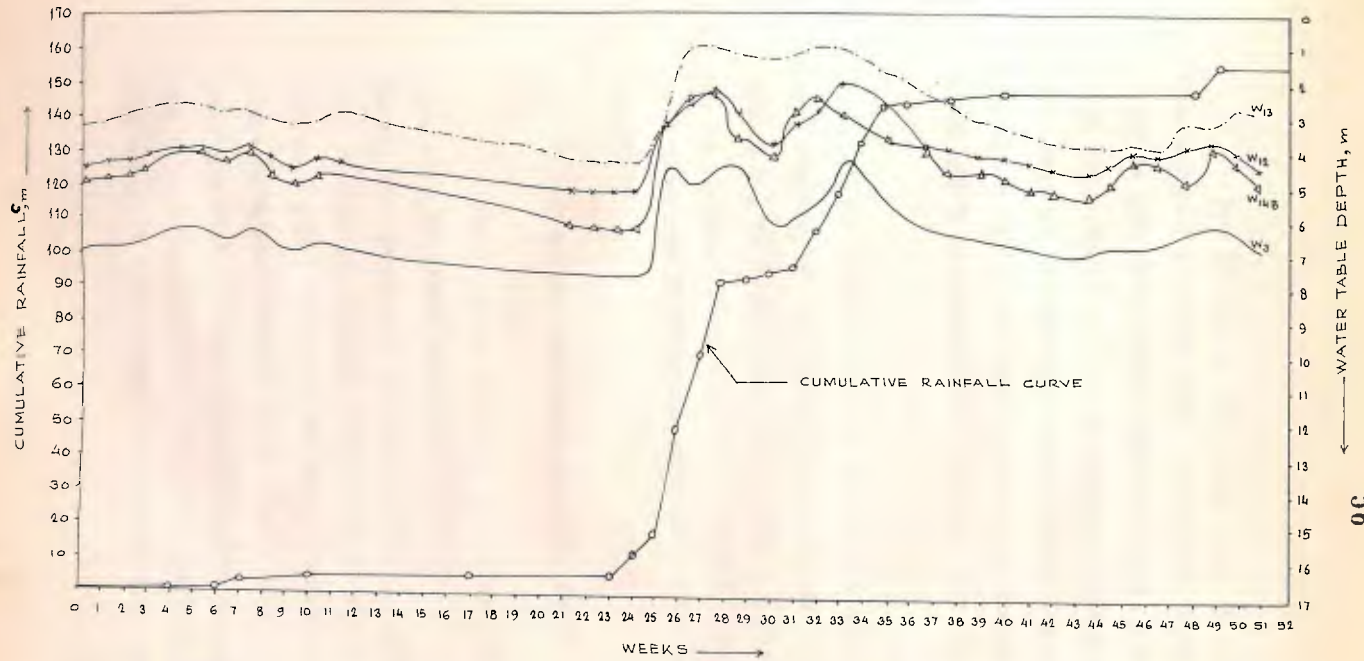


Fig. 4.4 EFFECT OF RAINFALL AND CANAL WATER ON THE WATER TABLE OF OPEN WELLS FOR THE YEAR 1978 AT POWARKHED.

Due to canal, the rate of rise of watertable increased at a higher rate. The water table peaks stabilised in the later years (1982 and 1983) and water tables have risen and caused water logging problem in most of the areas of Powarkheda during 1982-83 (Fig.4.5 and 4.6). The water tables are much within 3 m. during most of the times which is a dangerous situation for the survival of crops.

The introduction of preventive measures in the area maintained the water table at larger depth (more than 3 m.) in Powarkheda. While even overflowing wells can be observed in nearby areas specially Beora village. In Pathori and Chandrapura also water table is within 3m. depth.

#### 4.2 Behaviour of Cumulative Rainfall Curve :-

The 14 years rainfall data from 1972 to 1985 were used to study the behaviour of cumulative rainfall curve. The cumulative rainfall curves for different years were plotted on Y-axis against the weeks on X-axis. Two such graphs are shown in Fig.4.1 and 4.2. In general, the cumulative rainfall curve starts rising suddenly from the 24th week onwards and becomes almost parallel to the horizontal line from the 37th week onwards. Thus, the critical examination of these figures reveal that the

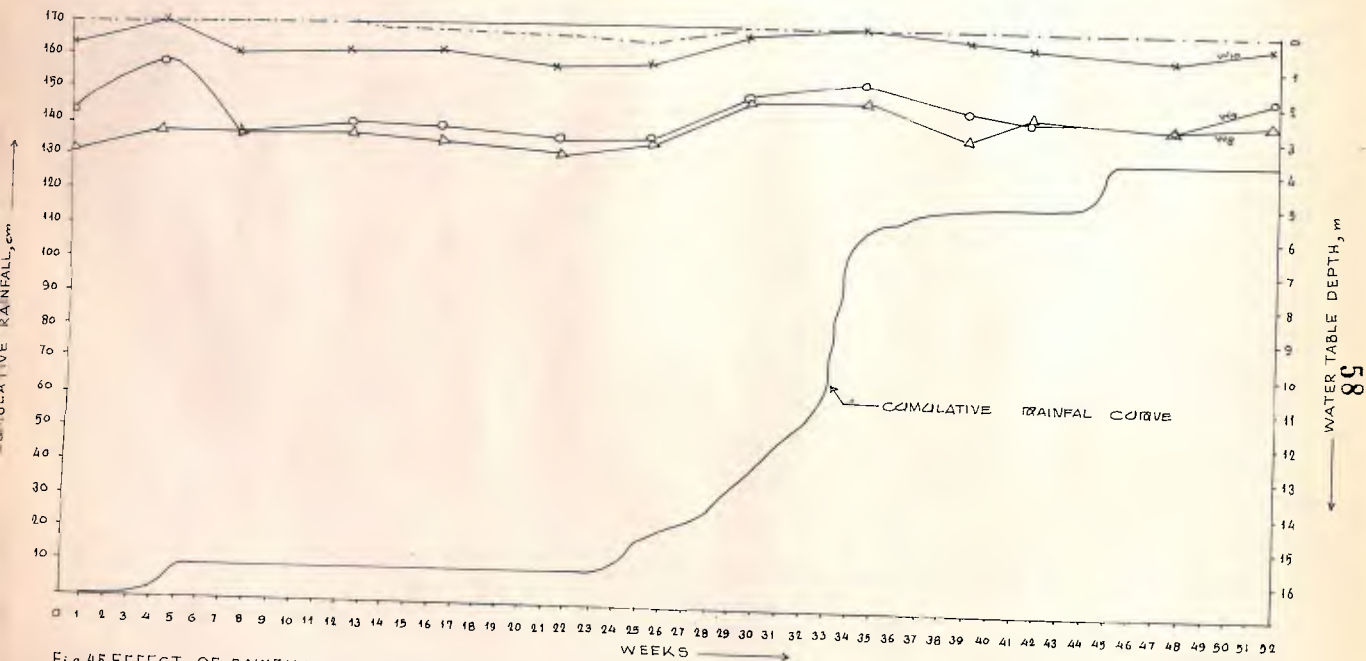


Fig.45 EFFECT OF RAINFALL AND CANAL WATER ON THE WATER TABLE OF OPEN WELLS DURING 1982 AT PATHODI AND BEORA

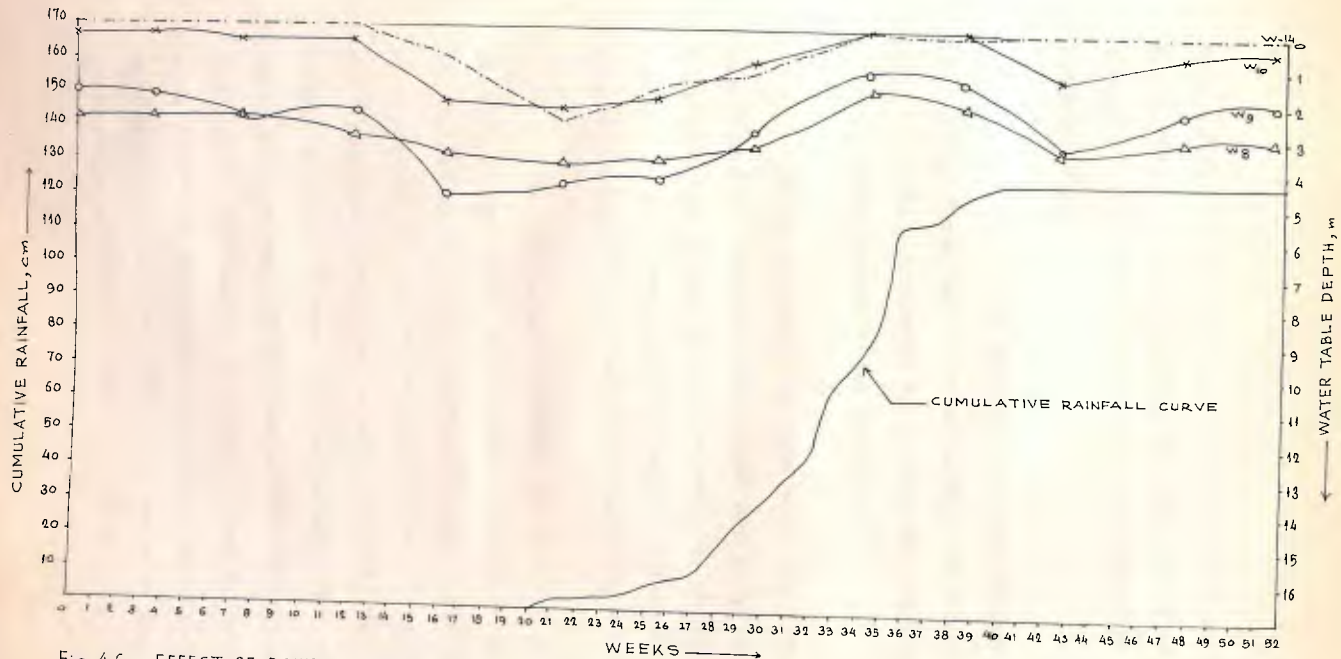


Fig 4.6 EFFECT OF RAINFALL AND CANAL WATER ON THE WATER TABLE OF OPEN WELLS DURING 1983 AT PATHODI AND BEORA

monsoon in Powarkheda occurs from the 24th week onwards and terminates in 37th week. The 24th and 37th week correspond to the middle of June and middle of September respectively.

To study the behaviour of cumulative rainfall at the end of these two critical weeks, the cumulative rainfall were noted for different years from the cumulative rainfall curve and are presented in table 4.1.

On an average, the 24th week and 37th week can be considered to represent the onset and termination of monsoon at Powarkheda (table 4.1). The week in which monsoon terminates has lesser coefficient of variation (3.672%) than the week in which monsoon starts ( $C_v = 3.854\%$ ).

The cumulative rainfall at the end of weeks in which monsoon starts show larger variations as shown by the coefficient of variation of 79.86% while the coefficient of variation of cumulative rainfall at the end of weeks in which monsoon terminates is only 24.583%. Thus, the cumulative rainfall at the onset of monsoon for different years show as much as 325 times more variation than the cumulative rainfall at the termination of rainfall. This also indicates that there are lesser variation in the cumulative rainfall at the end of monsoon than that in the cumulative rainfall at the onset of monsoon.

TABLE 4.1 Statistics for the cumulative weekly rainfall data in 14 years from 1972 to 1985 at the Powarkheda for two critical weeks.

Year	Cumulative rainfall at the onset and end of monsoon			
	Onset of Monsoon		End of Monsoon	
	Weeks	Cumulative rainfall (cm)	Weeks	Cumulative rainfall (cm)
1972	24	0.00	37	88.15
1973	23	1.80	39	116.69
1974	24	0.16	37	107.52
1975	25	5.14	37	106.97
1976	25	6.47	37	114.04
1977	24	5.21	37	153.40
1978	23	5.87	35	123.90
1979	24	12.24	34	38.55
1980	22	0.00	36	106.11
1981	23	12.78	39	108.04
1982	23	9.48	37	116.69
1983	24	4.67	38	118.94
1984	23	7.89	37	134.71
1985	25	2.51	38	82.36
X	23.71	5.301	37	108.29
S	0.914	4.234	1.359	26.621
$C_v$	3.854	79.868	3.672	24.583

### 4.3 Effect of Rainfall on Water Table

The water table does not respond as soon as the rainfall starts. The rainfall ceases in 37th week while the water table starts receding just from the 35th week onwards during 1972 (Fig.4.1). The rainfall curve for 1974 also ceases in 37th week but the water table starts receding from 34th week onwards with a time lag of 3 weeks (Fig.4.2) for all the wells under study.

