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Characteristics of Groundwater Hydrographs in Diverse Hydrogeological Setup of Madhya Pradesh, India

Anu Radha Bhatia[1] and R.M. Verma
Central Ground Water Board
North Central Region, Bhopal - 462 011, INDIA
E-mail: [1]aradha_bhatia@lycos.com

ABSTRACT: The state of Madhya Pradesh encompasses diverse setup of geological rock formations. The type of rock formation mainly controls the ground water occurrence and movement. Although, the sub-surface geology has been established by geophysical surveys and exploratory drilling by the Central Ground Water Board, to better comprehend the nature of the aquifer tapped by a well and changes of groundwater regime with time, it is imperative to monitor the groundwater levels regularly. Manual monitoring, especially high frequency monitoring of groundwater levels is a very tedious practice. High frequency monitoring of ground water level is being carried out by Digital Water Level Recorders, fitted in piezometers tapping different aquifers in diverse hydrogeological setups in Madhya Pradesh. Hydrographs produced by high frequency water level monitoring are of immense use. The shape, size and amplitude of a hydrograph will be different in different geological formation. Hydrographs are as useful to a hydrogeologist as an electro cardiogram to a heart specialist. The shape, size and amplitude of hydrograph can be utilized as indirect indicator of aquifer material beneath earth surface. In case of thick and highly permeable aquifers (high transmissivity), flatter shape of hydrograph indicates coarse grained consolidated or unconsolidated rocks and alluvium. Flatter shape of hydrograph may also be indicative of aquifers with low recharge and low permeability. The slope of rising limb as well as the falling limb of the hydrograph is steep in the case of confined aquifer and gradual and gentle in the case of unconfined aquifer. A gradual slope of the rising limb and slow dissipation or gentle slope of the falling limb is indicative of a weathered aquifer material, while a very steep slope of the rising limb and gradual dissipation or gradual slope of the falling limb is indicative of a fractured aquifer material. Amplitude is indicative of amount of recharge and thereby rainfall. Higher precipitation is evinced by higher amplitude and lower precipitation will reflect in lower peak.

INTRODUCTION

To better comprehend the nature of the aquifer tapped by a well and changes of groundwater regime with time, it is imperative to monitor the groundwater levels regularly. Monitoring and understanding changes in groundwater levels in response to natural processes and human interference is helpful in indicating the critical changes in groundwater regime and assist in water resource decision-making.

Groundwater hydrograph is a time series plot or a graph showing the variation of groundwater level or head with respect to time. The time scale may be in minutes, hours, days, months, years or decades and water level in meters, centimeters or feet measured with reference to ground level or sea level as datum plane. The slope, the amplitude as well as the alteration of the amplitude of the hydrograph have considerable influence as to interpretation of the geologic subsurface conditions and the water recharged to, or discharged from an aquifer. The shape of the groundwater hydrograph is dependent on:

- Rainfall duration and intensity.
- Natural discharges from aquifer like base-flow.
- Groundwater draft or withdrawal.
- Aquifer properties like porosity, permeability, vertical and lateral extent, etc.
- Confined/unconfined nature.
- Aquifer response i.e. lag between rainfall and (its) impact on groundwater.
- Recharge due to seepage from canals, return from irrigation or artificial recharge practices.
- Groundwater flow gradient.
- Barometric change, tidal variations, seismic vibrations and passage of trains.

The hydrographs considered in this discussion are plots of high frequency (6 hourly) monitoring of ground water level being recorded by Digital Water Level Recorders, fitted in piezometers tapping different aquifers in diverse hydrogeological setups in Madhya Pradesh. The water level is recorded in metres below ground level (m.bgl).

[1]Conference speaker

RAINFALL DURATION AND INTENSITY

Rainfall is the main source of recharge to the aquifer and rising limb of the hydrograph is due to monsoon rain. The hydrograph can give an indication of amount of precipitation during that year and recharge to the aquifer. Higher precipitation will show higher amplitude and lower precipitation will reflect in lower amplitude of hydrograph pertaining to that year. A temporally well distributed rainfall will have a gradual rising limb of the hydrograph while concentrated high rainfall spell will reflect in a steep rising limb of the hydrograph. Rainfall during pre-monsoon or post-monsoon can be easily seen as a small mound or kink in the falling limb of the hydrograph, similar to that created by artificial recharge. Inspite of the variations in annual rainfall, the general shape of the hydrograph of a well usually remains the same for different years, as evinced from the Multiple year hydrographs of Dhamora piezometer, Shivpuri District (Figure 1), Govindpura piezometer, Bhopal District (Figure 2) and Sardarpur piezometer, Dhar District (Figure 3).

NATURAL DISCHARGES FROM AQUIFER LIKE BASE-FLOW

The falling limb of the hydrograph results mainly due to natural discharges from aquifer like base-flow, evapo-transpiration and also due to groundwater draft or withdrawal.

Groundwater Draft or Withdrawal

Hydrograph of a well tapping an aquifer that is subject to groundwater draft by pumping is distinguishable by diurnal small sharp zig-zag kinks in rising and/or falling limb of the hydrograph during the period of groundwater draft or withdrawal.

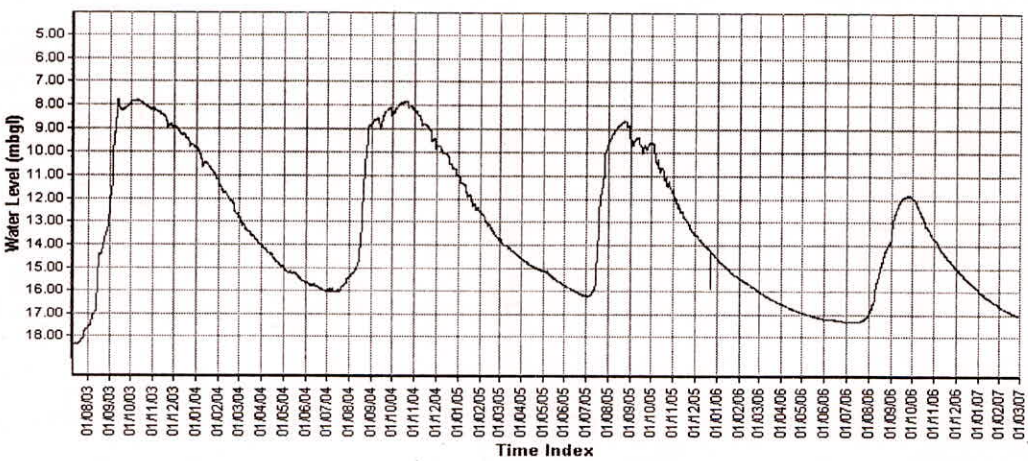

Fig. 1: Multiple year hydrograph of Dhamora piezometer, Shivpuri District (Fr. Vindhyan Sandstone)

