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# THE SUSTAINABLE GROUNDWATER RESOURCES OF THE DECCAN BASALTS, INDIA

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Report Prepared for the Overseas Development Administration

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## EXECUTIVE SUMMARY

In the semi-arid regions of the world, water for potable supplies and for supplementary irrigation is obtained mostly from shallow wells. Many of these areas are underlain by 'hard rocks', that is volcanic or ancient crystalline rocks, where groundwater most frequently occurs in aquifers within the shallow weathered and fractured layers. Yields from individual wells are usually low, less than 50 $m^3/d$, and in addition the quantity of water stored in these aquifers is often relatively small, perhaps equivalent to only 2-3 years average annual recharge, or even less. Further, the climatic conditions, low and variable rainfall, limit the quantity of recharge available to these aquifers and makes them susceptible to drought. The significance of these limitations are crucial as the aquifers often represent the only available source of water.

In India, there has been a long tradition of using large-diameter shallow dug wells for both potable supplies and for irrigation. Since the 1950s traditional water-lifting devices have been progressively replaced by motorised pumps. In addition there has been a considerable increase in the number of shallow irrigation wells, 30,000 to 40,000 each year in Maharashtra state alone. The increased exploitation of water resources to meet the demand of a rising population has resulted in a decline in water levels within these wells. The nature of the decline is not fully understood. It is possibly: a long-term decline due to abstraction exceeding average annual recharge; a decline restricted to the vicinity of the well caused by abstraction exceeding the capacity of the aquifer to transmit water to the well; or a short-term decline due to a number of years of below average recharge, with water levels recovering once rainfall returns to normal.

A project has been devised to study these resource issues. Field investigations will be carried out on a site in the Deccan Basalts of India in the region around Pabal, a village to the north-east of Pune in Maharashtra state. The project will be jointly undertaken by the University of Poona and the British Geological Survey under the ODA R & D programme. The objectives are to better understand the groundwater flow system within the Deccan Basalts by both determining the aquifer parameters and by detailed monitoring of groundwater levels and abstraction, and by modelling groundwater levels around a group of irrigation wells to ascertain whether overabstraction is responsible for a regional decline in the water-table. It is hoped data gathered on the quantity of the available groundwater resource and its use will enable the instigation of further studies on water management and agricultural practices to allow the sustainability of the present socioeconomic system to be evaluated.

# 1. INTRODUCTION

## 1.1 The Problem

In the semi-arid regions of the world, water for potable supplies and for supplementary irrigation is obtained mostly from shallow wells. Many of these areas are underlain by 'hard rocks', that is volcanic or ancient crystalline rocks, where groundwater most frequently occurs in aquifers within the shallow weathered and fractured layers. Yields from individual wells are usually low, less than 50 $m^3/d$, and in addition the quantity of water stored in these aquifers is often relatively small, perhaps equivalent to only 2-3 years average annual recharge, or even less. Further, the climatic conditions, low and variable rainfall, limit the quantity of recharge available to these aquifers and makes them susceptible to drought. The significance of these limitations are crucial as the aquifers often represent the only available source of water.

In India, there has been a long tradition of using large-diameter shallow dug wells for both potable supplies and for irrigation. Until recently, water-lifting devices relied upon manual or animal power, which effectively limited the quantity of water that could be withdrawn from individual wells. Since the 1950s these water-lifting devices have been progressively replaced by motorised pumps capable of much higher abstraction rates (Figure 1.1).

In addition there has been a considerable increase in the number of shallow irrigation wells, at least in part as a result of policies of the Government of India designed to encourage increased food production. In the state of Maharashtra alone, there are some 1.2 million shallow wells and each year 30,000 to 40,000 new wells are constructed (Lawrence, 1992).

Within Maharashtra, the Deccan basalts form the most important aquifers and groundwater from shallow wells in these basalts is widely used for the irrigation of crops such as sugar cane, corn and vegetables (Dhokarikar, 1990).