Thus, the water table does not respond to the initial rainfall events. This is due to the fact that the initial rainfall saturates the soil moisture and does not contribute to the water table.

The effect of different rainfall events on the water table of different open wells namely  $W_3$ ,  $W_{14A}$ ,  $W_{12}$  and  $W_{15}$  can be studied with the help of table 4.2, 4.3 and Fig.4.1 and 4.2 respectively for 1972 and 1974.

The critical examination of figures 4.1 and 4.2 alongwith tables 4.2 and 4.3 reveal the following results:

- (1) Water table varies randomly. In the beginning water table does not rise and even becomes constant with some amount of rainfall. This is due to the fact that rainfall saturates the soil moisture in this zone and does not contribute to the water table.

TABLE 4.2 Effect of rainfall events on Water Table of different wells for the year, 1972 at Powarkheda.

PARTICULARS	Water Table Characteristics for different wells			
	W <sub>3</sub>	W <sub>12</sub>	W <sub>14A</sub>	W <sub>15</sub>
(1) No rainfall region (0 to 24 weeks) rainfall curve rises from 24th week onwards.	The water table falls from zero week to about middle of 11th and 12th week by 1.3 m. and then rises by 1 m. within 1½ week. (upto 13th week). The water table remains almost constant from 13th week to 24th week and onwards upto 27th week.	The water table shows random behaviour, falling and rising upto 13th week. The water table then falls gradually between 13th to 23rd week and becomes constant upto 24th week.	The water table falls upto 2 m. (within 0 to 2 weeks) and then rises by 3 m. Within 2 to 4 weeks. After 4th week water table starts declining upto 17th week and then becomes nearly constant upto 26th week.	The water table Zig-zag pattern from beginning and attains a constant value from 17th to 21st week. The water table then falls upto 24th weeks.

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	W <sub>3</sub>	W <sub>12</sub>	W <sub>14A</sub>	W <sub>15</sub>
(2) 25 cm. rain- fall between 24th to 28th week. Rainfall curve rises from 24th week.	Water table rises by 1.0 m.	Water table rises by 1.3 m.	Water Table rises by 1.9 m.	Water table rises by 1.0 m.
(3) Nearly no rainfall (1cm.) between 28th to 31st week.	Water table falls by 0.4 m.	Water Table falls by 0.8 m. upto 31st week.	Water Table falls by 0.8 m.	Water table falls by 0.6 m. upto 30th week and then rises rises by 1.5 m. within a week.
(4) Sudden rise in rain fall curve from 31st week to 34th week with rain- fall of 48 cm. in 3 weeks.	Water table rises by 3.2m. water table rises from 32nd week onwards.	Water Table rises by 3.2m. It rises from middle of 31st and 32nd week.	Water Table rises by 4.1m. It rises from 32nd week.	Water Table rises by 2.0m. Water table rises from 30th week onwards.

	W <sub>3</sub>	W <sub>12</sub>	W <sub>14A</sub>	W <sub>15</sub>
(5) Rainfall curve further rises by 13cm. between 34th to 37th week and then curve becomes almost constant i.e. rain fall ceases after 37th week.	Water table rises by 0.5m. to attain its peak in nearly 35th week and it declines rapidly.	Water table rises by 0.2m. upto 35th week and then declines rapidly.	Water table rises by 0.5m. upto 35th week and then declines rapidly.	Water table rises by 0.2 m. upto 35th week and then declines rapidly.
(6) 90 cm. rain-fall is experienced during the year.	Total net fluctuation (amplitude) is 4.3 m.	Amplitude is 4.5 m.	Amplitude is 5.5 m.	Amplitude is 4.0 m. only.

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TABLE 4.3 Effect of rainfall events on water table of different wells for the year, 1974 at Powarkheda.

Particulars	Water table characteristics for wells.			
	W <sub>3</sub>	W <sub>12</sub>	W <sub>14A</sub>	W <sub>15</sub>
(1) No rainfall region (2 cm. only) from 9 to 22nd week.	The water table declines from 6th to 24th week by 1.0m.	The water table declines, rises, and then declines by 1m. upto 24th week.	The water table declines, rises, and then declines by 0.6 m. upto 24th week.	The water table declines to 10th week by 1.0m. and then becomes almost constant till 27th week.
(2) Rainfall curve starts rising from 22nd week onwards, but the total rainfall upto 24th week is only 2 cm. Rainfall from 24th week to 29th week is 33 cm.	Water table starts rising from 24th week onwards but the rate or rise is small, till 29th week 0.5m. rise.	Water table starts rising from 24th week onwards but the rate or rise is small till, 29th week 0.5m. rise.	Water table starts rising from 24th week onwards, but the rate or rise is small till, 29th week rise is 0.6 m.	Water table rises from 27th week onwards, and the rise is 0.3m. till 29th week.

	W <sub>3</sub>	W <sub>12</sub>	W <sub>14A</sub>	W <sub>15</sub>
(3) 70 cm rain-fall between 29th to 34th week.	Water table rises by 4.3m. and attains a peak in the middle of 33rd and 34th week.	Water table rises by 3.5 m. and attains a peak in 34th week.	Water table rises by 4.6 m. and attains a peak in 34th week.	Water table rises by 3.8 m. and attains a peak in 34th week.
(4) Rainfall curve rises very slowly from 34th week to 40th week rise is only 6 cm.	Water table <del>declines by</del> declines by 2.5 m.	Water table declines by 1.7 m. within the interval.	Water table declines by 1.9 m.	Water table declines by 1.7 m.
(5) There is 13 cm rainfall in 41st week. The cumulative rainfall curve therefore rises by above amount just within a week.	Water Table again attains a peak in 41st week and then	Water table attains a peak in 42nd week.	Water Table attains a peak in 42nd week.	Water Table attains a peak in 41st week and then declines.

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W <sub>3</sub>	W <sub>12</sub>	W <sub>14A</sub>	W <sub>15</sub>	
(6) Total rainfall of 123 cm. is experienced during the year.	Amplitude of water table is 4.8 m.	Amplitude is 4.0 m.	Amplitude is highest and is 5.1 m.	Amplitude is 4.1 m.

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- (2) Just after the constant water table, when the soil moisture is satisfied, the additional rainfall causes the water table to rise to attain its peak. The rate of rise of water table varies and it is very slow in the beginning but very fast just before attaining the peak. This is mainly due to the fact that after the soil moisture is satisfied the major portion of the rainfall contributes to water table causing higher rate of rise before the water table attains peak. This point is more clear from table 4.2, 4.3 and Fig. 4.1 and 4.2.
- (3) The water table does not rise immediately after it rains. The water tables have started rising with a time lead of 3 weeks in 1972 and with a time lead of 2 weeks in 1974. The well  $W_{12}$  and  $W_{15}$  during 1972 show some peculiar trend. The  $W_{12}$  and  $W_{15}$  during 1972 show the rising trend immediately after rainfall in 24th week. This could be due to the fact that these wells are located in depression areas where the rainfall accumulates as runoff and shows sudden rise in water table.
- (4) The water table rise ceases just before rainfall ceases by taking lead of few weeks. Thus, water table rise ceases in 35th and 34th week during

1972 and 1974 respectively, while the corresponding rainfalls for the both years cease in 37th week.

#### 4.4 Effect of Rainfall and Canal Water Level on Water Table of Open Wells

The introduction of canal irrigation results in the rise of water table. The regular periodic behaviour of the water table is distorted and instead of a well defined peak more than two or three water table peaks are seen in different weeks. Thus, the water table for 1977 (Fig.4.3) shows four different peaks. The first peak occurs somewhere in between 26th to 27th week. The well No.12 and 15 show clear peak in 26th week while the remaining two wells ( $W_3$  and  $W_{14A}$ ) show peaks in 27th week. The three other peaks for all the wells are seen in 31st, 35th and 37th weeks respectively.

The water table behaviour during 1978 depicts 2 clear defined peaks for all the wells as shown in Fig.4.4. However, the well  $W_3$  seems to be an exception for which there is one extra peak occurring in 26th week. The 2 peaks which are common for all the wells occur in 28th weeks and 33rd weeks with the exception of  $W_{14A}$  which attains second peak about 1 week in advance (32 week).

The number of peaks are the outcome of the canal

introduction in the area. This is clearly depicted in Fig.4.3 and 4.4 when they are compared with the water table behaviour (fig.4.1 and 4.2) before the introduction of canal. The rising water table between 46th to 48th SMW in 1977 (Fig.4.3) can be explained by the addition of water because of the canal irrigation. Similarly, the rising trend of water table in 1st to 6th SMW and from 48th SMW onwards (Fig.4.4) during 1978 can be explained by the rise in water table due to canal irrigation.

The amplitude of water table also decreases with the number of peaks starting from the 23rd week onwards. Thus, the amplitudes corresponding to 1st, 2nd, 3rd and 4th peaks during 1977 are 2.6, 2.0, 1.8 and 1.1 m. respectively for the  $W_{14A}$  while the amplitudes during 1978 are 3.9 and 1.7 m. for the same well having two peaks only. The exception being  $W_3$  and  $W_{12}$  during 1977 for which the amplitudes show no regular pattern because both  $W_3$  and  $W_{12}$  are located in same area. The decreasing amplitudes depict that the water table for this region is not only affected by the canal water level but also the rainfall during the period.

The water table observations of the problem villages namely Pathodi and Beora were available from December, 1981. Therefore, the study was also conducted on the water table behaviour of these wells namely  $W_8$ ,  $W_9$ ,  $W_{10}$  and  $W_{14}$  for the period of 3 years from 1982 to 1984 representing similar

characteristics as others. These wells also get recharge from canals in addition to the rainfall for the period. The monthly data has been plotted for these wells.

The water tables during 1982, 1983 and 1984 have shown drastic rise as is clear from Fig.4.5, 4.6, and 4.7 respectively.

The rate of rise of water table increased tremendously after the canal introduction. The water tables during 1977 and 1978 (Fig.4.3 and 4.4) show well defined peaks but during 1982, 1983, 1984 (Fig.4.5, 4.6 and 4.7) the peaks although less in number are platy-kurtic (reverse plate shape). In addition, the water tables have risen significantly and are well within 3 m. for most of the wells, during the crop growing season. The water table for two of the four wells reaches the ground surface for a month or two in the years under consideration. The effect of irrigation can be very well observed during December, January and February from the above figures. All the Figures 4.5, 4.6 and 4.7 show the similar characteristics as regards the water table behaviour is concerned. It is because the feeding source of these wells may be the same.