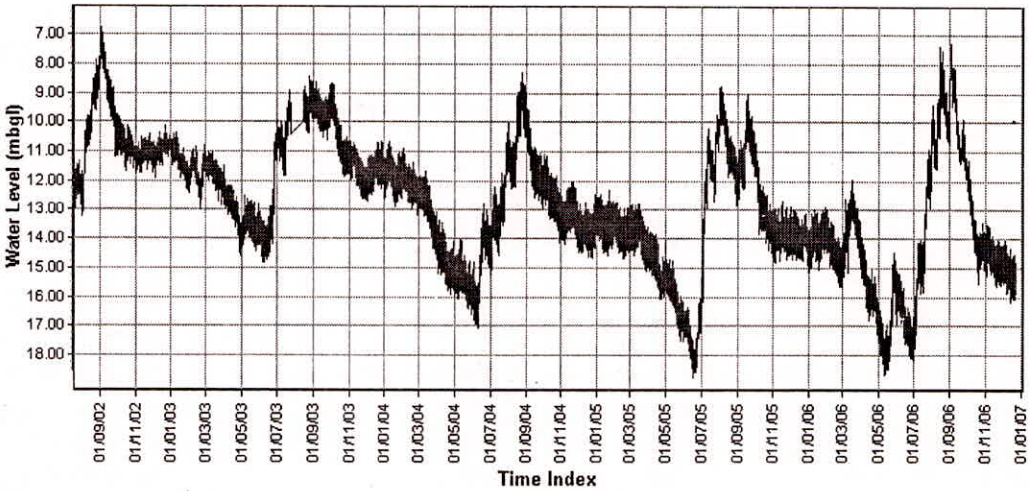

Fig. 2: Multiple year hydrograph of Govindpura piezometer, Bhopal District (Fr. Vindhyan Sandstone)

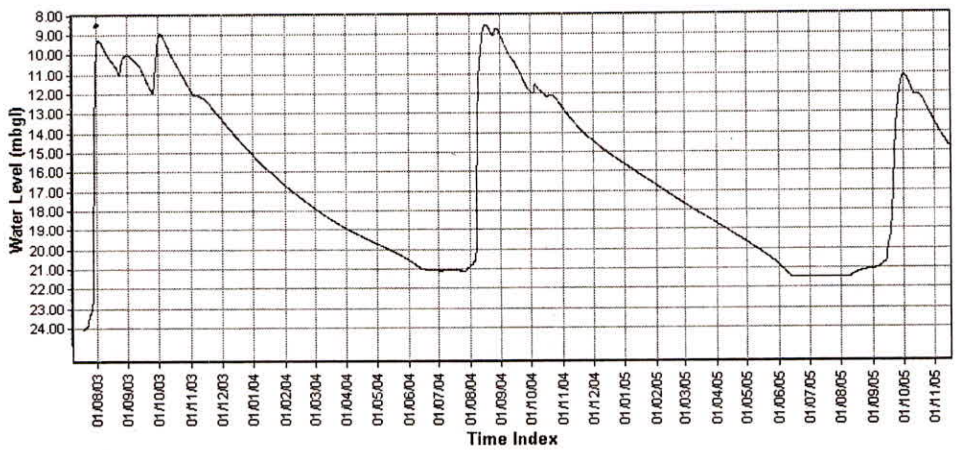

Fig. 3: Multiple year hydrograph of Sardarpur piezometer, Dhar District (Fr. Deccan Trap)

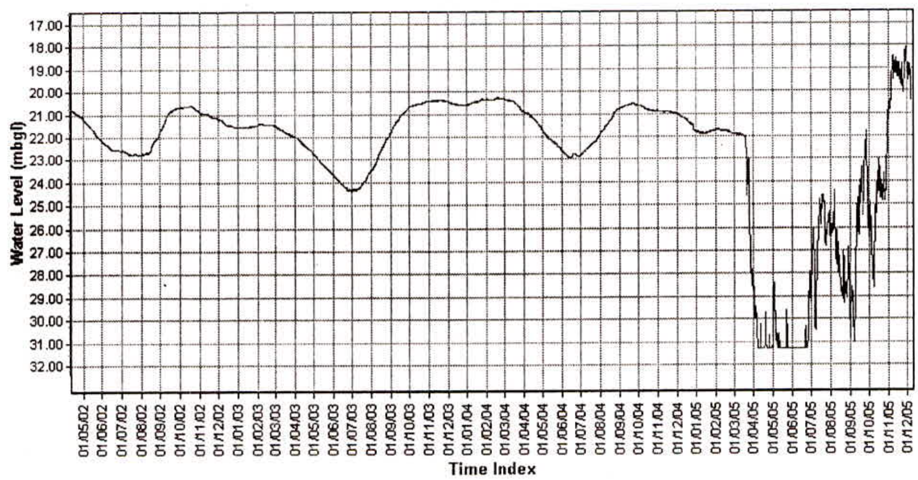

Fig. 4: Multiple year hydrograph of Jabalpur piezometer, Jabalpur District (Granite)

The hydrograph of piezometer in Jabalpur, Jabalpur district shown in Figure 4 pertains to an area of granite aquifer where from ground water withdrawal was negligible till the pumping started in March 2005. Monsoon rainfall during 2005 was 1734 mm as against normal rainfall of 1268.3 mm, reflected in the higher amplitude of the hydrograph in the post-monsoon during 2005. Another plausible reason for higher amplitude could be that pumping resulted in opening of joints/fractures (as in the case of hydro-fracturing) and aquifer receiving excess recharge through them (induced recharge).

Heavy withdrawal and over-draft results in decline of water levels over the years as seen in the case of hydrograph of piezometer in Gwalior city, Gwalior district (Figure 5).

Aquifer Properties

In case of thick and highly permeable aquifers (high transmissivity) as in the case of coarse grained consolidated or unconsolidated rocks and alluvium, where high water table gradients are common, large quantities of water may be transmitted through the aquifer. The groundwater is quickly drained and replenished, resulting in less fluctuation in water levels and a flatter shape of hydrograph. However, the seasonal fluctuation may be very high in piedmont zone. Single year hydrograph of Bareli piezometer, Raisen District tapping alluvial aquifer (Figure 6) exhibits a flatter shape of hydrograph. The high fluctuation peak in August–September may be due to unusually high rainfall.

The same may be the case of aquifers with low recharge and low permeability as seen in Single year hydrograph of Sausar piezometer, Chhindwara District tapping Quartzite (Figure 7).

