ANALYSIS OF DEPLETION CURVE FOR DYNAMIC GROUNDWATER STORAGE

By

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1. Introduction

Drought is a recurring climatic condition which affects large areas on earth. It is defined as a period of abnormally dry weather that is sufficiently prolonged to cause serious hydrologic imbalance in the affected area (Huschke, 1959). Areas affected by drought can range from a few hundred square kilometers to thousands of square kilometers. The most powerful effect of drought is to reduce agricultural production over a wide area. Other adverse impacts are: reduction in hydropower generation, shortage of drinking water, detoriotion in water quality, loss of aquatic lives, and reduction in recreational facilities. Other adverse economic impacts follow these losses.

Drought is the third most geologic hazard in terms of economic losses produced, ranking only behind floods and frost damage (Haas, 1978). Agencies at various levels of engineering organisations have to take action to reduce the effect of droughts. Adjustments to drought relevant for agriculture and for urban areas include the following:

i) Conservation of water; This includes protection of water supply by eliminating leakage and evaporation; alteration of cultivation practice to include strip cropping, minimum tillage and development of wind breaks.

ii) Diversification of crop and live stock and selection of drought-resistant crops;

iii) Development of groundwater resources to supplement surface water or existing groundwater supplies;

iv) Integration of waste-water reuse into community management;

v) Formulation of priorities among competing demands so that less vital uses can be minimized during drought.

The wise use of groundwater resources can play a significant role in reducing the impact of drought in both urban and rural environments. During years of drought, the rate of groundwater recharge is usually insufficient to keep pace with withdrawals or discharge to rivers. Groundwater potentials of a basin is finite. The rational limit of the rate of groundwater exploitation whether during drought or normal period should be such that protection from depletion is provided, protection from pollution is provided, negative ecological effects are reduced to a minimum and economic efficiency of exploitation is attained.

2. Well Hydrograph Approach

Groundwater, which is a renewable resource, is temporarily depleted when aquifers are over pumped. Aquifer storage is commonly described as temporary or permanent. The former refers to water stored between the highest and lowest levels of the water table and thus subject to seasonal drainage, which, averaged over a long period, itself provides a measure of the average recharge. However, below the minimum level of the water table in major aquifers lies a great volume of saturated soil that provides permanent storage available to wells of adequate depth but which can not be drained naturally. A good management practice during drought period demands adequate information on how much water is in dynamic storage and how much in static and how these volumes vary with time.

Several methods are used to present water-level data. The most common are well hydrograph, and water-level contour maps. From the study of water level hydrographs at a number of observation well, the water table fluctuation in a basin could be computed. The water table fluctuation can be used to calculate changes in quantity of groundwater in storage as well as to determine recharge of the aquifer or leakage from it to underlying aquifers (Hydrological Maps, Unesco WMO-1977).

The visual examination of hydrographs presenting the record of several years may yield the following indications (Mandal land Shiftan, 1981):

i) Water levels fluctuating around a constant mean indicate a state of hydraulic equilibrium that is usually associated with a stable hydrologic situation. However, the mere existence of a hydraulic equilibrium does not provide guarantee against the eventual influx of low-quality water.

ii) Decreasing mean water levels associated with a constant or decreasing amplitude of yearly oscillation suggest diminished natural replenishment, which may be caused by drought years, by changes of surface cover (e.g., urbanization), or by the diversion of river flow from the area.

iii) Decreasing mean water levels accompanied by increasing yearly oscillation are the result of intensified groundwater abstraction.

These indications do not prove the existence of a certain situation. They provide only hints and have to be corroborated in each case by additional lines of evidence.

2.1 Evaluation of Change in Groundwater Storage

The change in groundwater storage in a basin during a certain time period can be computed from the water table fluctuation exhibited in the basin during the time period. The simplest way to show water-table fluctuations is to show water-table position at two or more different times on separate maps.

This is an effective method, particularly when the maps can be shown on the same page or sheet. A second method is to show contours of the water table at two or more different times by different line patterns, or by lines of different colour, on the same map.

The extent of the fluctuations can be shown by isolines derived from two or more sets of water-table elevations. Such maps are particularly useful in areas where lowering of water table is excessive or is considered to be potentially so.

Using the elevation themselves, the change in water level can be determined by subtracting the water level at each data point at the end of the time period from the water level at the beginning of the time period. The resultant changes in water table position can then be contoured.

The change in storage in a groundwater basin, $\triangle S$, during a time period (t) can be computed using the relation;

$$\triangle S = \sum_{i=1}^{N} \triangle h_i \, A_i \, S_{yi} \qquad \text{----(1)}$$

in which;

S_{yi} = specific yield of the aquifer in the area A_i;
$\triangle h_i$ = water level change in the i^th observation well;
A_i = the area of i polygon which is the weightage of water level observation in the i^th observation well; water level changes are weighted by drawing a Thiessen polygon around each observation well.
N = total number of observation wells.

2.2 Trend Analysis

The main objective of studying hydrologic time series is to understand the mechanism that generates the data so that the future sequences may be simulated or to forecast the future events over a short period of time. These are attempted by making inferences regarding the underlying laws of the stochastic process from the historical data and then by postulating a model that fits the data which can in turn be used for simulating or forecasting the future values. It is therefore necessary to identify the various components of the hydrologic time series and its characteristics.

In general, a time series can be divided into two components, viz., deterministic and stochastic. Deterministic components are those which can be determined by predictive means, where as the stochastic component consists of chance dependent events. Hydrologic time series has both these components. The deterministic components are the trend and the cyclicities. The stochastic component is due to erratic atmospheric circulation.