The water table study for the nearby area was also carried out with the help of Fig.4.8 plotted from water table data of Kulhamadi and Chandrapura. The water table in  $W_{30}$  of Chandrapura, and  $W_{13}$  and  $W_{20}$  of Kulhamadi

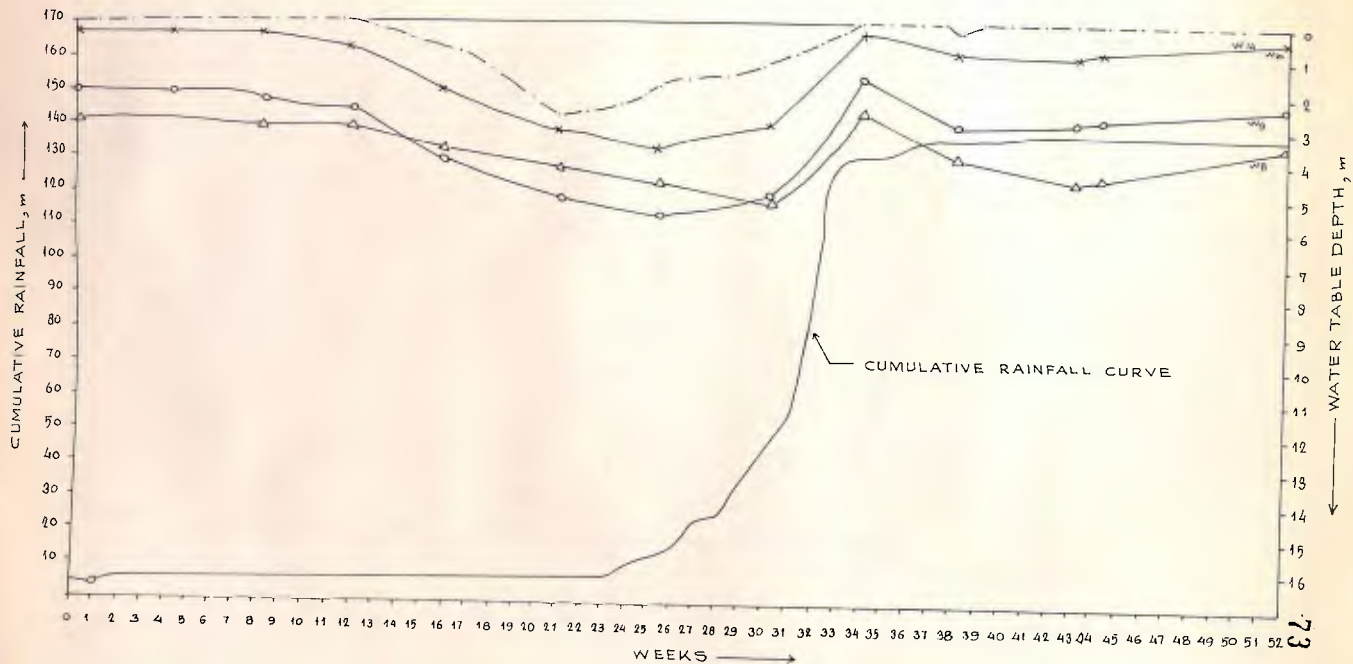


Fig.4.7 EFFECT OF RAINFALL AND CANAL WATER ON WATER TABLE OF DIFFERENT OPEN WELLS DURING 1984 AT PATHODI AND BEORA



--- RECORD NOT AVAILABLE

YEAR	ANNUAL RAINFALL (mm)
1982	1325
1983	1262
1984	1379
1985	867.5

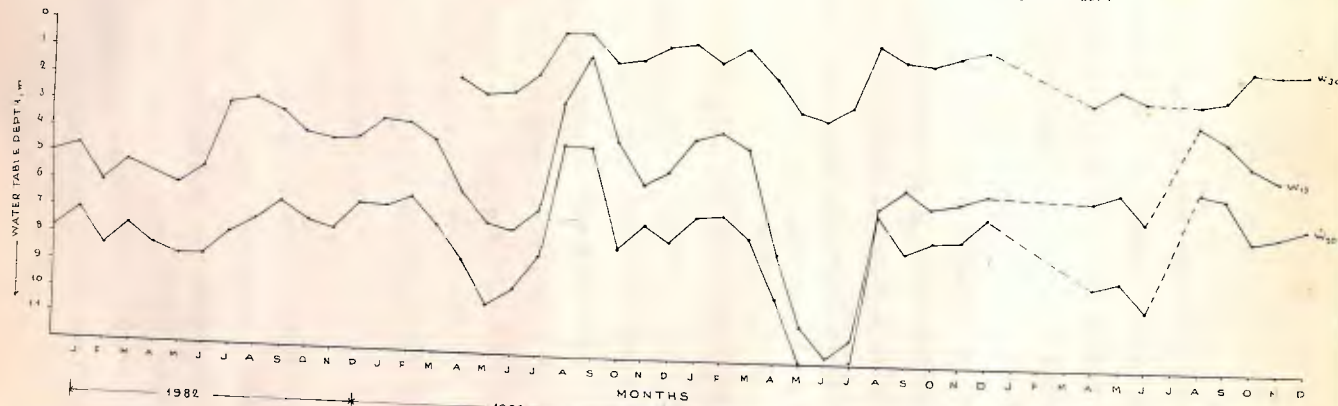


Fig. 8 WATER TABLE BEHAVIOR OF VILLAGE CHANDRAPURA AND KULHAMADI FROM 1982 TO 1985

behave almost in the same fashion. The effect of rainfall is overlapped by balanced supply of canal water and hence the effect due to rainfall cannot be traced out. The water table conditions in Kulhamadi indicate that it is well within the safe limit (the water table being more than 3 m.) while the situation existing in Chandrapura is very serious. The water table in  $W_{30}$  for Chandrapura is less than 3 m. in all the months and even attains zero level some times during the entire period of study. This well responds appreciably to the seepage from canal.

During the survey of water table in different villages nearby Powarkheda, in the month of November, 1986, it was found that the canal water had immediate response to water table in the wells and in the fields at Beora village. As soon as the water was delivered into the canal, the water was just overflowing in the well located in the school premises of Beora village. This condition is very serious, not only affecting the existing crop but also creating unfavourable condition for the next crop.

The water table conditions for the Pathori village were also serious. The water tables were 3.28 m., 2.15 m., 2.70 m. and 1.18 m. respectively in the  $W_9$ ,  $W_{10}$ ,  $W_{11}$ , and  $W_{29}$ . The present water table condition in Kulhamadi in  $W_{12}$  and  $W_{13}$  was 7.39 and 4.52 m. The water table in Powarkheda farm and village were well above 4 m. in all the wells namely  $W_5$ ,  $W_6$ ,  $W_7$  and  $W_8$ .

#### 4.5 Effect of Canal Water on the Water Table of Open Wells

The effect of canal water level on the water table of open wells was studied with the help of water table data of open wells for which the maximum record was available. For, this purpose open well  $W_{16}$  was selected. The effect of canal water level on water table of open wells can be determined by subtracting the effect of rainfall on water table from the combined effect of rainfall and canal water level on water table of open wells. The study can be easily conducted with the help of table 4.4.

The available water table data for 3 years period before introduction of canal and four years data after introduction of canal for  $W_{16}$  was used for the purpose of this analysis. The period during which water table rises in any particular year was identified and was divided into different intervals having some slope. The corresponding rainfall during that period was also obtained from the rainfall record. This above information was obtained for the water table records before and after the introduction of canal and was tabulated in Table 4.4. The intensity of rainfall (I) and rate of rise of water table (WR) was calculated on the assumptions that either the rainfall or water table change is at uniform rate within the week.

As per the information available on canal delivery schedule, the available data were used to carry out the run

TABLE 4.4 Effect of Canal Water and Rainfall on the use of Water Table.

Year	Weekly interval & days.	Rainfall during week	Intensity of rainfall I	Magnitude/Rise of water table and rate of rise	
		cm.	cm/day.	Magnitude of rise. (WR)	Rate or rise (WR)
1	2	3	4	5	6
Before introduction of canal	25-27(14)	17.00	1.2143	20	1.4285
	32-33( 7)	41.08	5.8686	140	20.0000
	33-34( 7)	3.38	0.4828	90	12.8571
1972					
1973	22-46(168)	114.55	0.6818	230	1.3690
1974	9 -18(63)	--	--	130	2.0630
	22-31(63)	57.56	0.9136	110	1.7460
	31-33(14)	42.23	3.0164	220	15.7140
After introduction of canal	22-26(28)	10.03	0.3582	35	1.2500
	26-30(28)	22.90	0.8178	128	4.5710
	30-35(35)	69.65	1.9900	10	0.2850
	39-42(21)	0.39	0.01857	62	2.9520
1982					

Contd.....



analysis. The weeks during which canal ran was denoted by 1 and 0 indicates that the canal did not run during the week.

The critical examination of table 4.4 and 4.5 reveal the following results.

The rise in water table is mainly associated with the intensity of rainfall before the canal was introduced. The exception being the 9th and 18th week of 1974 during which the water table has risen at the rate of 2.063 cm./day with no rainfall input. This could be due to the irrigation water applied to crop or recharge by some other means.

The relationship between the intensity of rainfall and rate of rise of water table was studied with the help of regression analysis using principle of least squares. The quadratic equation (second degree polynomial) does not show significant improvement over linear equation. However, third degree polynomial describes the data best.

Thus, the relationship between intensity of rainfall (I) and the rate of rise of water table (WR) for the years before introduction of canal can be described by third degree polynomial of the form,

$$(WR) = 26.1335 - 41.9857I + 189552I^2 - 2.0413I^3$$

$$\text{with } r = 0.9554$$

TABLE 4.5 Canal delivery Schedule for the different years.

Year	Weeks	Corresponding period.	Canal operation
1982	1 - 4	1st Jan to 28th Jan.	1
	4 - 6	28th Jan to 11th Feb.	0
	7 - 10	12th Feb to 11th Mar.	1
	11 - 37	12th Mar to 16th Sept.	0
	38 - 39	17th Sept to 30th Sept.	1
	40 - 50	1st Oct to 16th Dec.	1
	51 - 52	17th Dec to 31st Dec.	0
1983	1 - 45	1st Jan to 11th Nov.	0
	45 - 52	12th Nov to 31st Dec.	1
1984	1 - 14	1st Jan to 8th Apr.	1
	15	9th Apr to 15th Apr.	0
	16	16th Apr to 22nd Apr.	1
	17 - 38	23rd Apr to 22nd Sept.	0
	39 - 52	24th Sept to 31st Dec.	1
1985	1 - 24	1st Jan to 17th June	1
	25 - 44	18th June to 4th Nov.	0
	45 - 52	5th Nov to 31st Dec.	1

The relationship is graphically presented in Fig.4.9.

For the periods after introduction of canal, the table 4.4 and 4.5 show that the canal was run in the period during which there was no rainfall. Therefore, no mixing occurs. Thus, the rise in water table in the year, 1982 to 1985 can be contributed purely to either canal water or rainfall.

The table 4.4 shows that the rate of rise in water table 2.952 cm/day in 1982, 1.0570 and 0.357 cm/day in 1983, 2.283 cm/day in 1984 and 1.25 cm/day in 1985 corresponding to weeks 39 to 42, 43 to 48 to 52, 46 to 52 and 18 to 22 weeks respectively are mainly associated with the canal operation.

The rate of rise of water table associated with the rainfall are 1.25, 4.57 and 0.285 cm/day in 1982, 0.678, 1.428 and 4.714 cm/day in 1983, 9.357 cm/day in 1984 and 2.443 cm/day in 1985 respectively in the weeks 22 to 26, 26 to 30, 30 to 35, 22 to 26, 26 to 30, 30 to 35, 31 to 35 and 24 to 34.

Thus, rate of rise of water table associated with the rainfall events were separated out and the relationship was developed between rate of rise of water table and intensity of rainfall.

The relationship can be described by a third degree polynomial of the form (Fig.4.10).