Distinction between the two cases may be made in the case of pumping from the aquifer or conducting short duration pumping tests, wherein small draw-down with fast recuperation in the case of highly

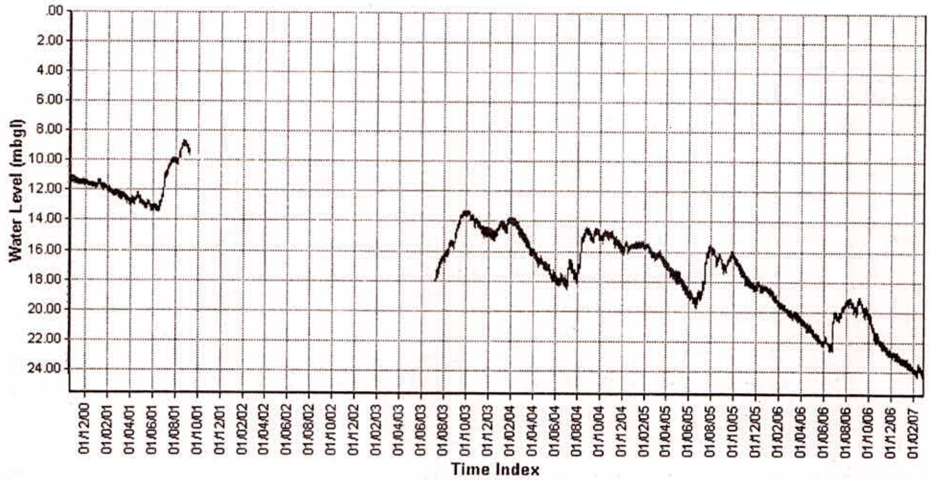

Fig. 5: Multiple year hydrograph of Gwalior piezometer, Gwalior District (Vindhyan Sandstone) (Data gap from 1.10.2001 to 1.07.2003 due to instrument failure)

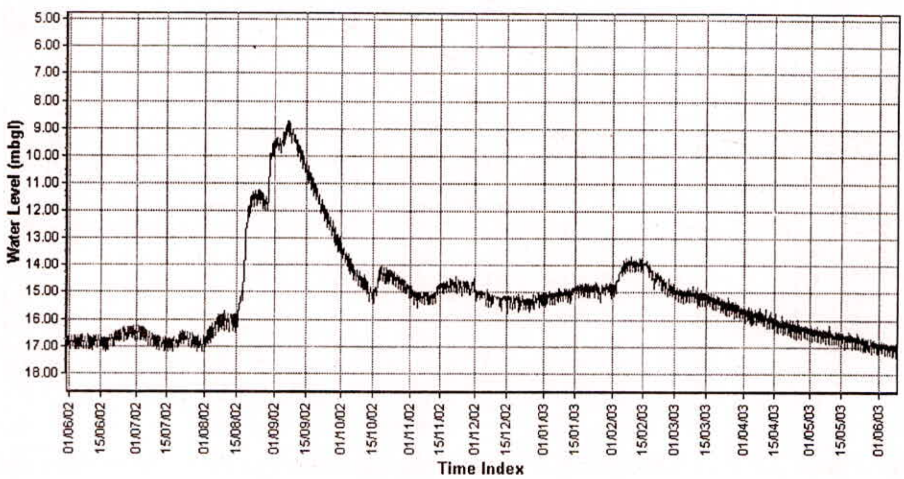

Fig. 6: Single year hydrograph of Bareli piezometer, Raisen District (Alluvium)

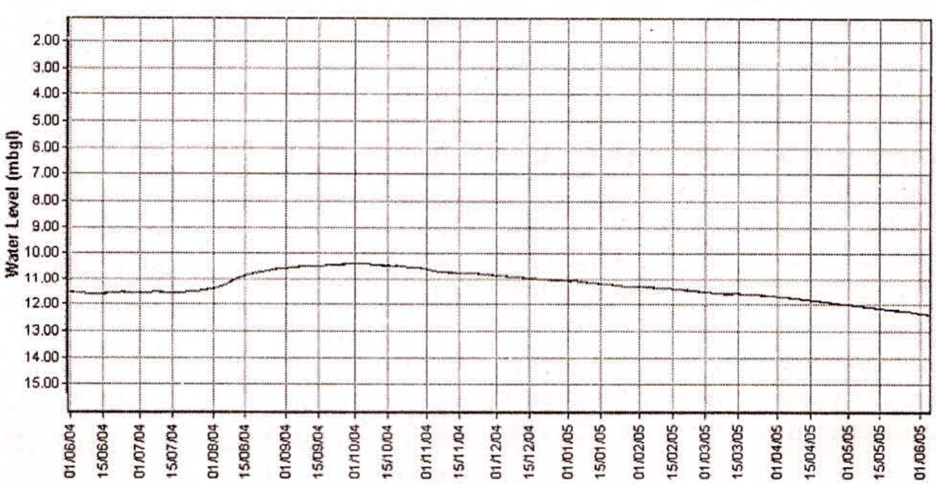

Fig. 7: Single year hydrograph of Sausar piezometer, Chhindwara District (Quartzite)

permeable aquifers and high draw-down with slow recuperation in the case of aquifers with low recharge and low permeability will be noted.

The higher rate of water level rise in the bores may be due to lower specific yield of the aquifer.

Confined/Unconfined Nature

Fluctuation of the water level under confined condition or piezometric surface is related to the elastic properties of the aquifer and the confining layers. There is also a response to fluctuation of the water table, to saturation or desaturation of the overlying material. Water levels of wells tapping phreatic aquifers are not usually affected by barometric change, tidal variations, seismic vibrations and passage of trains, but piezometric heads of artesian wells (tapping confined aquifers) are affected by them. However, the general water table may also respond to them.

Confined conditions have high rate of rise of water level with recharge and high rate of recession with discharge. The sudden rise in water level in confined aquifer is due to the fact that prior to the ground water movement in a horizontal direction, i.e. the flow process, the hydrograph almost generally indicates first of all the transmission of pressure. The rising as well as the falling limbs of the hydrograph are steep in the case of confined aquifer and gradual in the case of unconfined aquifer.

In transient phases, whereby an aquifer is confined by an overlying confining layer during periods of high water level becomes unconfined by desaturation and water level falling below the base of overlying confining layer, the rate of recession and rise, as the case may be, changes abruptly at the contact time (Karanth, 1989). The water level changes are more rapid under confined conditions than under unconfined condition. This can be seen in the hydrograph of Mhow piezometer, Indore District (Deccan Trap) (Figure 8).

Weathered Formation as Aquifer

A gradual slope of the rising limb and slow dissipation or gentle slope of the falling limb is indicative of a weathered aquifer material (Figure 9).

Fractured Rock as Aquifer

A very steep slope of the rising limb and gradual dissipation or gradual slope of the falling limb is indicative of a fractured aquifer material. Such behaviour of water level change can be seen in fractured granite (Figure 10), fractured Vindhyan Sandstone (Figure 11) and fractured Deccan Trap (Figure 12).