The trend may be loosely defined as ´long term change in the mean´. A difficulty with this definition is deciding what is meant by ´long term . For example, climatic variable sometimes exhibits cyclic variation over a very long time period of about 50 years or so. If the data of only about 20 years are available, then the long term cyclic variation would appear to be a trend. On the other hand if the data of say 200 years are available, even the long term cyclic variation would be clearly visible. Nevertheless for all practical purposes of analysis of short term data, it may still be more meaningful to think of such long term oscillation as trend. The existence of trend in hydrological series may be due to low frequency oscillatory movement induced by climatic changes or through changes in land use and catchment characteristics. Trend analysis is generally done on annual series and not on seasonal series so as to suppress the effect of periodic component. The primary objective of groundwater analysis when drought condition prevails in an area is determination of reliable aquifer yield. There are two basic approaches to the establishment of such information. The first is based upon a water balance equation which requires the identification of the various elements of the hydrologic cycle as they affect a particular system and subsequent quantification of those elements. The second approach is based upon analytical techniques which simulate groundwater behaviour as it is known to conform to various physical laws. The two approaches are complementary and neither one can be regarded as a suitable substitute for the other.

The application of time-series techniques to groundwater problems is a logical extension of the water balance approach, allowing a water balance equation to become dynamic and thus simulate a groundwater system in time (Houston, 1983). A system model essentially consists of input which is acted upon by a transfer function in order to produce output. The input data may be represented by recharge and discharge and the output by water table data. The transfer function of a system model is estimated a posteriori by statistical techniques which produce a minimum error. In this the systems model differs basically from analytical or numerical models which are based upon physical laws established a priori.

2.3 Depletion Curve Analysis

The dynamic storage of the ground water system can be estimated by using a unicell model by the record of discharge on weekly or monthly basis.

Assuming that there is no pumping and replenishment after the monsoon is over, the equation of continuing for natural drainage will be;

$$dS/dt = -Q(t)$$

$$S(t) = t_o \; D(t)$$

$$dS(t)/dt = t_o \,(\, dQ(t)/dt) \qquad ----(2)$$

$$t_o \,(dQ(t)/dt) = -Q(t)$$

$$dQ(t)/dt + (1/t_o)\; Q(t) = 0. \qquad ----(3)$$

Solution is :

$$Q(t) = Q_o \; e^{(-t/t_o)} \qquad ----(4)$$

The total value of storage may thus be given by;

$$Q(t) \int_0^{\alpha} Q(t)\, dt = \int_0^{\alpha} Q_o \; e^{-(t/t_o)}$$

$$Q(t) = Q_o \; t_o \qquad ----(5)$$

For the total volume of storage, Q(t), the value of deplection time (t_o) is required. This value can be estimated by using the equation 4. as follows;

$$\text{Log } Q(t) = \text{Log } Q_o - (t/2.3 \; t_o) \qquad ----(6)$$

The slope of the plot of Log Q(t) against time (t) will estimate the value of 2.3 t_o, yielding the value of depletion time.

3. General description of Krishna basin

Krishna basin lies between 13 30´ to 18 44´ N latitude to 73 12´ to 81 36´ 10" E longitude, covering parts of Maharashtra, Karnataka and Andhra Pradesh State (Fig. 1). The climate of the basin is characterised by a hot summer and general dryness during the major part of the year except during South-west monsoon. The rainy season generally commences in the month of June and lasts till October or so, with the withdrawal of the monsoon by about the first week of October the day temperature increases slightly. However, the night temperatures decrease steadily with the day after the withdrawal of monsoon. The Krishna basin comes under the influence of south-west monsoon and this season lasts over the basin till the end of September. Rainfall of about 564.88 mm which forms 72.08 percent of the total annual rainfall in the basin is received during the south-west monsoon season. The basin also received some rainfall during north-east monsoon season and estimates indicate that about 17.64% of total annual rainfall over the basin is received during north-east monsoon season. Evapo-transpiration losses in the basin vary betwen 90 mm to 220 mm from winter to summer months. The details of sites chosen for the study are given in Table 1.

3.1 Departure Analysis of Krishna Basin

There are many simple indices that can be used to see immediate effect of drought on streamflow. In the following section departure analysis of streamflow data for the selected sites of Krishna river basins was carried out.

Table 1 : Details of sites chosen for stream flow studies in Krishna basin.

Sl.No.	Name of Site	Distt.	State	Stream	Catchment area (Km)
1.	Karad	Satara	Maharashtra	Krishna	5462
2.	Dhond	Poona	- do -	Bhima	11,660
3.	Narsingpur	Sholapur	- do -	- do -	22,865
4.	Takali	- do -	- do -	- do -	33,916
5.	Wadakwal	Sholapur	Maharashtra	- do -	12,092
6.	Yadgir	Gulbarga	Karnataka	- do -	69,863
7.	Bawapuram	Kurnool	Andhra-Pradesh	Tunga-bhadra	67,180

A commonly used index to see the effects of drought on streamflows is to compare the runoff depth or volume for a given duration i.e. fortnight, month or a year with long term mean or standard period normal value for the same duration. It has been suggested that if the runoff is found to be less than 75% of normal runoff at a site, the year would be considered as drought year and if it occurs in 25 or more than 25% of years, then the area would be considered as drought prone. Drought is classified as severe drought and moderate drought depending upon percentage departure of runoff volumes as given below (CWC, 1982) :

Percentage departure	50%	- Severe
Percentage departure	25-50%	- Moderate

The results of the deviation of annual flows during ´87 -´88 from long term average flow for the chosen sites are given in Table 4.3. As evident from the Table, the annual flows for the year 1985-86 for all chosen sites were deficient by more than 25% of normal flow indicating year 1985-86 as drought year. In the year 1986-87, all sites except Karad showed annual deficiency of more than 25 percent. However, during year 1987-88 again all sites showed annual deficiency of more than 25%. The classification of drought based on above criteria (moderate, normal and severe drought) during years 1985-86, 1986-87 and 1987-88 for all the chosen sites of Krishna basin is given in Table 2.