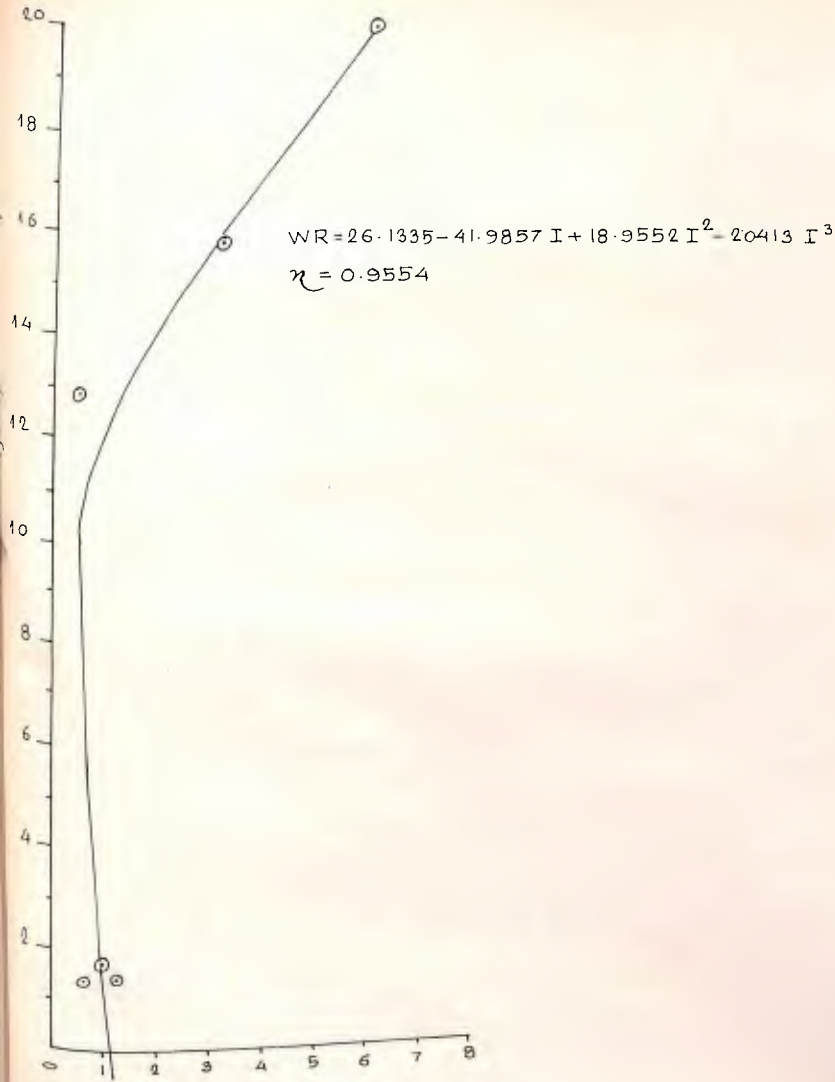


Fig. 4.9 RELATIONSHIP BETWEEN RATE OF RISE OF WATER TABLE (WR) AND RAINFALL INTENSITY (I) BEFORE INTRODUCTION OF CANAL.

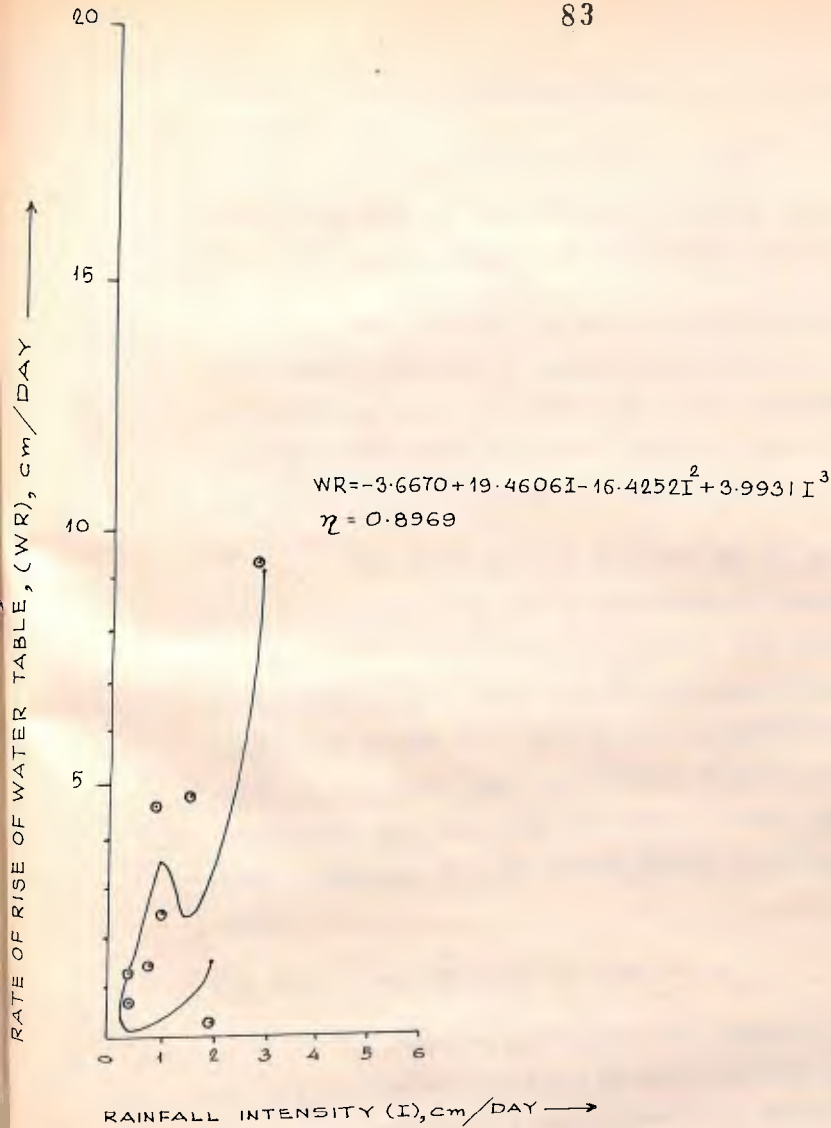


Fig. 4.10 RELATIONSHIP BETWEEN RATE OF RISE OF WATER TABLE (WR) AND RAINFALL INTENSITY (I) AFTER INTRODUCTION OF CANAL

$$WR = -3.6670 + 19.4606I - 16.4252I^2 + 3.9931I^3$$

$$\text{with } r = 0.8969$$

Where WR = Rate of rise of water table in cm/day.

and I = Intensity of rainfall in cm/day.

The constants of the polynomials along with the error sum, error sum of square, and correlation ratio are shown in table 4.6. There is large variation in the rate of water table rise and therefore linear equation fails to account these variations.

The rates of rise in <sup>well</sup> table due to rainfall are more consistent after the introduction of canal than the period before introduction as shown by the coefficients of variations of 73.184% and 94.377% respectively. This is mainly due to the fact that after the introduction of canal in the area, the fluctuations in water table have been stabilised, and therefore the rate of water table rise are more consistent than the period before introduction of canal.

#### 4.6 Statistical Analysis of Water Table Data

In order to generalise the behaviour of water table in different years the minimum, maximum water levels alongwith their time of occurrence were tabulated for each well and for every year. The different parameters

TABLE 4.6 Constants of the equations for relationship between rate of rise of water table and intensity of rainfall before and after introduction of canal.

EQUATION	Constants of the equations						
	Before introduction of Canal					Error sum.	Error sum sq.
	a	b	c	d	n		
$WR = a + b (IR)$	2.5822	3.0894	-	-	0.7726	0.0003	140.65753
$WR = a + b (IR) + c (IR)^2$	2.6323	3.0270	$9.8608 \times 10^3$	-	0.7726	0.0002	140.65756
$WR = a + b (IR) + c (IR)^2 + d (IR)^3$	26.1335	-41.9857	18.9552	-2.0413	0.9554	-0.0051	30.4546

25

Contd.....

EQUATIONS

Constants of the equations

After introduction of canal

	a	b	c	d	n	Error sum.	Error sum sq.
WR = a+b (IR)	0.3270	2.3600	-	-	0.6666	0.0014	35.7595
WR=a+b(IR)+c(IR) <sup>2</sup>	1.7978	-0.6137	1.0000	-	0.7076	0.0094	32.1357
WR=a+b(IR)+c(IR) <sup>2</sup> +d(IR) <sup>3</sup>	-3.6670	19.4606	-16.4252	3.9931	0.8969	0.0003	13.7099

namely  $X_1$ ,  $X_n$ ,  $R$ ,  $U_1$  and  $U_n$  corresponding to the water table fluctuation curves of different open wells were determined for different years from 1972 to 1985 and are shown in Appendix-B. The statistical parameters namely number of observations ( $n$ ), mean ( $\bar{X}$ ), sample standard deviation ( $S$ ) and coefficient of variation ( $C_v$ ) corresponding to the above parameters were also determined and are shown in Table 4.7.

There is considerable fluctuation in minima and maxima before the introduction of canal. The fluctuation have reduced after the introduction of canal. The values of  $X_1$ ,  $X_n$ ,  $R$ ,  $U_1$  and  $U_n$  vary with well. In general, the lowest water table for 1972 has higher values than 1974. The range of water table for 1972 is higher than 1974. The range also varies with time. During 1975, the watertable has attained higher depth than 1976 and the peak is also at higher depth than 1976. The range during 1977 is more from 1978. The other parameters can be easily studied with the help of Appendix B.

In general, the peak occurs in between 28th to 37th week while the lowest depth of water table is attained in between 1 to 51 weeks, showing large variation (appendix B).

TABLE 4.7 Statistical parameters of water table corresponding to parameters of water table fluctuation curves for different years at powarkheda.

Years	Statistical parameters.	Parameters of water table fluctuation curves.				
		$X_1$	$X_n$	R	$U_1$	$U_n$
1972	n	6	6	6	6	6
	$\bar{X}$	8.225	3.0917	5.133	10.167	34.667
	s	1.120	0.868	0.817	11.531	0.516
	$C_v\%$	13.613	28.094	15.918	113.421	1.490
-----						
1974	n	7	7	7	7	7
	$\bar{X}$	7.858	3.190	4.668	14.57	33.714
	s	1.224	0.711	1.0194	5.028	0.756
	$C_v\%$	15.577	22.30	21.818	34.509	2.242
-----						
1975	n	9	7	7	9	7
	$\bar{X}$	9.281	4.667	4.848	25.89	36.857
	s	1.022	0.775	1.526	2.205	0.378
	$C_v\%$	11.011	16.618	31.470	8.516	1.025

on  
or

		$X_1$	$X_n$	R	$U_1$	$U_n$
1976	n	9	9	9	8(9)	9
	$\bar{X}$	6.650	2.388	4.384	21.50(24.78)	34.11
	s	1.381	0.921	0.865	0.926(9.870)	2.315
	$C_v\%$	20.762	38.556	19.725	4.306(39.840)	6.788
1977	n	7	7	7	6(7)	7
	$\bar{X}$	5.987	1.774	4.213	24.830(28.000)	35.57
	s	1.006	0.692	0.396	1.722(8.524)	0.976
	$C_v\%$	17.800	38.985	9.414	6.936(30.440)	2.743
1978	n	9	9	9	8(9)	9
	$\bar{X}$	6.147	2.380	3.750	23.625(21.11)	32.44
	s	1.129	1.069	0.397	0.517(7.557)	2.555
	$C_v\%$	18.378	44.90	10.581	2.191(35.797)	7.875

		$X_1$	$X_n$	$\bar{n}$	$U_1$	$U_n$
1982	n	4	4	4	3(4)	4
	$\bar{X}$	4.767	1.975	2.793	23.330(17.750)	29.50
	S	0.578	0.612	0.953	2.309(11.325)	11.00
	$C_v\%$	12.124	30.97	34.14	6.897(63.80)	37.29
1983	n	4	4	4	4	4
	$\bar{X}$	5.075	2.77	2.797	22	35
	S	7.62	0.488	0.387	0	0
	$C_v\%$	15.015	21.443	13.850	0	0
1984	n	4	4	4	4	4
	$\bar{X}$	5.967	2.85	3.087	30.50	35
	S	0.585	0.242	0.368	6.137	0
	$C_v\%$	9.803	8.491	11.94	20.122	0

		$x_1$	$x_n$	R	$u_1$	$u_n$
1985	n	4	4	4	4	4
	$\bar{x}$	5.775	3.065	2.71	36	33
	s	1.613	0.384	1.480	13.856	14.629
	C <sub>v</sub> %	27.926	12.525	54.589	38.490	44.329

The values in paranthesis show the statistical parameters, if the extreme events are not ignored from the analysis. The units for  $x_1, x_n$  R are in m and  $u_1$  and  $u_n$  are in weeks.

\*\*\*\*\*



The variation of the lowest and highest water table (Maxima and minima) for 6 of the open wells  $W_3$ ,  $W_{12}$ ,  $W_{14A}$ ,  $W_{10}$ ,  $W_{15}$  and  $W_{16}$  are shown in figure 4.11. The maxima and minima show larger fluctuations before the introduction of canal and the fluctuations have reduced thereafter.