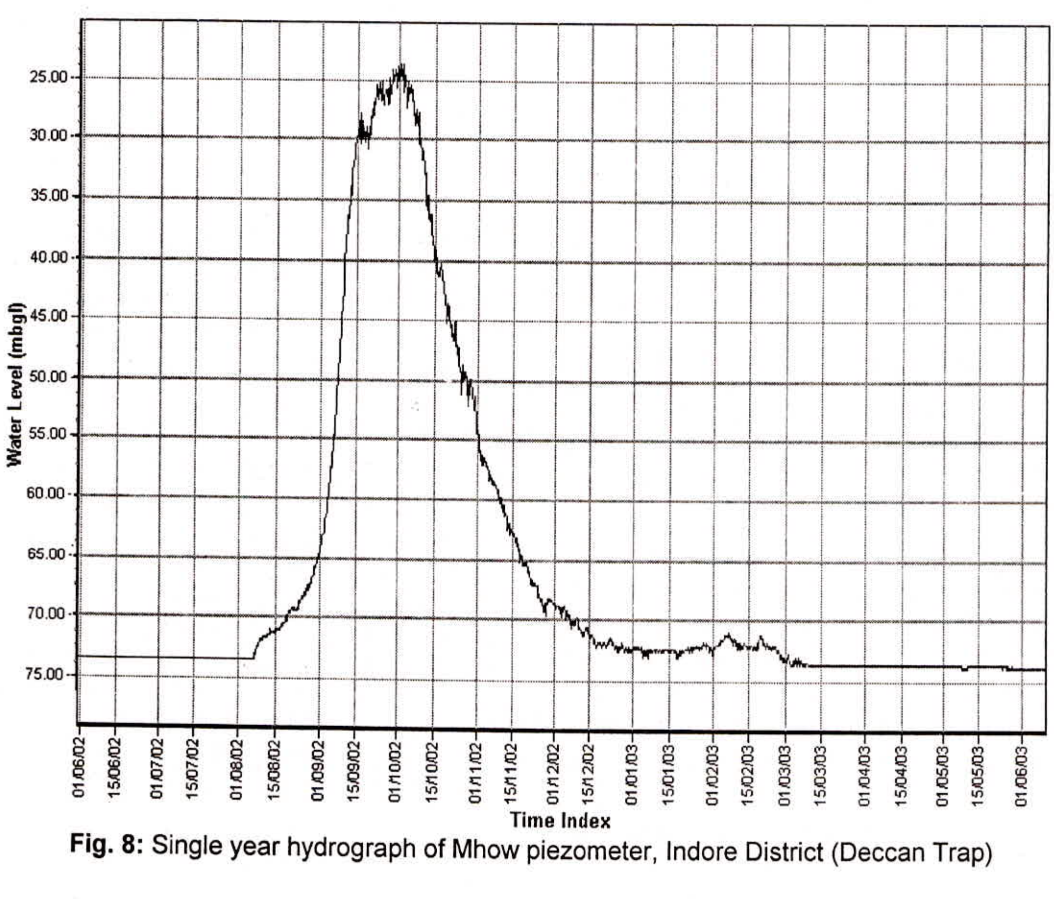

Fig. 8: Single year hydrograph of Mhow piezometer, Indore District (Deccan Trap)

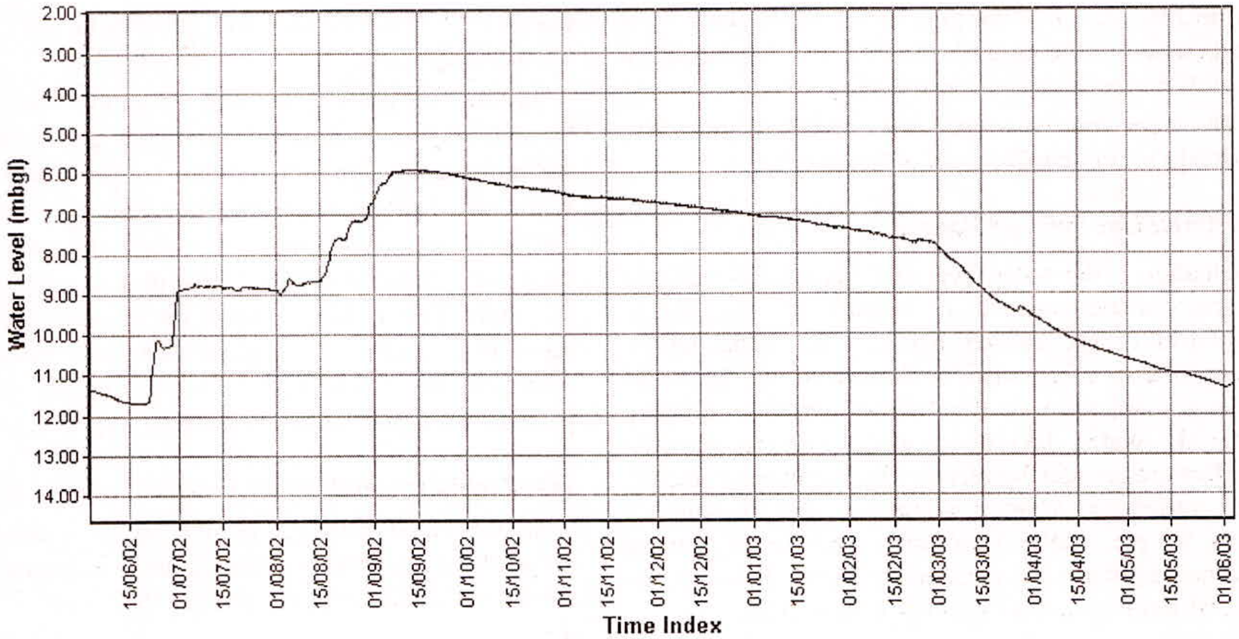

Fig. 9: Single year hydrograph of Amla piezometer, Betul District (Weathered Granite)

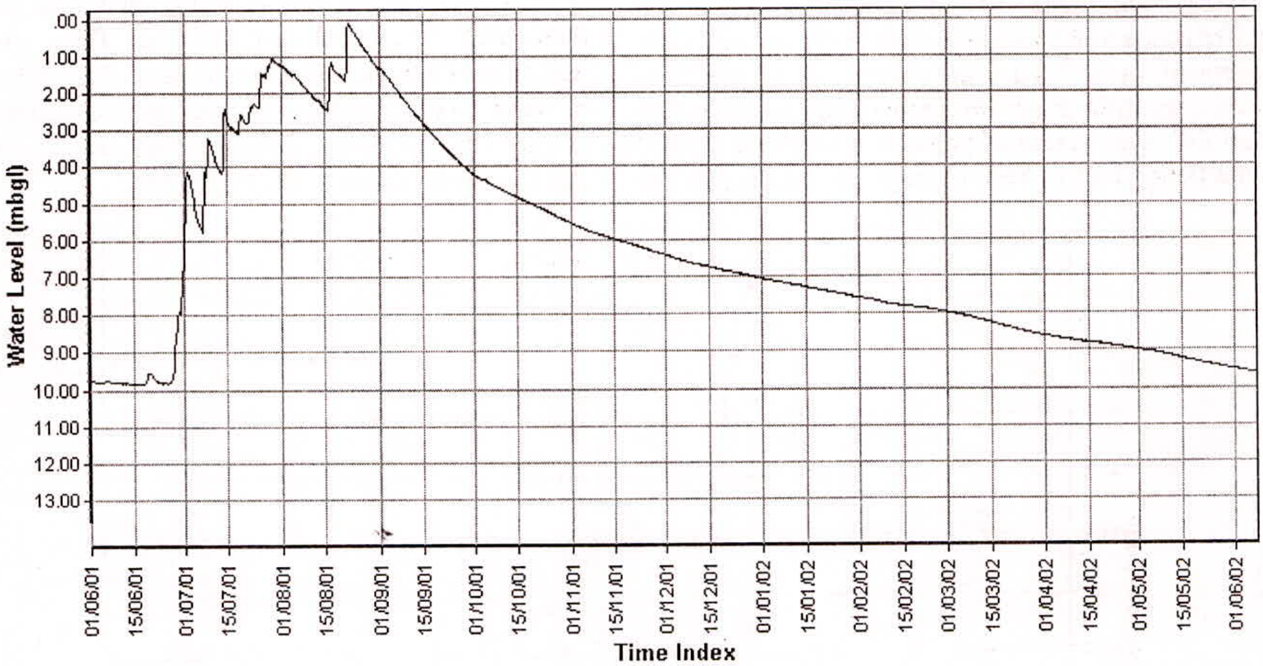

Fig. 10: Single year hydrograph of Orchha piezometer, Tikamgarh District (Fractured Granite)