Table 2 : Drought classification at seven sites of Krishna basin from ´85-´87

Year	Name of Site						
	Karad 1	Dhond 2	Narsinghpur 3	Takali 4	Yadgir 5	Wadakwal 6	Bawapuram 7
1985-86	M	S	S	S	S	S	S
1986-87	N	M	S	S	S	S	S
1987-88	S	S	S	S	S	S	S

M-moderate, S-severe, N-normal

3.2 Discharge analysis of Krishna basin by unicell model

To estimate the value of depletion time, the monthly data of Krishna basin at seven sights (Fig.1) from June '77 to May '86 has been subjected to depletion curve analysis. The results have been plotted in Fig. 2 to 8 and the estimated value of $2.3*t_o$ have been estimated only for years 1983 to 1986 reported in Table 3.

Table 3 : Estimated value of depletion time, (2.3 x t_o) in months, for seven sites of Krishna basin.

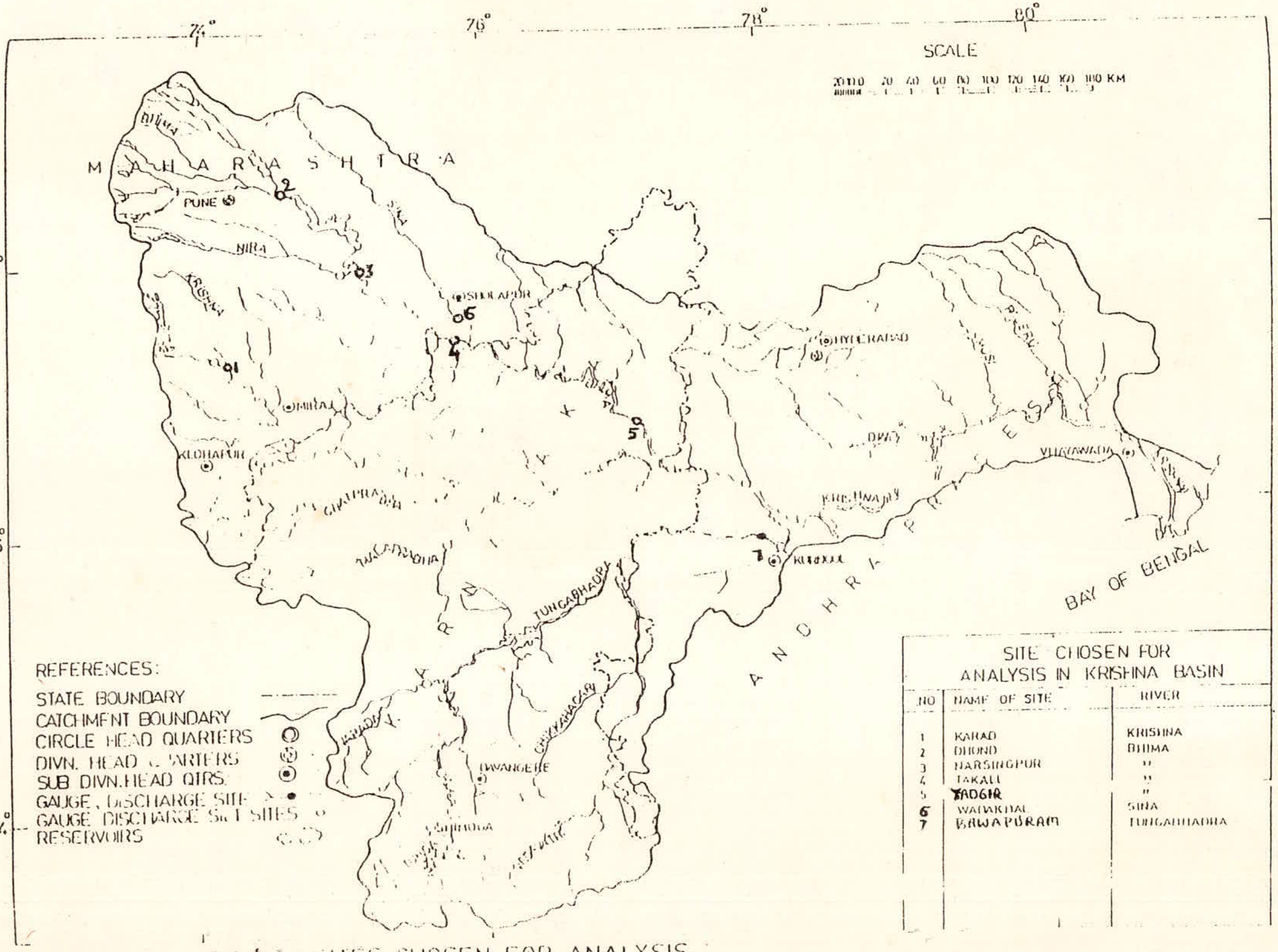
Year	Name of Site							*
	Karad	Dhond	Narsinghpur	Takali	Yadgir	Wadakwal	Bawapuram	Percent departure of annual flow from long term average
	1	2	3	4	5	6	7	
83-84	1.7	1.8	1.1	1.0	1.1	3.0	1.2	Positive at 6
84-85	1.2	1.2	0.7	0.8	1.1	0.4	0.4	Negative at all sites
85-86	0.8	1.0	0.3	0.3	0.9	0.2	0.4	- do -

* Hydrological Aspects of Drought (CS-37).

4. References

1. National Institute of Hydrology (1990). Report on Hydrological Aspects of Drought (CS-37).

2. Mandel. S and Shiftan, Z.L. (1981). Ground water resource investigation and development. Academic press Inc. New York.