The variation of range for different open wells for different years is shown in Fig.4.12. The range also has decreased after the canal introduction in the area. The coefficient of variation of the weeks at which water table attains peak is minimum as compared to the coefficient of variation for other parameters (Table 4.7). Thus, the time of peaks lie within a short interval and are more consistent. The week during which the water table is farthest from ground level also has lesser coefficient of variation if the extreme values are not considered. The mean values of different parameters were collected from table 4.7 and are presented in Table 4.8

The mean of the means were calculated with the help of Table 4.8 from the 10 years discontinuous record from 1972 to 1985.

The relationship was developed between mean of range of water table and years by using the principle of least squares.

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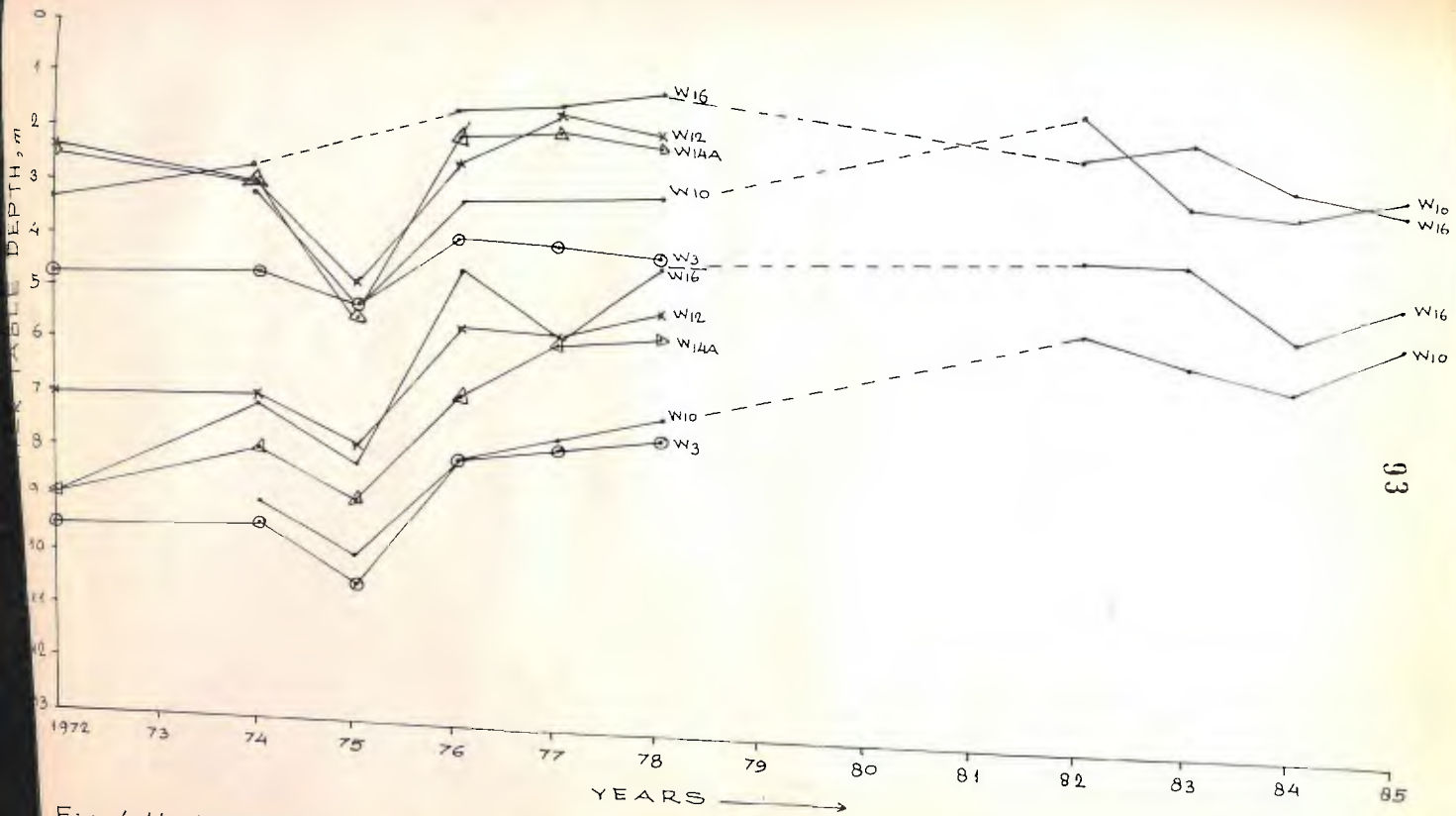


Fig. 4.11 VARIATION OF THE MAXIMA AND MINIMA OF WATER TABLE FOR THE YEARS 1972 TO 1985 AT POWARKHEDA.

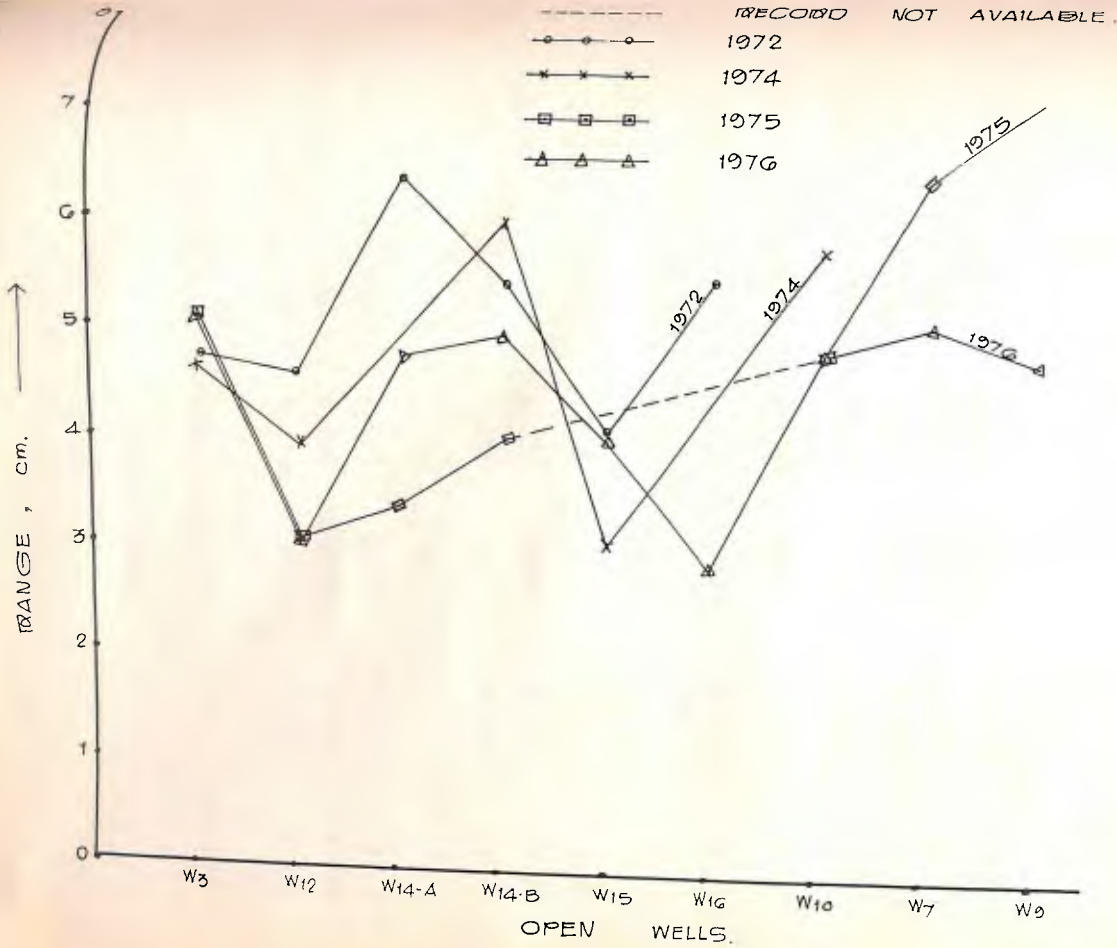


Fig. 4.12 VARIATION OF RANGES FOR DIFFERENT OPEN WELLS IN DIFFERENT YEARS AT POWARKHEDA

TABLE 4.8 Mean values of different parameters from table 4.7.

Year	Mean values of different parameters				
	$\bar{X}_1$ m.	$\bar{X}_n$ m.	$\bar{R}$ m.	$\bar{U}_1$ week	$\bar{U}_n$ week
1972	8.225	3.092	5.133	10.167	34.667
1974	7.858	3.190	4.668	14.570	33.714
1975	9.281	4.667	4.848	25.890	36.857
1976	6.650	2.388	4.384	21.500 (24.780)	34.11
1977	5.987	1.774	4.213	24.830 (28.000)	35.57
1978	6.147	2.380	3.750	23.625 (21.110)	32.44
1982	4.767	1.975	2.793	23.336 (17.750)	29.50
1983	5.075	2.277	2.797	22.00	35.00
1984	5.967	2.850	3.087	30.50	35.00
1985	5.775	3.065	2.710	36.00	33.00
$\bar{X}$	6.573	2.766	3.838	23.24	33.986
$S(\bar{X})$	1.443	0.826	0.934	7.271	2.023
$C_v(\bar{X})\%$	21.961	29.856	44.232	31.286	5.954

The relationship can be described by a linear equation of the form,

$$\bar{R} = 5.149 - 0.1986X$$

Where  $\bar{R}$  is the mean of ranges for different open wells.

X is the coded values of years.

X = 0 for 1972, X = 1 for 1973, X = 2 for 1974...  
and X = 13 for 1985.

The mean range decreases as the number of years increase (Fig.4.13).

The mean range and X are negatively correlated with significantly high correlation coefficient of - 0.875.

The coefficient of variation for the mean time of peak is lowest (5.954%) and hence the peak can be expected to occur in 34th week with great certainty as compared to the occurrence of maxima. Similarly, the data for maxima of water table are most consistent than the minima as shown by the coefficient of variation of 21.961 and 29.856% respectively. The coefficient of variation for the ranges i.e. amplitudes show the highest variation ( $C_v = 44.232\%$ ) as shown in Table 4.8.

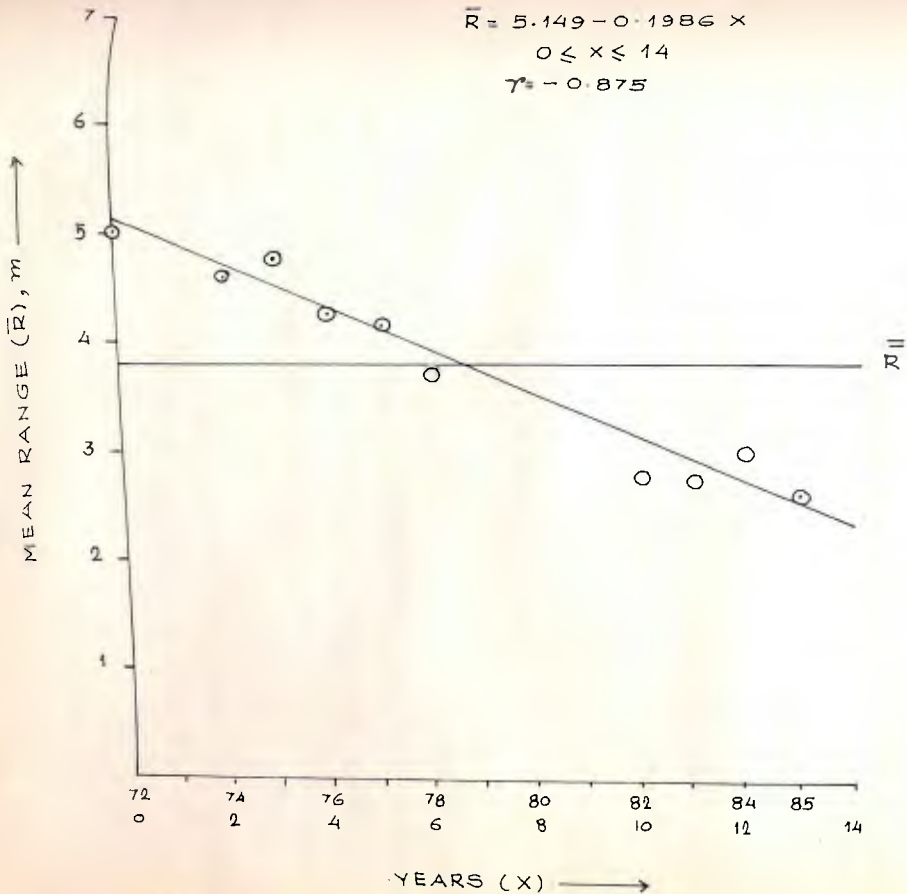


Fig. 4.13 RELATIONSHIP BETWEEN MEAN RANGE ( $\bar{R}$ ) AND YEARS (X) FOR 10 YEARS DATA FROM 1972 TO 1985

#### 4.7 Behaviour of Maximum Water Table

The behaviour of maximum water table was studied with the help of water table fluctuation curves for three different samples wells namely  $W_{12}$ ,  $W_{14A}$ , and  $W_3$  for the 10 years record from 1972 to 1981. The maxima of water table deviate year after year. The deviation of water table for different wells for different years were calculated with reference to the maxima of water table for the preceding year starting from 1972. The deviations were then added without ignoring the signs to know whether the water table has decreased or increased. The Fig. 4.14 shows that the water table has relatively increased in the later years. This is also clear from the table 4.9 because of net positive deviations.