Two or Multiple Aquifer System

Piezometers tapping multiple aquifer system may give rise to a plateau like risen flat peak, especially when the top shallow aquifer is discharged and almost dries up. Single year hydrograph of Jaora piezometer, Ratlam District (Figure 13) and Sehore piezometer, Sehore District (Figure 14), both tapping a two-aquifer system in Deccan Trap and as evinced by abrupt rise in water level when the shallow aquifer is recharged, a gradual rise and gradual fall at the peak and abrupt fall in water level when the shallow aquifer is discharged. This can be distinguished from confined conditions wherein water level changes are more rapid and sharper peaks of hydrograph are observed. However if the top aquifer has high potential and retains water throughout the year, the hydrograph may not show any signs that the piezometer is tapping multiple aquifer system.

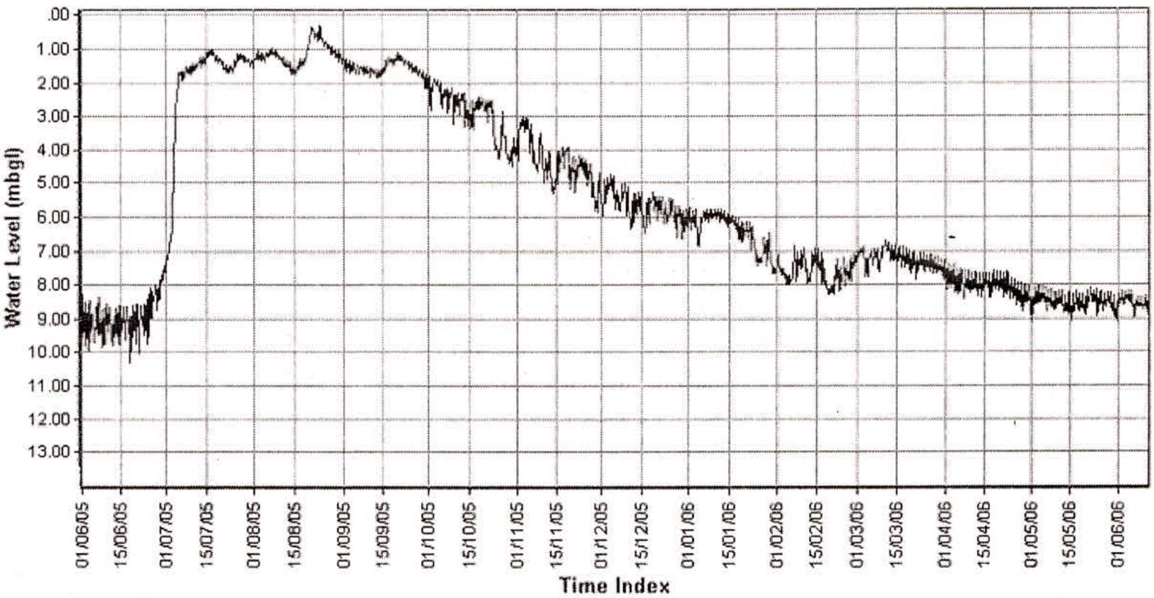

Fig. 11: Single year hydrograph of Patera piezometer, Damoh District (Fractured Vindhyan Sandstone)

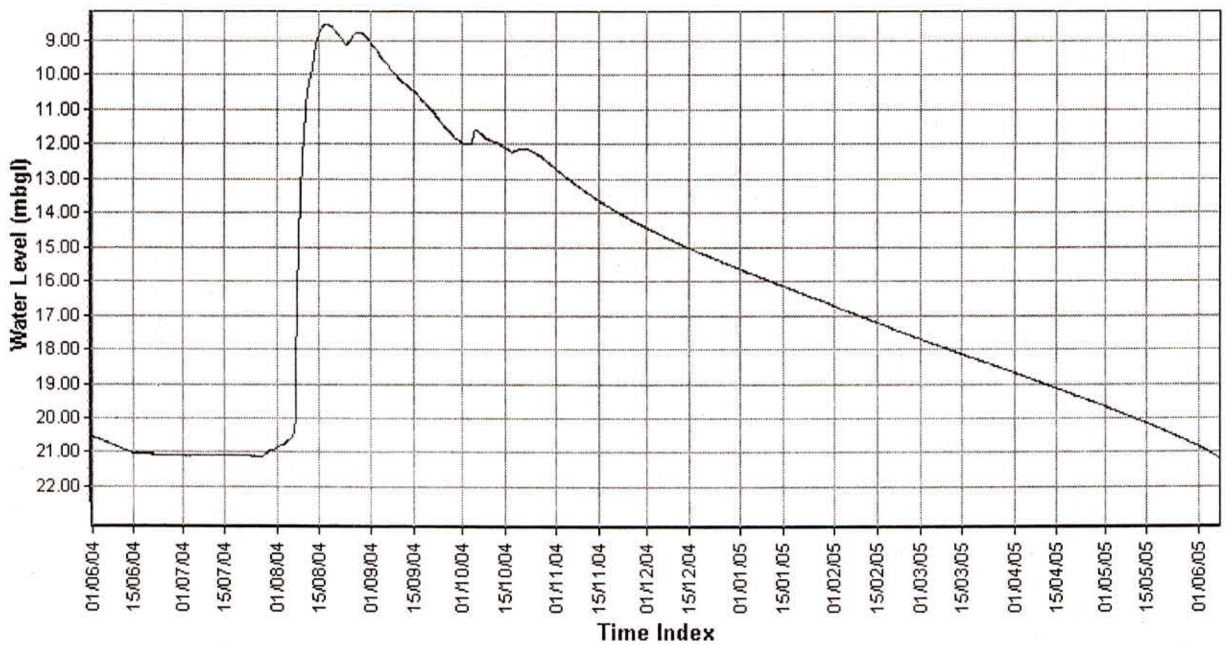

Fig. 12: Single year hydrograph of Sardarpur piezometer, Dhar District (Fractured Deccan Trap)

Recharge Due to Seepage from Canals, Return from Irrigation or Artificial Recharge Practices

Effect of canal seepage (during rabi season) is reflected as small mounds in the falling limb of the hydrograph during canal irrigation. The hydrograph of Handia piezometer, Harda District (Figure 15) tapping Fractured Granite, lying in Tawa canal command area shows the recharge effect by canal irrigation during rabi season (September end to March). The water level rises above ground level during canal irrigation phase sometimes.