In recent years concern has been expressed about the apparently widespread fall in the water-table over large areas of the state and the 'failure' (or drying-up) of many wells (Bastemeyer and Lee, 1992). There is considerable debate within India as to whether excessive pumping of groundwater for irrigation is largely responsible for the decline in the water-table. One reason for the uncertainty in the cause of the apparent decline is the absence of meaningful water level data. This is because the distance between wells used for groundwater monitoring by the various government agencies is often in excess of 5-10 km. This makes reliable interpretation of the data to confirm whether groundwater levels are declining regionally due to overpumping, practically impossible. At such distances neighbouring monitoring wells may be in aquifers not in direct hydraulic interconnection. It requires a denser monitoring network to provide an adequate knowledge of the response of water levels around pumping wells. Even with an adequate monitoring system, the answer is not as simple or as straightforward as it might appear, as groundwater levels fluctuate naturally as a result of both recharge (generally from rainfall) and discharge (normally to streams) processes. It is therefore necessary to differentiate between the various factors causing the decline in the water levels within the shallow wells.

Figure 1.1 Motorised pump being used on a dug well in the Deccan Basalts.

## 1.2 Possible Causes

Factors that might account for the apparently 'greater than normal' decline in water levels observed in the shallow wells include:-

(1) Groundwater discharges from the shallow aquifer (principally groundwater abstraction for irrigation) exceeding the average annual recharge, producing a long term decline in the water table (see Figure 1.2a).

(2) The abstraction rate exceeding the capacity of the aquifer to transmit water to the well at a sufficient rate and depleting aquifer storage locally around the irrigation wells (see Figure 1.2b). This may result in individual abstraction wells 'drying up' although the total groundwater discharges from the aquifer do not exceed the average annual recharge. In this case the low permeability of the aquifer effectively regulates abstraction.

(3) The groundwater discharges do not exceed the average annual recharge but that successive 'dry' years have resulted in lower than average recharge producing a consequent short term decline in water levels (see Figure 1.2c). Water levels may decline over successive dry years but recover once rainfall returns to normal.

## 1.3 Proposed Research

In reality, more than one of the above factors could be responsible. To resolve the question as to whether current groundwater abstraction is sustainable, requires an understanding of the groundwater system including a detailed knowledge of the aquifer parameters (Rao, 1991). It should then be possible to predict how water levels in, and around, an irrigation well or group of irrigation wells, respond to pumping and whether the aquifer resources are sufficient to sustain that level of groundwater development. Further, and perhaps of greatest importance, it should indicate the likelihood of excessive abstraction by wells lowering water levels in public supply wells and in the worst case causing the latter wells to be abandoned. Once the sustainable resource is known then further investigations into the effects of reduced recharge due to climate change, water management strategies and agricultural practices can be carried out.

To further understanding of these important issues a project has been devised that will be jointly undertaken by the University of Poona and the British Geological Survey under the ODA R & D programme. The objectives are:

(a) to gain a better understanding of the shallow aquifer within the Deccan basalts by both determining the aquifer parameters and by detailed monitoring of groundwater levels and abstraction in a selected study area,

(b) to model groundwater levels around a group of irrigation wells to ascertain whether overabstraction is responsible for a regional decline in the water-table,

(c) to gather information on the present water use to enable the instigation of further studies on water management, agricultural practices and to evaluate their socio-economic impact.