#### 4.8 Long Term Variation of Water Table

The water table behaves in a stochastic process. The long term variation of water table was studied with the help of four sample wells ( $W_3$ ,  $W_{12}$ ,  $W_{16}$ ,  $W_{10}$ ) specially for which the maximum record was available. The water table variations are shown in Figs. 4.15, 4.16 and 4.17 respectively for  $W_3$ ,  $W_{12}$  and  $W_{16}$ . The variation of ranges for  $W_3$ ,  $W_{10}$ ,  $W_{12}$ , and  $W_{16}$  are shown in Fig. 4.18 and presented in Table 4.10.

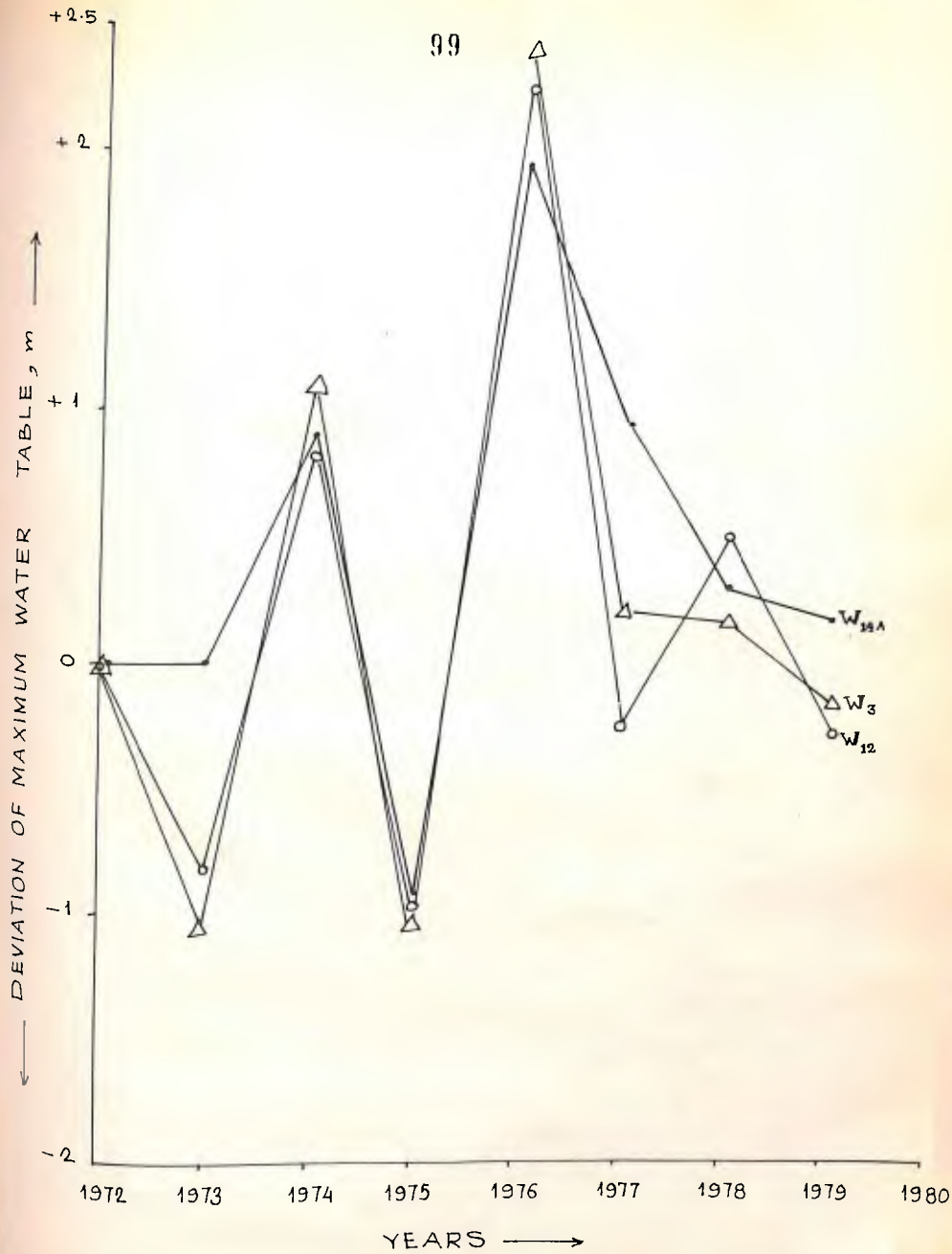


Fig. 4.14 DEVIATION OF MAXIMUM WATER LEVEL FOR DIFFERENT YEARS FROM THE MAXIMA OF

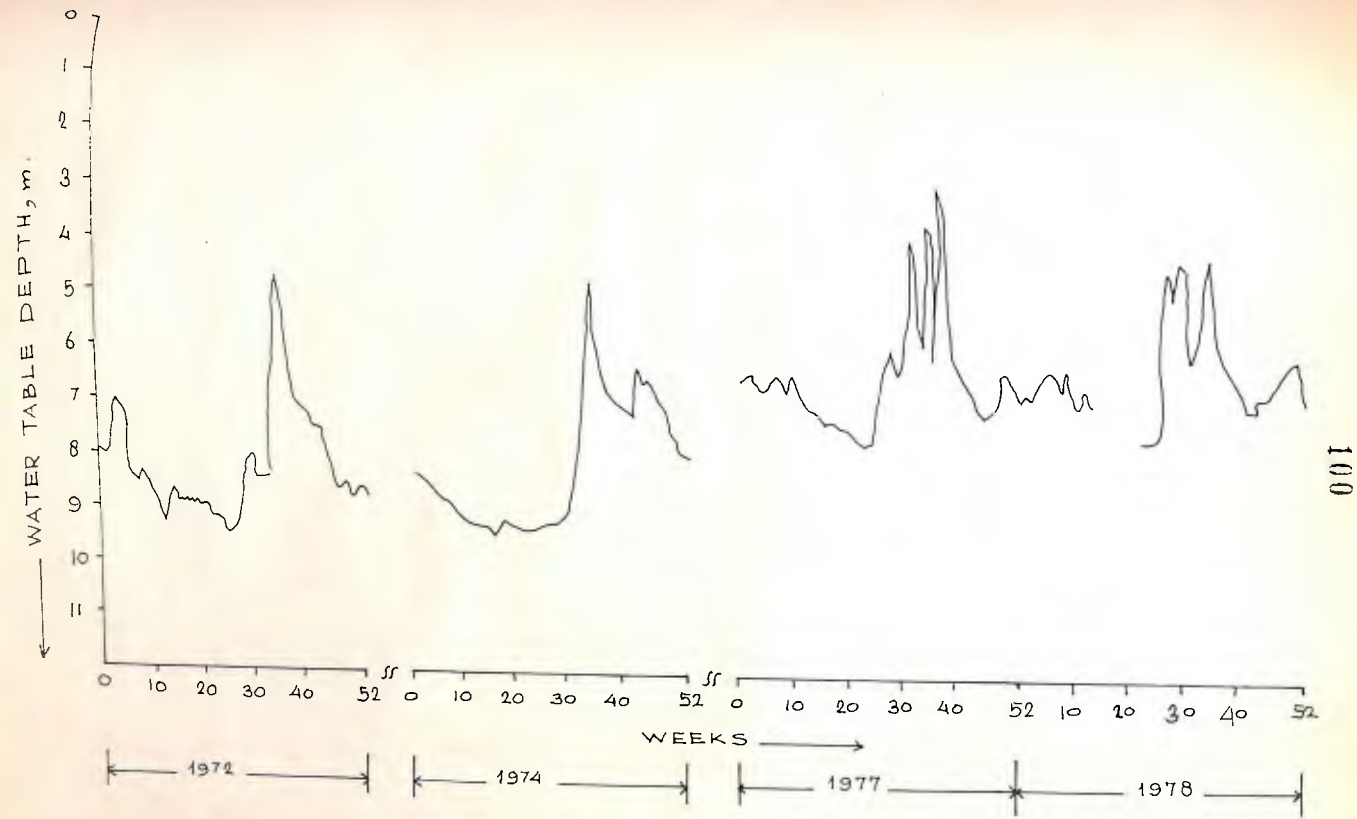


Fig 4.15 LONG TERM VARIATION OF WATER TABLE FOR W<sub>3</sub> AT POWARKHEDA

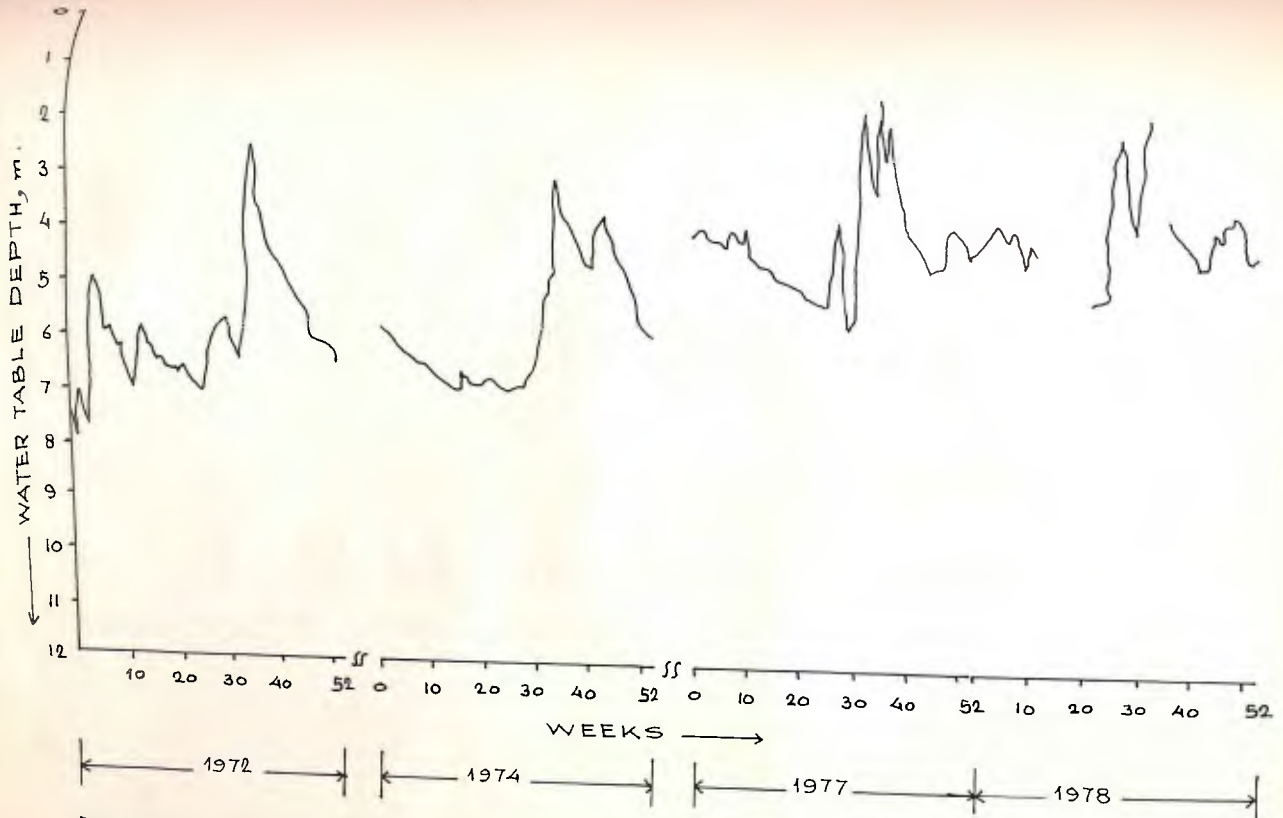


Fig. 4.16 LONG TERM VARIATION OF WATER TABLE FOR W<sub>12</sub> AT POWARKHEDA



FIG. 4.17 LONG TERM VARIATION OF WATER TABLE FOR W<sub>16</sub> AT POWARAKHEDA.