Powarkhera village lies in Tawa canal command area of Hoshangabad district in Narmada alluvium. Waterlogging conditions prevail in a small area in the Tawa canal command, where Hydrogeologists had long since been recommending conjunctive use of ground water and surface water for irrigation. One option to mitigate the effect of waterlogging, was to recharge the deeper aquifer in the area with water from the phreatic aquifer. But this option could not be considered as the head of the deeper (locally confined) aquifer was higher than or almost equal to that in the phreatic aquifer, as the aquifer in Narmada alluvial valley, on a regional scale is a single aquifer with clay lenses, resulting in multi-aquifer system at a local level. The hydrograph of piezometer at Powarkheda (Figure 16), tapping the deeper (second) alluvial aquifer shows the head rising above 2 m.bgl (metres below ground level), due to canal seepage during rabi irrigation (reflected as small mounds in the falling limb of the hydrograph during rabi irrigation) clubbed with groundwater pumping (conjunctive use) (reflected as small downward kinks in the hydrograph during rabi irrigation), whereby the water level remains below 3 m. bgl.

Artificial recharge to an aquifer being tapped by a piezometer may reflect in sharp upward peaks in hydrograph of the peizometer. Artificial recharge to the aquifer is also reflected as small mounds or kinks in the rising and/or falling limb of the hydrograph. The hydrograph of piezometer at Musakhedi, District Indore (Figure 17) where CGWB constructed a rain water harvesting structure (2 recharge shafts) in the year 2000, shows the effect of artificial recharge. The confined aquifer used to become unconfined in the pre-monsoon period by desaturation and water level falling below the base of overlying confining layer, but after 2003, the aquifer retains its confined nature for major part of the year.

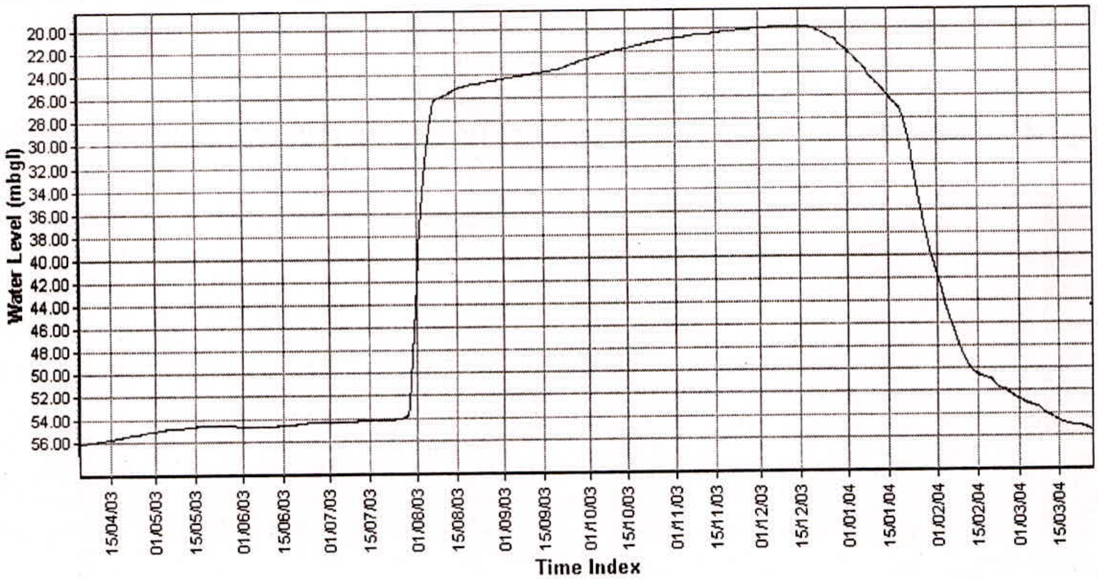

Fig. 13: Single year hydrograph of Jaora piezometer, Ratlam District (Deccan Trap)

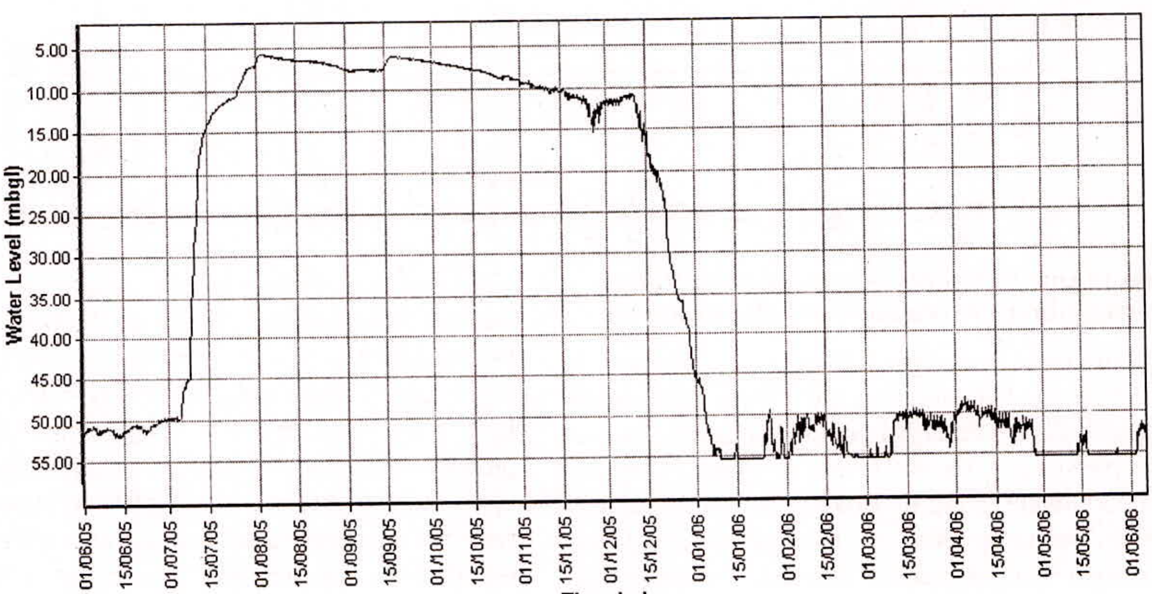

Fig. 14: Single year hydrograph of Sehore piezometer, Sehore District (Deccan Trap)