SITE CHOSEN FOR ANALYSIS IN KRISHNA BASIN

NO	NAME OF SITE	RIVER
1	KARAD	KRISHNA
2	DHOND	BHIMA
3	NARSINGPUR	"
4	TAKALI	"
5	YADGIR	"
6	WADAKBAL	SINA
7	BAWAPURAM	TUNGABHADRA

FIG. 1 : SITES CHOSEN FOR ANALYSIS.

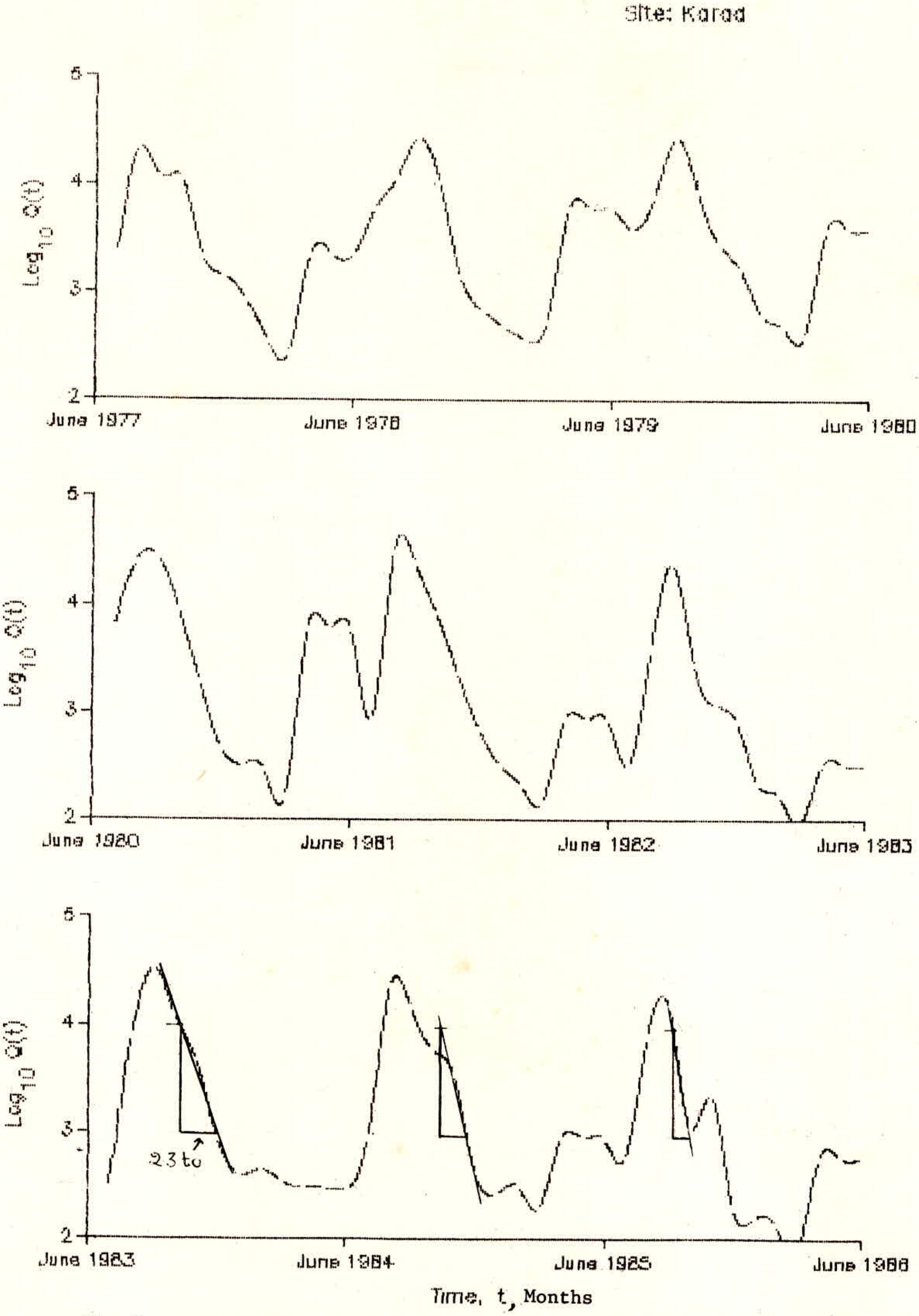


Fig. 2: Depletion curve and interpretation of depletion line for gauge site Karad of Krishna basin.