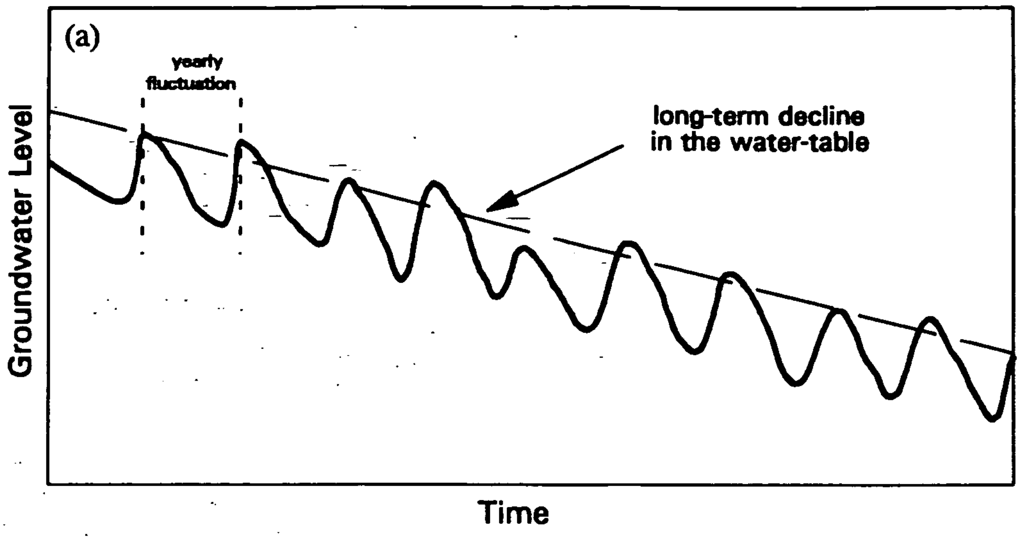

Figure 1.2 (a) Schematic illustrating a long-term decline in the water table.

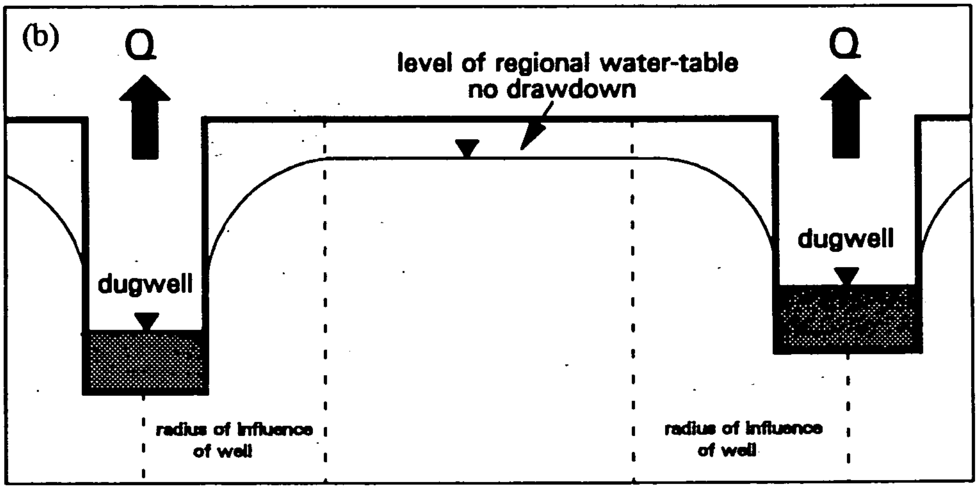

Figure 1.2 (b) Schematic illustrating the lack of interference of wells and the the non-influence on the regional water table.

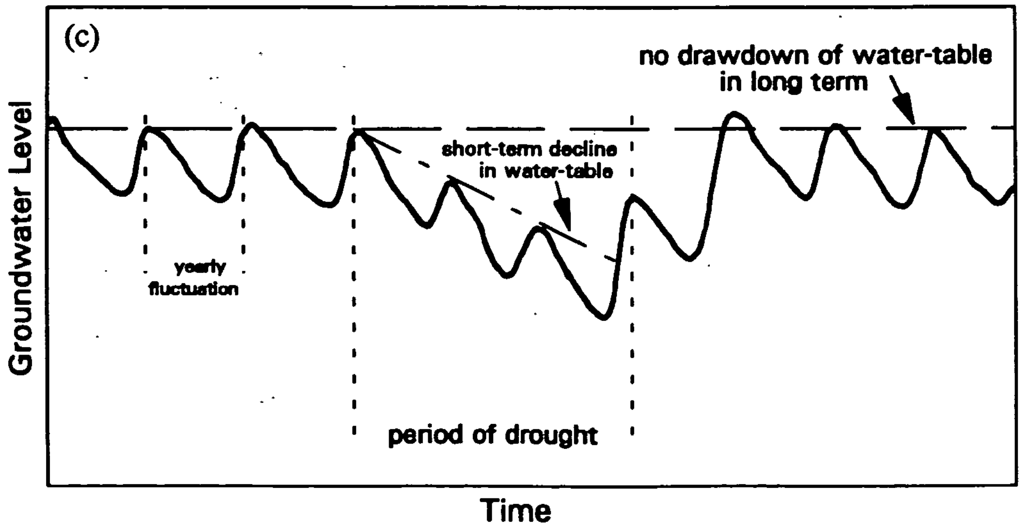

Figure 1.2 (c) Schematic illustrating a short-term decline in the water table.