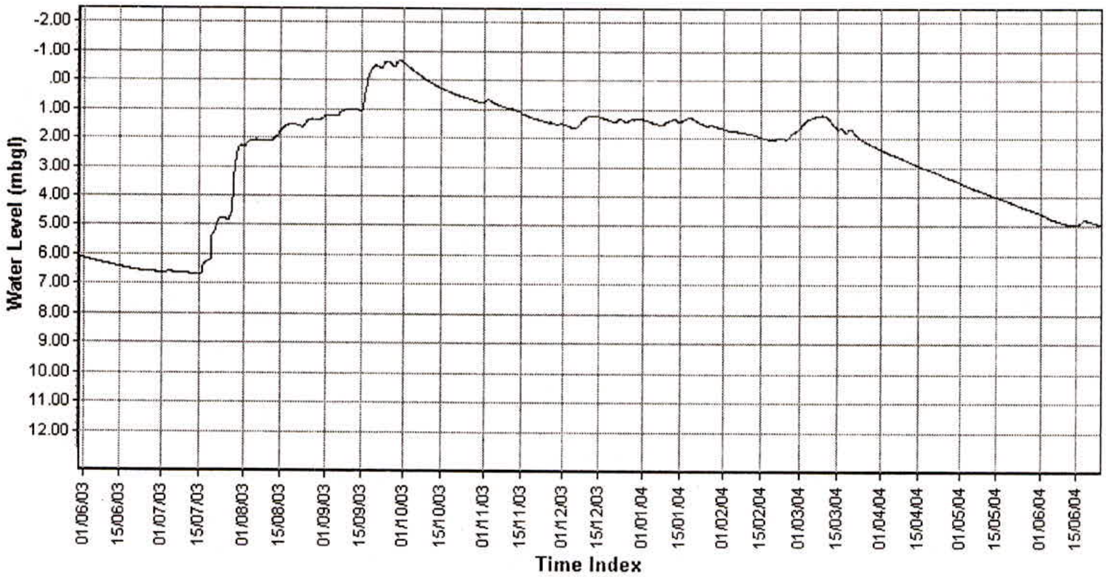

Fig. 15: Single year hydrograph of Handia piezometer, Harda District (Fractured Granite)

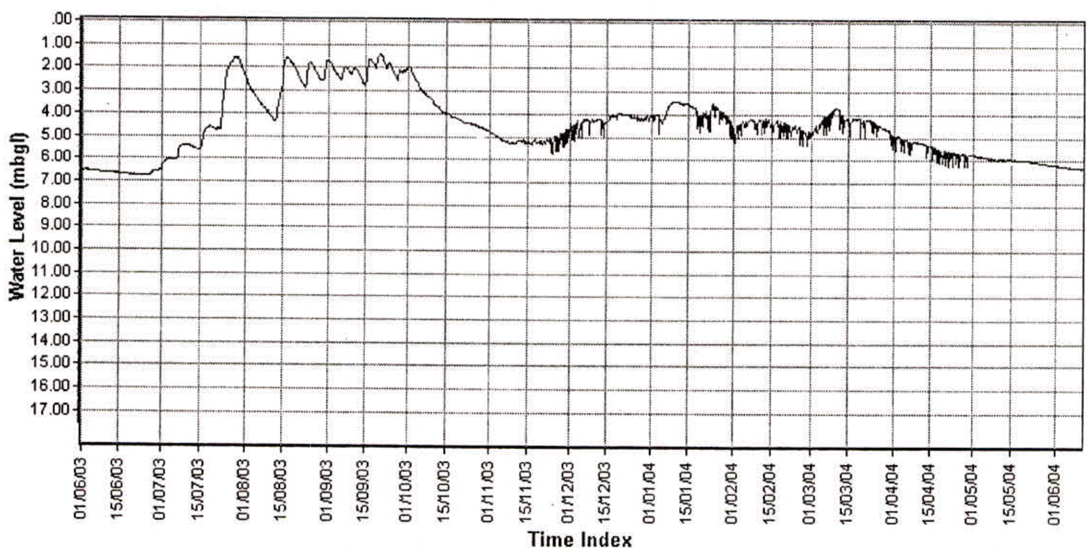

Fig. 16: Single year hydrograph of Powarkhera piezometer, Hoshangabad District (Alluvium)

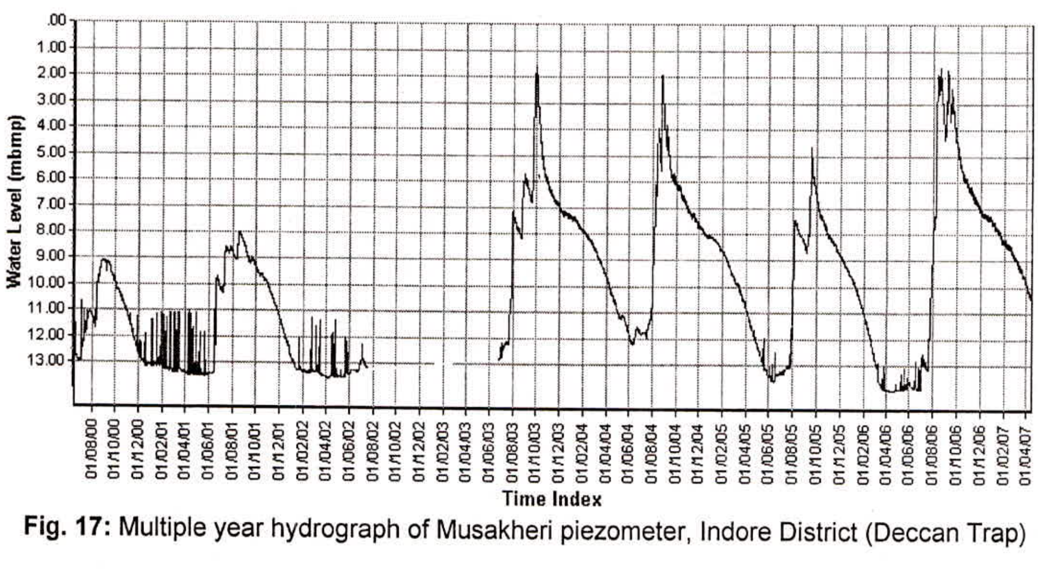

Fig. 17: Multiple year hydrograph of Musakheri piezometer, Indore District (Deccan Trap)

GROUNDWATER FLOW GRADIENT

In area with steep groundwater flow gradient the seasonal fluctuation will be very higher as compared to similar aquifer with gradual groundwater flow gradient. Groundwater flow gradient is steep on hill slopes and piedmont zones and may be in the vicinity of river banks. Groundwater flow gradient is gradual in plain areas.

Barometric Change, Tidal Variations, Seismic Vibrations and Passage of Trains

The effect of barometric changes, tidal variations, seismic vibrations and passage of trains is not perceptible in the hydrographs examined. Minor daily zig zag undulations in the hydrographs may be attributed to diurnal barometric changes. There seemed to be some unusual behaviour in the hydrograph of Govindpura piezometer, Bhopal District on the day of Jabalpur earthquake, but similar behaviour was seen on some other days also, so the unusual behaviour occurring on the day of the earthquake may be mere coincidence.

A complex behaviour of the hydrograph may be difficult to interpret as in the case of Runija piezometer, Ujjain District (the aquifer in the area has a good potential) (Figure 18) and Khujner piezometer (the aquifer in the area has a medium potential—sustains pumping throughout the year) (Figure 19), both in Deccan Trap; Garhakota piezometer, Sagar District in Vindhyan Shale (the aquifer in the area has a poor potential—sustains pumping throughout the year) (Figure 20) and Tendukhera pizometer, Narsimhapur district in Lameta Limestone (poor potential) (Figure 21), all show erratic behaviour, which may be the case of leaky aquifer or multiple aquifer system or poor specific yield, delayed yield or erratic discharge/recharge pattern and one has carry out field investigations to comprehend their shape.