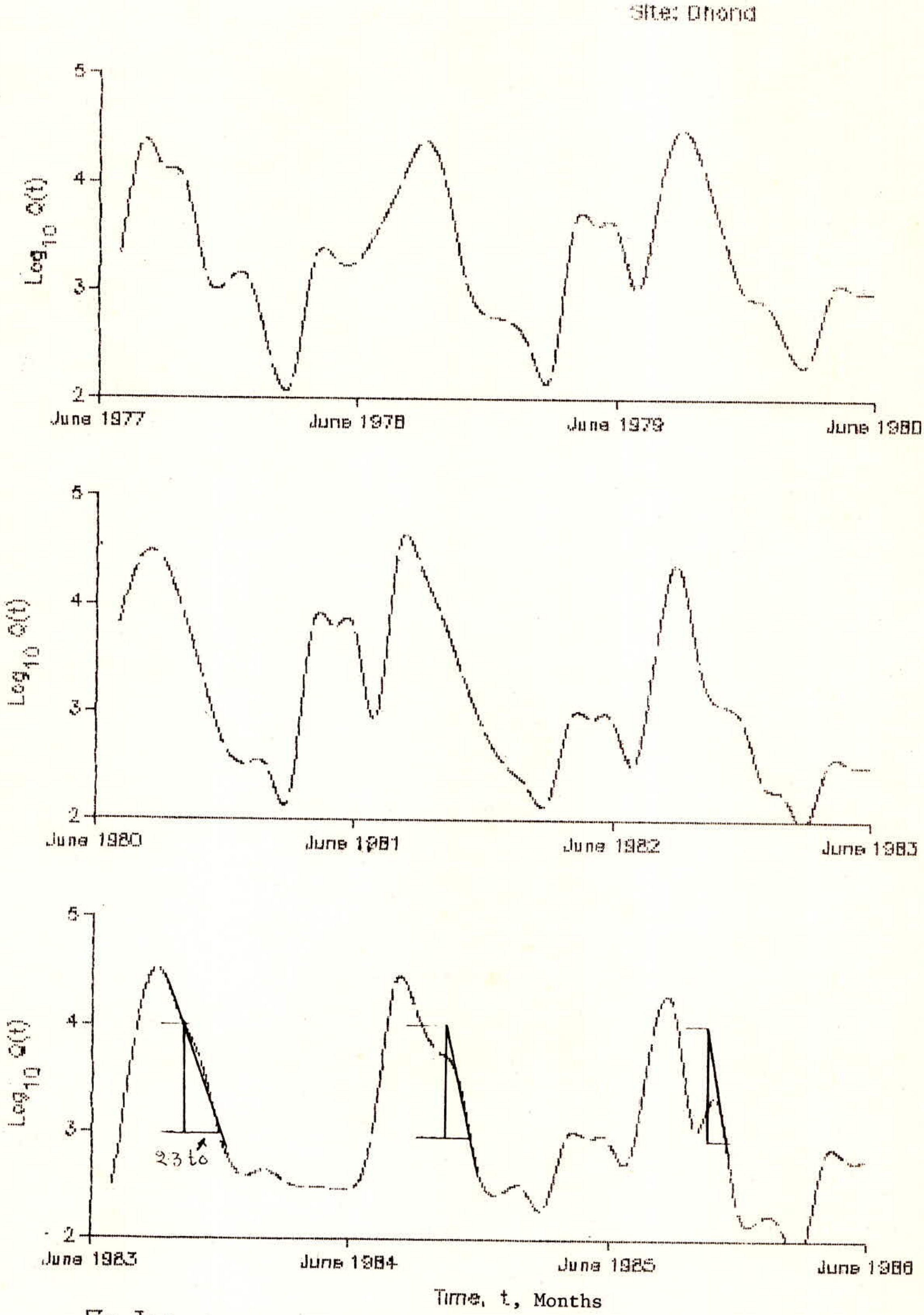


Fig. 3: Deple tion curve and interpretation of depletion line for gauge site Dhond of Krishna basin.