For this purpose a 'typical' village was selected where groundwater is extensively used for irrigation. The village selected was Pabal which is located to the north-east of Pune (Figure 1.3).

Figure 1.3 Location map for Pabal village.

## 2. BACKGROUND TO PABAL VILLAGE

Pabal appears typical of many villages in this area of Maharashtra; the village area comprises a relatively densely populated centre of between 10,000 and 15,000 people surrounded by a less densely populated area which is intensively cultivated. The cultivated land is generally flat and its outer boundary is marked by gently sloping basaltic hills of low relief (Figure 2.1). Where present the soils on these hills are thin or even absent, and are generally not cultivated.

### 2.1 Agriculture and Irrigation

The total population of Pabal village is about 20,000 within an area of 30 km$^2$. Practically all the flat land around the village appears to be cultivated (at least for part of the year), the main crops are corn, vegetables and sugar cane. The cropped land is irrigated by shallow dug wells, many fitted with diesel pumps. The wells are typically 10-15 m deep and 4 to 6 m in diameter. The upper part of the well is usually lined with

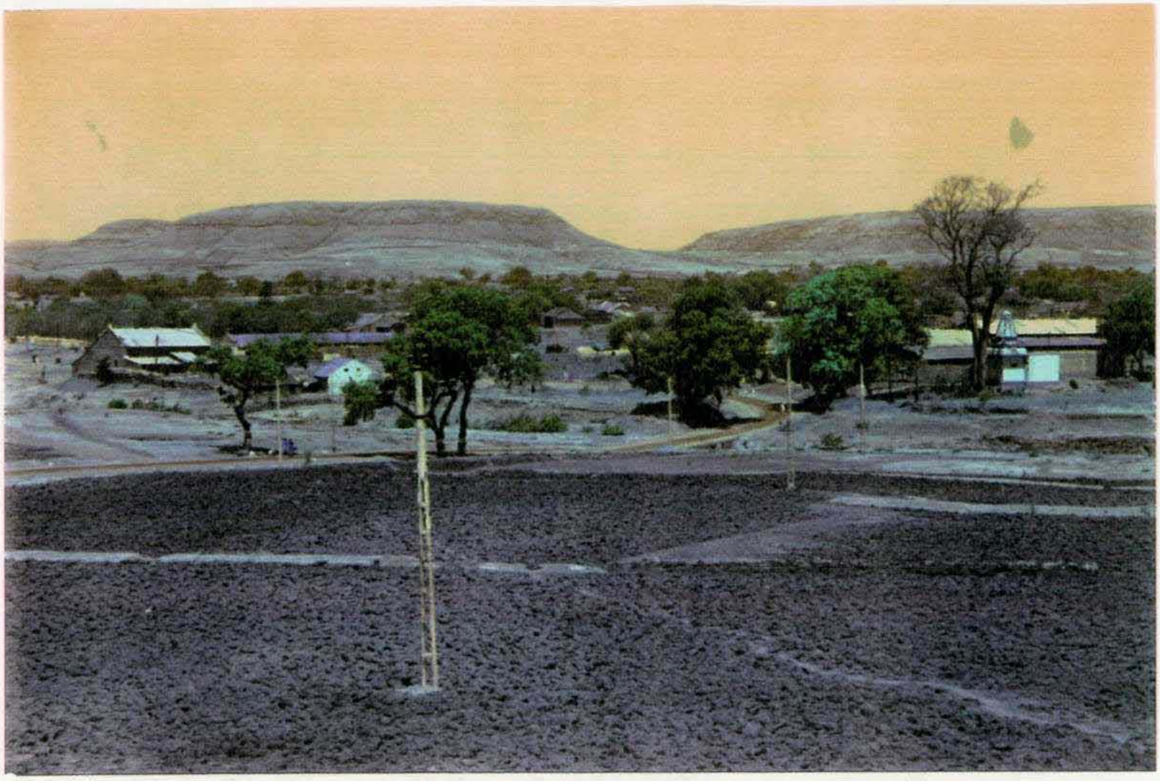

Figure 2.1 Pabal village, with low relief basaltic hills in the background.