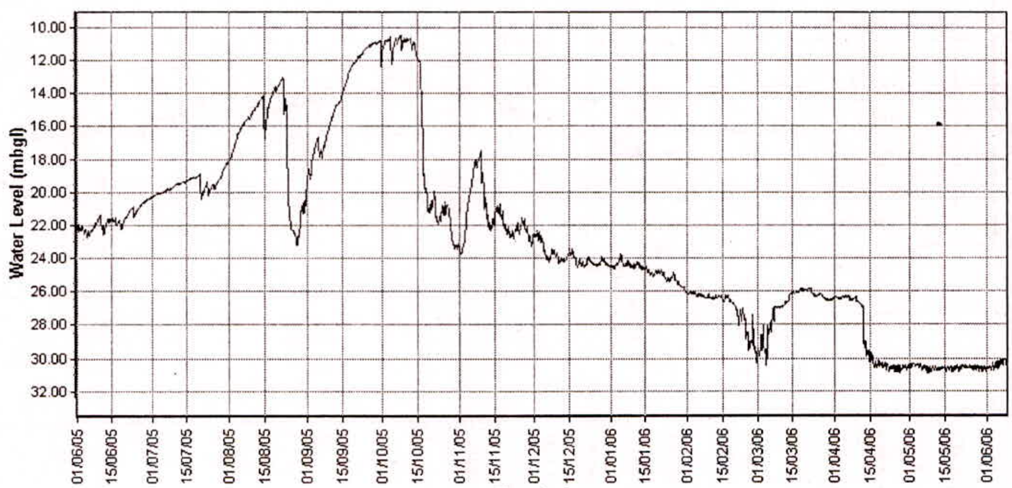

Fig. 18: Single year hydrograph of Runija piezometer, Ujjain District (Deccan Trap)

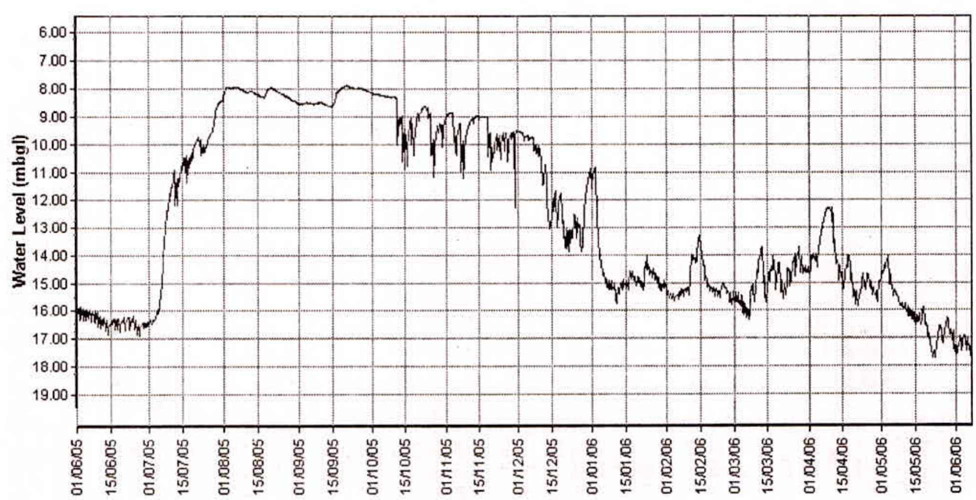

Fig. 19: Single year hydrograph of Khujner piezometer, Rajgarh District (Deccan Trap)

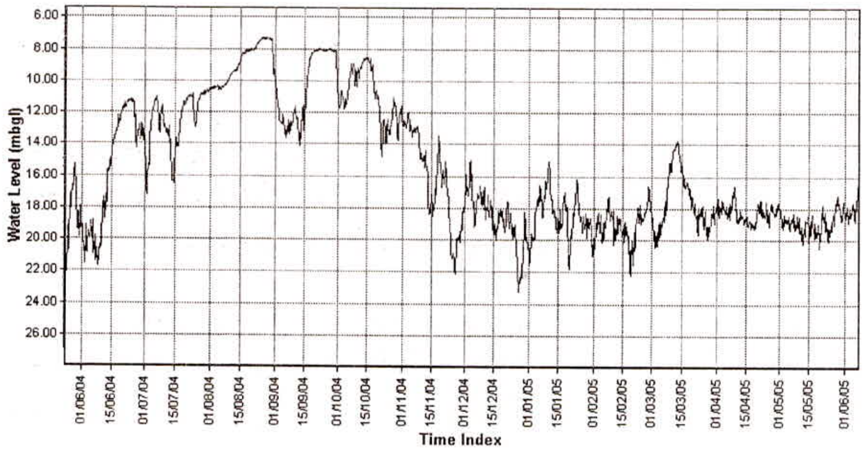

Fig. 20: Single year hydrograph of Garhakota piezometer, Sagar District (Vindhyan Shale)

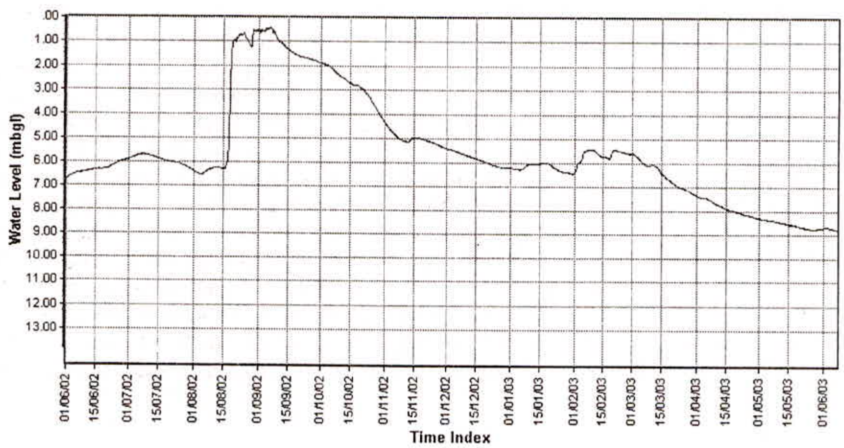

Fig. 21: Single year hydrograph of Tendukheda piezometer, Narsimhapur District (Lameta Limestone)

CONCLUSIONS

The hydrograph can give an insight into understanding changes in groundwater level behaviour in response to natural processes and human interference, understanding the hydrogeological set-up of an area and is also helpful in indicating the critical changes in groundwater regime and thereby assist in water resource decision-making. It helps in:

- understanding the groundwater regime, especially areas where over-exploitation from aquifer(s) is taking place and taking necessary steps to control and regulate groundwater use.
- decision making regarding measures and techniques for artificial recharge to aquifer in areas showing over-exploitation from aquifer and depleting groundwater resources.
- assessing areas where water-logging conditions have developed or are likely to develop and need for conjunctive use measures.
- assessing the efficacy of corrective interventions like artificial recharge to aquifer or conjunctive use of surface and groundwater.
- planning optimum irrigation and irrigation scheduling; design of tubewells etc.

Understanding the hydrograph and the processes involved in shaping it is imperative as precursor to ground-water modeling.

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