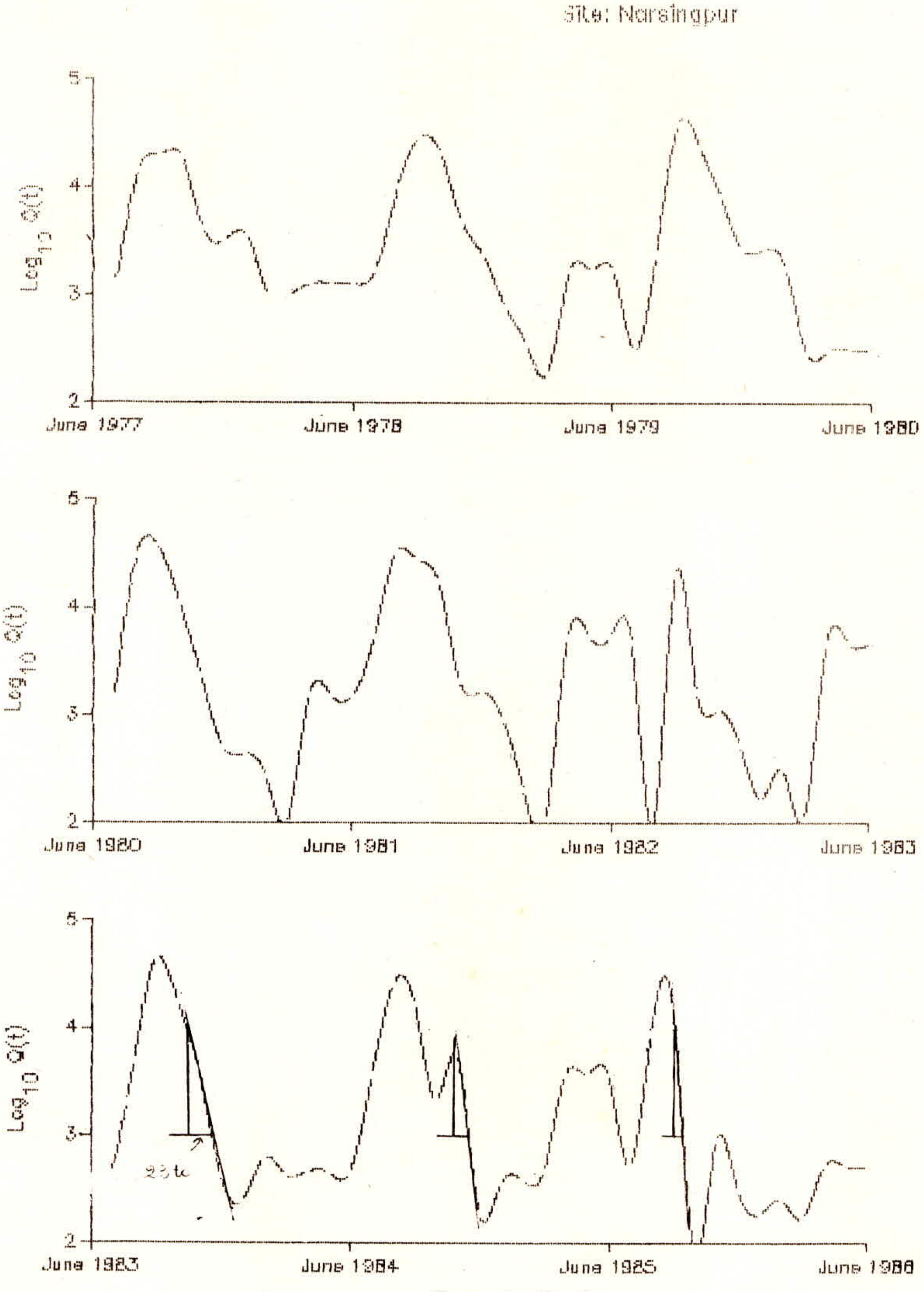


Fig. 4: Depletion curve and interpretation of depletion line for gauge site Narsingpur of Krishna basin.

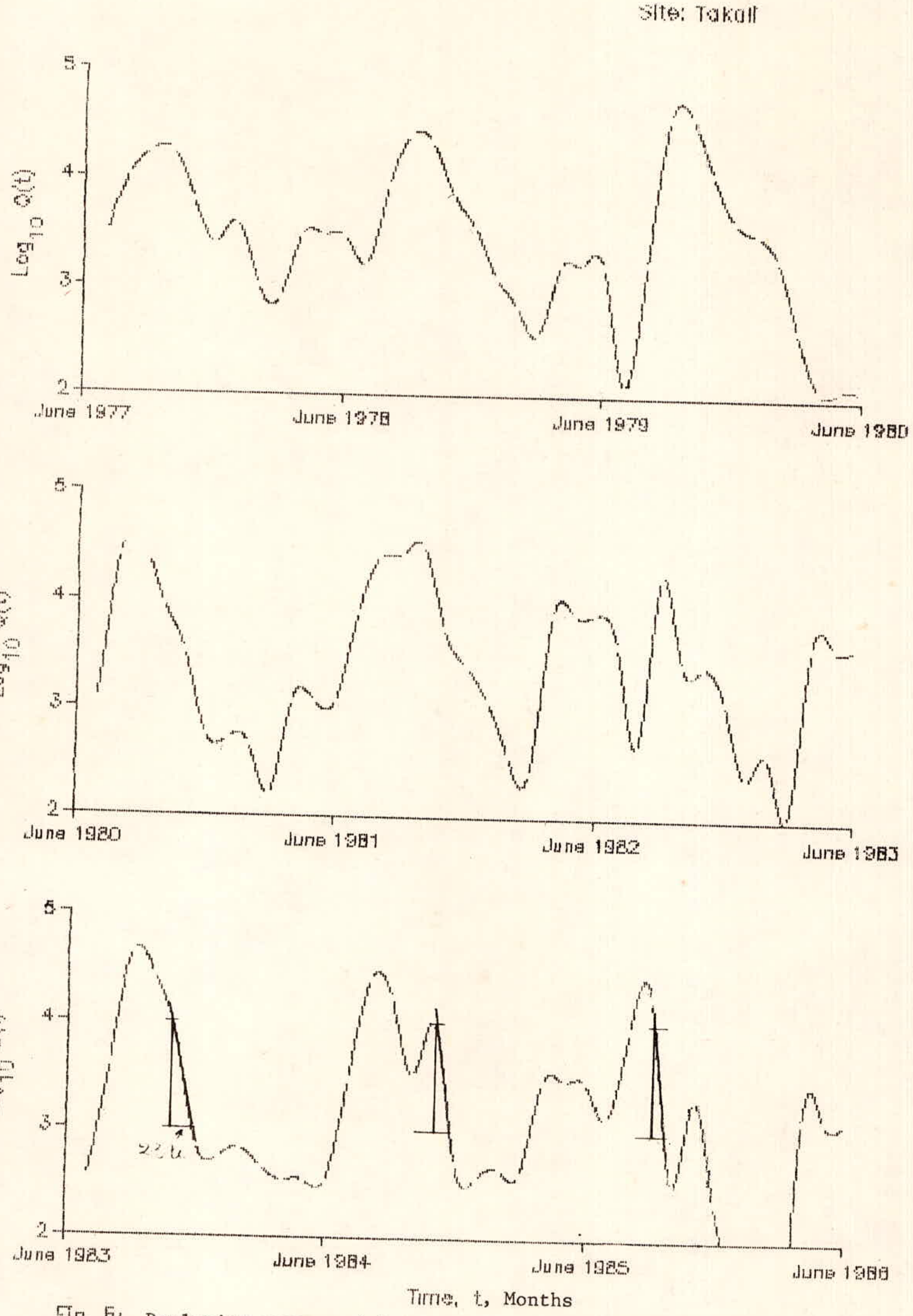


Fig. 5: Depletion curve and interpretation of depletion line for gauge site Takali of Krishna basin.