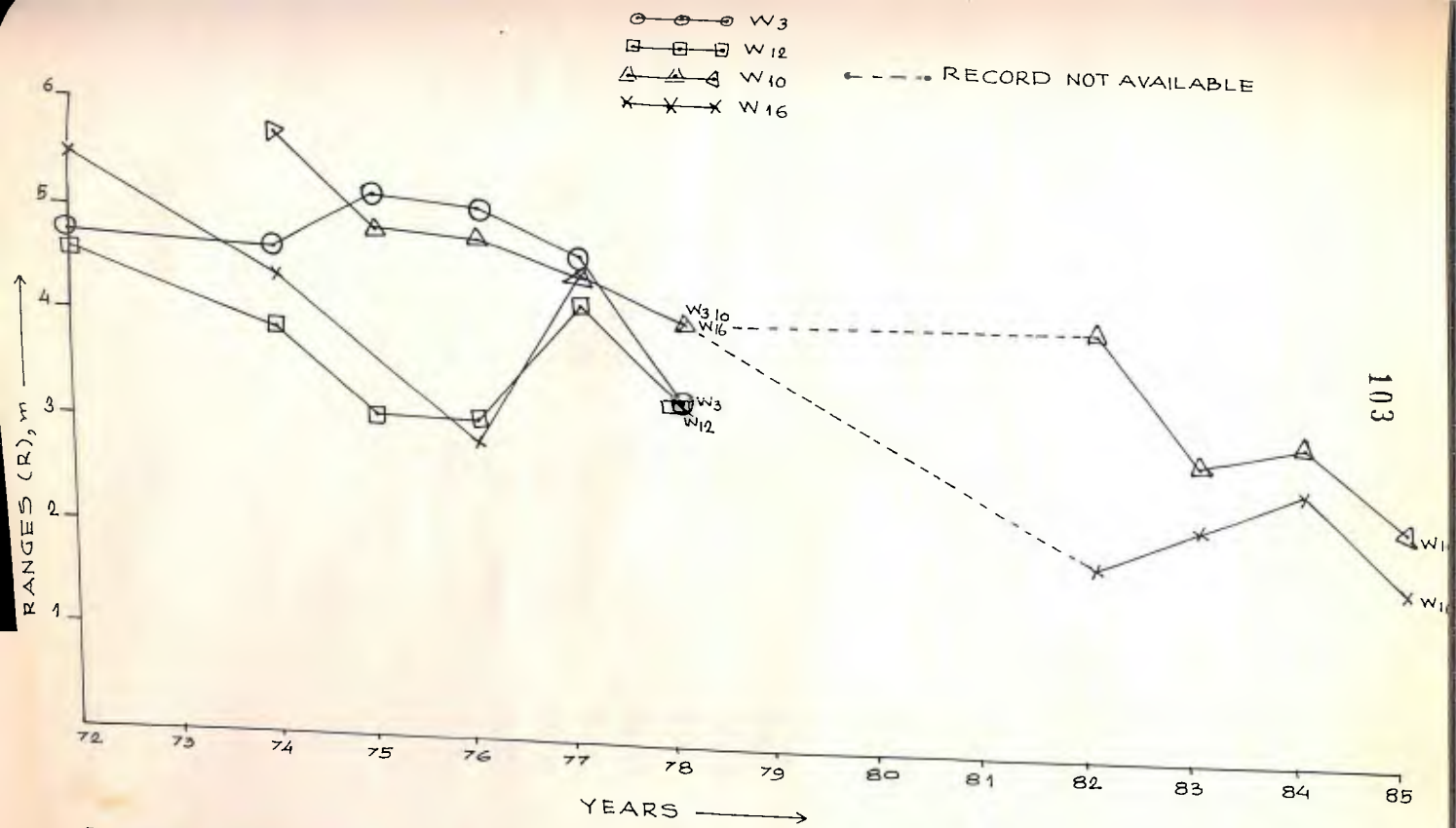


Fig. 4.18 LONG TERM VARIATION OF RANGES FOR DIFFERENT WELLS AT POWARKHEDA.

TABLE 4.9 Behaviour of maximum water table for  $W_{12}$ ,  $W_{14A}$  and  $W_3$  for the ten years records from 1972 to 1981 at Powarkheda and their deviations with reference to preceding year.

Year	Maximum value and deviation of water table with reference to water table of preceding year starting from 1972.					
	$W_{12}$		$W_{14A}$		$W_3$	
	Maximum during year (m)	Deviation (m)	Maximum during year (m)	Deviation (m)	Maximum during year (m)	Deviation (m)
1972	7.00	-	8.90	-	9.45	-
1973	7.81	-0.81	8.87	+0.03	10.50	- 1.05
1974	6.95	+0.86	7.96	+0.91	9.40	+1.50
1975	7.88	-0.93	8.80	-0.84	10.44	-1.04
1976	5.56	+2.32	6.80	+2.00	8.01	+2.43
1977	5.75	-0.19	5.80	+1.00	7.78	+0.23
1978	5.20	+0.55	5.68	+0.12	7.58	+0.20
1979	5.63	-0.43	5.45	+0.23	7.90	-0.62
Net deviation (m)		+ 1.37		+3.35		+ 1.65

The amplitude (range) vary with the well numbers and with time. It is clear from table 4.10 that the amplitudes have higher values before the introduction of canal and have lesser values after the canal was introduced into the area. The coefficient of variation was lowest (13.817%) for  $W_3$  while it was highest for  $W_{16}$  ( $C_v = 40.495\%$ ). Thus, there are less variation in ranges in  $W_3$  from year to year, while  $W_{16}$  shows larger variations year after year. The minimum water table occurs in between 32 to 35th week while the maximum water table occurs somewhere in between 22nd to 25th week. In general, the coefficient of variation is lower for the week in which peak occurs than the weeks in which water table is farthest from the ground level. Thus, the times of occurrence of peak show smaller variability as compared to the time of occurrence for maximum water table.

Thus, the coefficient of variation of time of occurrence of peaks are 3.614, 5.727, 23.54 and 24.56% respectively for  $W_3$ ,  $W_{12}$ ,  $W_{16}$  and  $W_{10}$  respectively while the corresponding coefficients of variation for the time of occurrence of maximum water table are 16.912, 8.374, 84.13 and 35.869% respectively (Table 4.10).

The decrease in amplitudes of open wells are therefore associated with the faster rise in water tables due to introduction of canal and it would lead to stabilise the

TABLE 4.10 Parameters for long term variation of water table for  $W_3$ ,  $W_{12}$ ,  $W_{16}$  and  $W_{10}$  at Fawarkheda from 1972 to 1985.

Years	Parameters for wells											
	$W_3$			$W_{12}$			$W_{16}$			$W_{10}$		
	$U_1$	$U_n$	R	$U_1$	$U_n$	R	$U_1$	$U_n$	R	$U_1$	$U_n$	R
	week	week	m	week	week	m	week	week	m	week	week	m
1972	25	35	4.75	25	35	4.60	3	34	5.50	-	-	-
1974	15	34	4.68	25	34	3.90	10	33	4.40	14	33	5.72
1975	25	36	5.14	25	37	3.06	25	-	-	24	37	4.76
1976	22	34	5.07	22	31	3.04	51	35	2.86	22	33	4.79
1977	24	37	4.68	28	35	4.18	47	35	4.46	25	35	-
1978	23	34	3.38	23	34	3.30	1	34	4.05	23	34	4.02
1982	-	-	-	-	-	-	1	35	1.88	26	13	4.04
1983	-	-	-	-	-	-	22	35	2.24	22	35	2.83
1984	-	-	-	-	-	-	31	35	2.61	26	35	3.06
1985	-	-	-	-	-	-	24	12	1.71	48	43	2.55
X	22.33	35.00	4.617	24.667	34.33	3.68	21.5	32.00	3.301	25.55	33.111	3.971
S	3.777	1.265	0.638	2.065	1.956	0.643	18.088	7.533	1.337	9.167	8.131	1.103
$C_v$	16.912	3.614	13.817	8.374	5.727	17.54	84.13	23.54	40.495	33.869	24.56	27.765

amplitude and establish a constant fluctuations year after year after the long period of time.

#### 4.9 Rate of water table rise

The water tables for different wells have risen significantly after the canal introduction in the area. The insufficient amount of information due to discontinuous records limits any mathematical generalisations about the rate of water table rise. However, it can be said that the rate of water table rise was definitely slow than, the period after the introduction of canal in the area. The rates of water table rise are the functions of time as well as inputs and outputs components of hydrologic cycles.

The net effect of all the factors influencing the water table can be easily traced out by the relative position of the minima of water table. Since the minima varies in a random fashion, the product derived out of it will also represent random behaviour. Thus, the rate of water table rise also represents the random behaviour. The accurate information on the rate of water table rise can be obtained by removing the randomness of the time series and only if the data base is not less than 30 years period. Thus, it does not seem possible to arrive at certain rate of water table rise due to insufficient and discontinuous record available at present.

#### 4.10 Preventive Measures and Control of Water Table

Large areas are being brought under canal irrigation in our country since independence, with the result the sub-soil water has risen and some areas are getting water logged. When soil pores within the root zone of crops are saturated with water, the normal circulation of air so essential for plant growth is cut off. The seepage from unlined canals and application of excess of water without any consideration of water requirements of the crops are the main causes of water logging, specially in the absence of adequate drainage. The drainage of agricultural lands is, therefore, very essential and should be integrated with the development of irrigation system to keep our lands permanently productive.

The best preventive measure will be the one in which the root cause is removed. The construction of reservoirs, canals, roads, and other structures have completely disturbed the natural drainage and hence the country is facing the problem of water logging alongwith the salinity and alkalinity problems. It is, therefore, imperative to not to go for such structures. Had these structures been already constructed the country either has to bear with natural calamities or to find some other way of solving the problem.

The seepage from canals must be controlled by use of proper lining materials. The farm water conveyance system should be improved to check the seepage losses, and the rainfall should be disposed of from the depressional areas which are causing the above problems. The impermeable barrier if present below the soil profile should be broken off.

The rise of water table not only creates the water logging problems and unfavourable conditions for plant growth but also brings the salts to surface creating salinity and alkalinity problems. We should emphasize on the proper water management instead of giving importance to the irrigation or drainage. Canals should be designed on the basis of total amount of water required for the crops grown in the area and the water to the each crop be given based on its water requirement and the critical stage important for irrigation scheduling.

Seepage control measures, water management to improve efficiency of irrigation and surface and sub surface drainage are the principle methods for controlling the ground water table. Certainly, the first two should be encouraged where it is practical to reduce land damage and conserve water. Sub surface drainage should be used in most of the areas where water logging is a chronic problem. The pumping of wells in combination with the installation of surface drains

has also been used to reduce the water logging and soil salinity problems on the farm lands.

The most of the open wells were lying as dead wells at Powarkheda and in nearby villages. The water level in those wells was so high that it could easily be taken out for irrigation. It is, therefore, important that in present circumstances, the more emphasis be given on the use of these wells for the purpose of irrigation instead of supplying water through canals to the water logging.

It will not be unwise to cultivate the high water requiring crops and to plant Eucalyptus on the field boundaries and along the road sides. These plants will not only reduce the waterlogging by way of drawing water from the deeper layers required for its metabolic activities and transpiration but also boost the farmers financially.