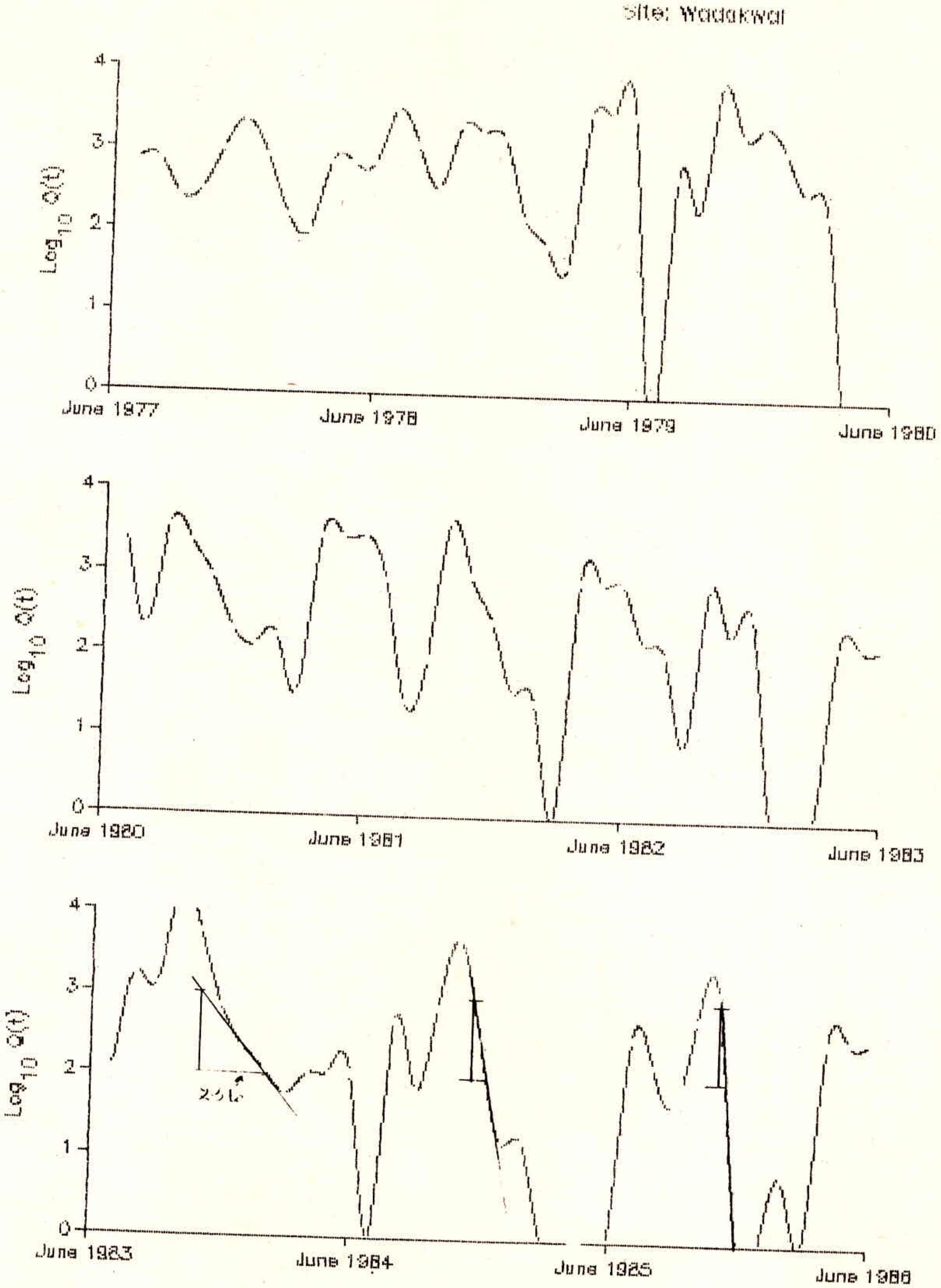


Fig. 6: **Depletion curve and interpretation of depletion line for gauge site Wadakwal of Krishna basin.**

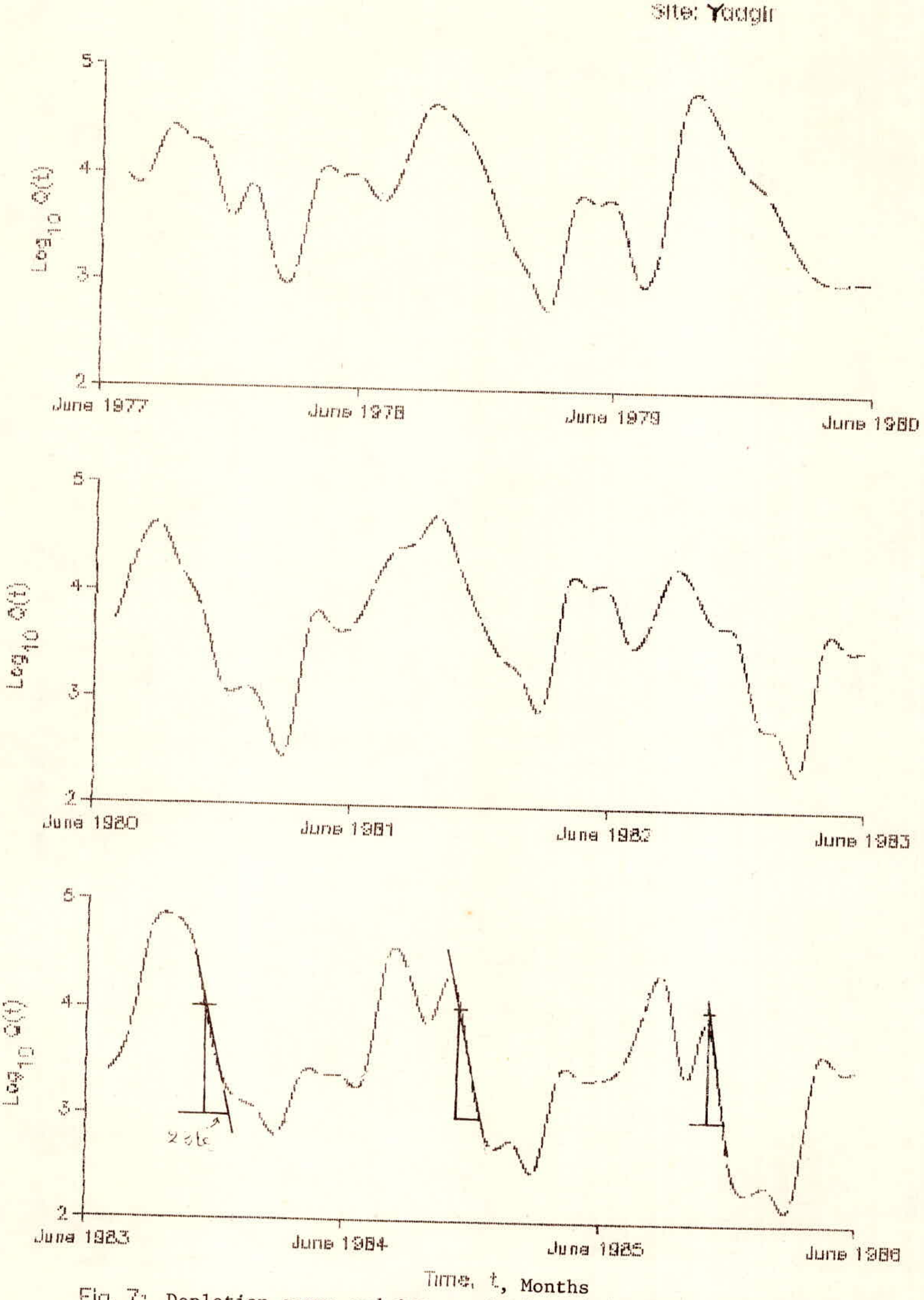


Fig. 7: Depletion curve and interpretation of depletion line for gauge site Yadgir of Krishna basin.

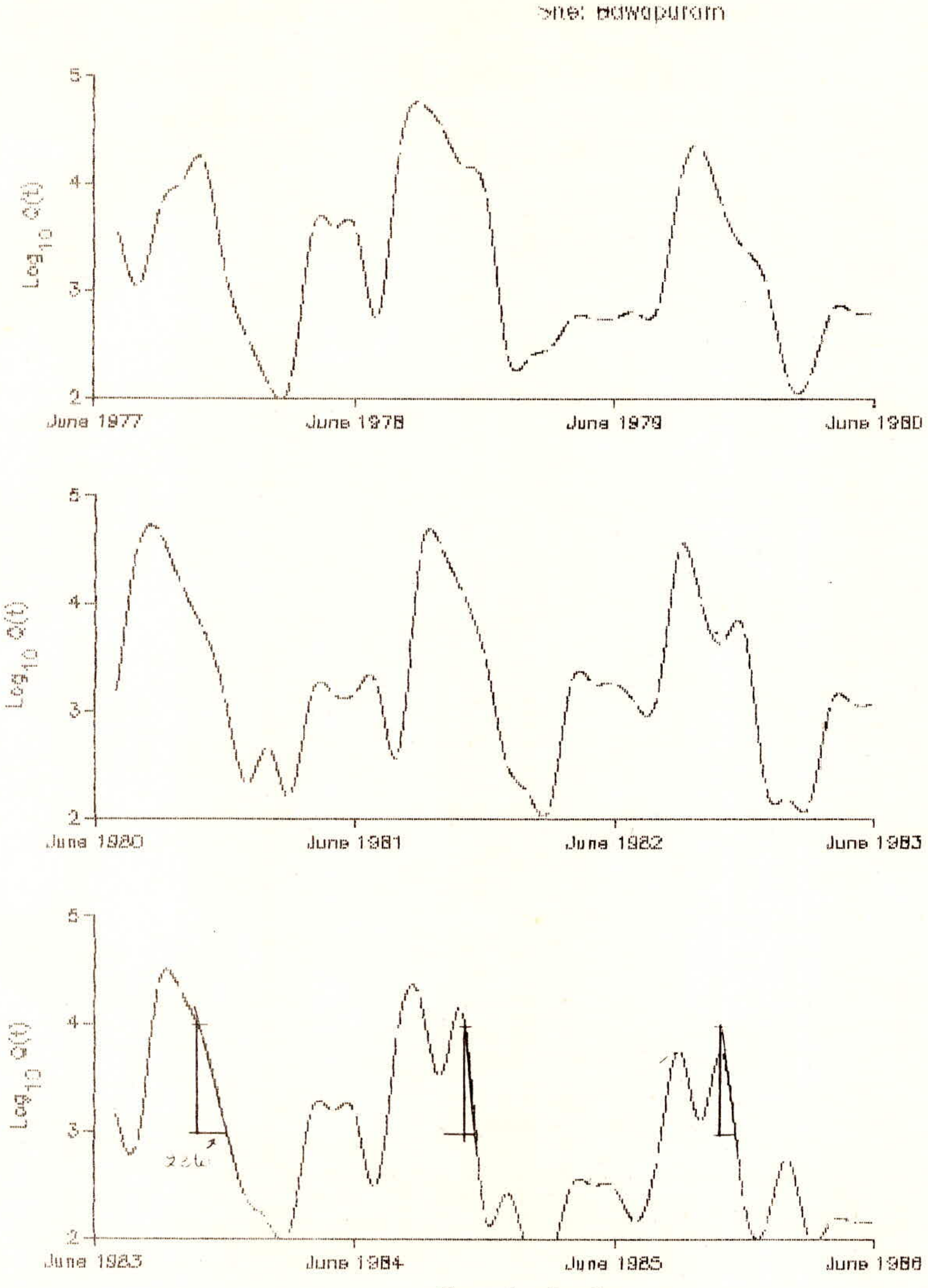


Fig. 8: Depletion curve and interpretation of depletion line for gauging site Bawapuram of Krishna basin.