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# CHAPTER - (V)

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## SUMMARY AND CONCLUSION

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SUMMARY AND CONCLUSION :

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Water table is a continuous random variable and it varies in a periodic fashion attaining maxima and minima at some fixed time. Water table generally depletes in dry season from January to May and September onwards, provided it is not being recharged from surface sources like river, ponds or canals. The water table changes with time. The magnitude of change (increase) in levels depend upon the season and total amount of rainfall occurred prior to the season, in addition to different input and output components of hydrologic cycle. Rainfall events in begining do not bring sudden change in water table, but it satisfies the soil moisture pores prior to bringing any change in water table.

From the study of water table data, rainfall data and canal delivery schedules, the following conclusions are drawn :

1. Water table does not respond to the initial rainfall events. The water table rises with some time lag of two to three weeks. This is due to the fact that the rainfall saturates the soil moisture in this zone and does not contribute to water table.

2. Rate of rise of water table has increased with the introduction of canal in the area. The introduction of canal distorts the regular periodic character of the water table and instead of single well defined peak, more than one peak are observed.
3. Rate of rise of water table varies with time after the onset of monsoon rains. It is slow in beginning but very fast just before attaining the peak. This is due to the fact that after the soil moisture is satisfied, the major portion of the rainfall contributes towards the rise in water table. The rise in water table ceases just before the rainfall ceases by taking a time lead of 2-3 weeks.
4. The rates of rise in water table are more consistent after the introduction of canal irrigation than the period before the introduction of canal as shown by coefficients of variations of 73.184% and 94.377% respectively.
5. The relationship between the mean of the ranges ( $\bar{R}$ ) for different wells considered for 14 years period and the year ( $X$ ) can be described by linear equation of the form,



$$\bar{R} = 5.149 - 0.1986X$$

$$= -0.875$$

Where  $\bar{R}$  = mean of the ranges for different wells  
for 14 years period,

$W = 1, 2, \dots, N$  (Number of wells considered for analysis  
during the year).

$X$  = coded value of years with base in 1972

Thus  $X = 0$  for 1972, 1 for 1973, 2 for 1974

- - - - -  $X = 12$  for 1984 and on on.

Thus, the mean range decreases with time.

6. The canals should be lined properly in addition to the surface drainage system for water logging control. The crops with high water requirement should be encouraged in the area.

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APPENDIX - A

Weekly rainfall data (cm.) of Powarkheda for 14 years period from 1972 to 1985.

Weeks	Rainfall for different years.						
	1972	1973	1974	1975	1976	1977	1978
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	0.12	-	-
4	-	-	-	-	-	-	0.36
5	-	0.73	-	-	-	-	-
6	-	0.63	-	-	-	-	0.08
7	-	-	-	-	-	-	2.01
8	-	0.44	-	0.25	-	1.20	-
9	-	-	-	-	-	1.71	-
10	-	-	-	1.5	-	-	1.37
11	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-

Contd.....

Contd.....App.A

Weeks	1972	1973	1974	1975	1976	1977	1978
14	-	-	-	-	0.06	-	-
15	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-
17	-	-	-	-	-	-	0.16
18	-	-	-	-	-	0.33	-
19	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-
21	-	-	0.01	-	0.47	0.67	-
22	-	-	0.07	-	-	-	-
23	-	-	0.08	1.78	2.98	-	1.09
24	-	2.62	-	-	-	1.30	5.79
25	2.34	-	10.25	1.61	3.26	7.64	6.03
26	7.64	1.82	2.62	4.41	-	21.22	31.40
27	9.37	3.70	3.07	7.32	20.87	3.96	21.96
28	5.67	33.70	13.58	1.99	10.82	0.25	21.08
29	-	33.85	5.60	3.44	10.25	3.34	0.94
30	-	0.45	16.49	0.12	1.30	9.31	1.92
31	1.08	0.65	4.07	3.10	23.04	3.81	1.78
32	4.46	6.42	10.21	20.91	3.96	11.96	10.25
33	41.08	7.10	32.02	17.45	0.83	1.96	11.28
34	3.38	6.6	8.27	5.25	1.25	15.55	14.80
35	10.25	-	0.53	10.72	18.32	33.54	10.80
36	-	10.14	0.60	8.56	8.67	3.64	0.51

Contd.....

Contd.....App. A

	1972	1973	1974	1975	1976	1977	1978
37	2.88	1.05	0.05	18.56	8.26	32.01	-
38	-	2.38	0.03	-	0.08	-	1.38
39	-	5.41	2.05	0.17	-	-	-
40	-	-	0.81	-	-	3.18	2.09
41	-	-	12.93	0.80	-	-	-
42	-	-	-	-	-	-	-
43	0.56	-	-	-	-	-	-
44	-	0.15	-	-	-	-	-
45	-	-	-	-	4.701	-	-
46	-	-	-	-	-	-	-
47	-	-	-	-	1.47	5.98	-
48	1.05	-	-	-	-	0.79	0.79
49	-	1.10	-	-	-	-	6.54
50	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-
52	-	-	-	-	-	0.13	-

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Contd.....

Contd.....App. A

Weeks	1979	1980	1981	1982	1983	1984	1985
1	-	-	0.41	-	-	0.32	-
2	-	-	-	0.27	-	5.12	-
3	1.07	-	0.08	0.19	-	-	-
4	1.35	-	-	3.26	0.09	-	-
5	-	-	-	5.58	-	-	-
6	2.16	-	-	-	-	-	-
7	3.15	-	-	0.18	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	2.20	-	-	-	-	-	-
11	-	-	4.48	-	-	-	-
12	-	-	-	-	-	-	-
13	-	-	-	-	-	-	0.93
14	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-
19	-	-	7.65	-	-	-	-
20	-	-	-	-	-	-	-
21	-	-	-	-	2.22	-	-
22	2.31	-	-	-	-	-	-
23	-	4.06	0.16	-	-	2.45	0.73

Contd.....

Contd.....App. A

	1979	1980	1981	1982	1983	1984	1985
24	-	11.88	3.30	2.55	2.36	2.91	0.15
25	5.61	8.89	12.01	7.38	1.71	-	0.70
26	5.86	11.06	5.6	-	2.65	5.74	6.52
27	1.65	8.01	15.36	-	1.51	7.94	1.67
28	7.53	0.61	4.65	8.93	8.89	1.02	4.08
29	1.26	-	3.53	6.56	7.46	8.20	1.89
30	1.67	7.35	7.29	7.41	4.25	0.33	1.64
31	1.83	10.80	4.28	7.43	8.49	19.85	14.50
32	-	3.34	22.52	4.57	5.69	29.24	19.55
33	0.39	2.17	6.00	12.74	15.35	43.94	18.12
34	0.51	0.71	0.04	39.21	12.09	3.18	-
35	-	32.09	0.19	5.70	7.72	1.34	2.49
36	-	5.14	1.58	1.87	33.48	2.14	1.49
37	-	-	1.62	2.78	0.64	2.33	4.19
38	-	-	4.35	0.49	4.34	-	3.71
39	-	-	2.94	0.40	4.40	0.44	0.17
40	-	-	-	-	1.88	-	4.07
41	-	-	-	0.39	1.02	1.31	-
42	-	-	-	-	-	-	0.15
43	-	-	-	0.09	-	0.16	-

Contd.....



APPENDIX - B

Values of  $X_1$ ,  $X_n$ ,  $U_1$ ,  $U_n$  and R from water table fluctuation curves in different years from 1972 to 1985 for open wells at Powarkheda.

OPEN WELLS	Parameters for different years.									
	1972					1974				
	$X_1$ m.	$X_n$ m.	R m.	$U_1$ weeks.	$U_n$ weeks.	$X_1$ m.	$X_n$ m.	R m.	$U_1$ weeks.	$U_n$ weeks.
W <sub>3</sub>	9.45	4.70	4.75	25	35	9.40	4.72	4.68	15	34
W <sub>12</sub>	7.00	2.40	4.60	25	35	6.95	3.05	3.90	25	34
W <sub>14A</sub>	8.90	2.50	6.40	3	35	7.96	3.00	4.96	14	35
W <sub>14B</sub>	8.40	2.95	5.45	4	35	8.58	2.60	5.98	14	34
W <sub>15</sub>	6.70	2.60	4.10	1	34	6.02	2.98	3.04	10	33
W <sub>16</sub>	8.90	3.40	5.50	3	34	7.10	2.70	4.40	10	33
W <sub>10</sub>	N.A.	N.A.	N.A.	N.A.	N.A.	9.00	3.28	5.72	14	33

Open Wells	Parameters for different years.									
	1975					1976				
	$X_1$	$X_n$	R	$U_1$	$U_n$	$X_1$	$X_n$	R	$U_1$	$U_n$
m.	m.	m.	weeks.	weeks.	m.	m.	m.	weeks.	weeks.	
$W_3$	10.44	5.30	5.14	25	36	8.01	3.94	5.07	22	34
$W_{12}$	7.88	4.82	3.06	25	37	5.56	2.52	3.04	22	31
$W_{14A}$	8.80	5.40	3.40	25	37	6.80	2.03	4.77	22	37
$W_{14B}$	8.74	4.75	3.99	28	37	7.10	2.15	4.95	20	31
$W_{15}$	8.76	N.A.	N.A.	25	N.A.	4.78	0.78	4.00	22	36
$W_{16}$	8.16	N.A.	N.A.	25	N.A.	4.50	1.64	2.86	51	35
$W_9$	10.56	3.40	7.16	31	37	7.10	2.32	4.78	22	33
$W_{10}$	9.96	5.20	4.76	24	37	8.10	3.31	4.79	20	33
$W_7$	10.23	3.80	6.43	25	37	7.90	2.80	5.10	22	37



Open wells	Parameters for different years.									
	1977					1978				
	$X_1$	$X_n$	R	$U_1$	$U_n$	$X_1$	$X_n$	R	$U_1$	$U_n$
m.	m.	m.	weeks.	weeks.	m.	m.	m.	weeks.	weeks.	
W <sub>3</sub>	7.78	3.10	4.68	24	37	7.58	4.20	3.38	23	34
W <sub>12</sub>	5.75	1.57	4.18	28	35	5.20	1.90	3.30	23	34
W <sub>14A</sub>	5.80	1.90	3.90	24	37	5.68	2.10	3.58	24	28
W <sub>14B</sub>	6.40	1.80	4.60	25	35	6.20	2.41	3.79	24	33
W <sub>15</sub>	4.38	0.80	3.58	23	35	4.28	0.90	3.38	24	33
W <sub>16</sub>	5.91	1.45	4.46	47	35	5.25	1.20	4.05	1	34
W <sub>9</sub>	5.89	1.80	4.09	25	35	6.60	2.08	4.52	24	28
W <sub>10</sub>	N.A.	N.A.	N.A.	N.A.	N.A.	7.12	3.10	4.02	23	34
W <sub>7</sub>	N.A.	N.A.	N.A.	N.A.	N.A.	7.41	3.53	3.78	24	34

Parameters for Different years.

Open wells.	1982					1983				
	$X_1$ m.	$X_n$ m.	R m.	$U_1$ weeks.	$U_n$ weeks.	$X_1$ m.	$X_n$ m.	R m.	$U_1$ weeks.	$U_n$ weeks.
$W_{16}$	3.98	2.10	1.88	1	35	3.99	1.75	2.24	22	35
$W_9$	5.00	2.75	2.25	22	35	5.49	2.45	3.04	22	35
$W_{10}$	5.34	1.30	4.04	26	13	5.70	2.87	2.83	22	35
$W_7$	4.75	1.75	3.00	22	35	5.12	2.04	3.08	22	35
	1984					1985				
	$X_1$	$X_n$	R	$U_1$	$U_n$	$X_1$	$X_n$	R	$U_1$	$U_n$
$W_{16}$	5.88	2.70	3.18	39	35	8.15	3.30	4.85	48	34
$W_9$	6.60	3.10	3.50	26	35	5.20	3.47	1.73	24	43
$W_{10}$	6.18	3.02	3.06	26	35	5.20	2.65	2.55	48	43
$W_7$	5.21	2.60	2.61	31	35	4.55	2.84	1.71	24	12

N.A. - Record not available.