Figure 2.2 Dug well lined at the surface with basalt blocks.

brick or cement to prevent the soft and deeply weathered rock caving-in whilst the lower part which is essentially competent rock is left unlined (Figure 2.2). There are some 300 irrigation wells in the village (on average 1 well per 10 ha) and abstraction rates are in the range 50-300 $m^3/d$.

The majority of crops within this area are grown on a seasonal basis. During the monsoon season (July-September) they are primarily rainfed with occasional supplementary irrigation from dug wells. During the winter season (October-March) when the rains cease, crops are irrigated by well water with some additional water obtained from surface water sources. In summer (April-June) the sole supply of irrigation water is from the dug wells.

The area of land producing crops during the summer months depends on water levels in the wells (Figure 2.3), which in turn depend on the recharge that has occurred during the rainy season and the subsequent management of water use (Deolankar and Kulkarni, 1985a). Shallow wells whose abstraction is scaled according to the previous years rainfall, can last throughout the year. However, wells where abstraction is not limited may dry up. This may be due to a lack of understanding on the part of the owner(s) of the well behaviour or that there are simply too many people using the well (or a combination of both). The users of a well will, through time, naturally increase as the ownership is shared among the descendants of the previous generation (Deolankar and Kulkarni, 1985b). As such the requirements of the well will likely increase, though the land cultivated per head may be reduced.

Given that groundwater resources are finite, sustainable development may require: the more efficient use of water; the planting of less water-intensive crops; better soil and water management.

## 2.2 Potable Water Supply

Drinking water is obtained in the village from a deep community dug well and from various production wells. The community dug well is known to have run dry making it necessary to ship water to the village by lorry from other areas. This incurs considerable expense. In areas outside the village centre drinking water is obtained from the irrigation wells. Drinking water has precedence over irrigation water and if one owner's well dries up, drinking water will be obtained from neighbours wells.

## 2.3 Solutions to Water Shortage

One solution to the problem of the drying up of wells and one that is increasingly popular, is to deepen existing dug wells (Figure 2.4) or convert them to dug-cum-bore wells to intercept more productive zones in the basalt. In some hydrogeological settings this may be an appropriate solution. However, in other instances it may be only a short-term solution and water levels may continue to decline since groundwater resources available to the well may not have significantly increased. Indeed, in the deep aquifers it may well exacerbate the problem since the lower storage coefficients of the confined aquifer will result in the cone of depression around wells extending considerably further. This will lead to well interference and a regional decline in water levels. In addition, previous investigations have shown that the deeper aquifers are often of limited extent

Figure 2.3 Crop producing and non-producing land during the summer months.

Figure 2.4 The deepening of a large diameter dug well.

and that their potential for sustainable development is consequently low (Herbert et al, 1981). If any increase in abstraction rate is not sustainable it may only increase the problem.

### 2.4 Research Required

There are many questions that need to be answered. How much groundwater is stored in the aquifer and how does the storage vary spatially? What recharge is there to the aquifer and how does this compare to the abstraction especially in periods of drought? Are groundwater levels in the long-term declining? What radius of influence is resultant from a highly productive well and what effect does it have on neighbouring wells? What is the optimum spacing of dug wells? Are the deeper aquifers a sustainable resource?

If answers can be obtained to these questions then they can be used in combination with investigations into water management and agricultural practices along with socioeconomic studies to help the local people achieve a system with a stable long-term supply.

## 3. GEOLOGY AND HYDROGEOLOGY

### 3.1 Regional Geology

The Deccan trap basalts occupy an area of more than 500,000 km$^2$ and are believed to be more than 1500 m thick in some places. These lavas were erupted in the Cretaceous-Tertiary period some 65 ± 10 million years ago. Individual lava flow units can vary from a few metres up to 100 m thick. Field mapping has shown that at least two types of lava flow exist (Kale and Kulkarni, 1992). The first type is the classic flood basalts which corresponds to quiet periods of upwelling of low viscosity lava and is characterised by extensive lava flows of compact basalt with generally only thin layers of amygdaloidal or vesicular basalt at the top and base of the flow. The second type correspond to more explosive activity and to more viscous lavas. These flows are generally less extensive than the first type, show abrupt changes in thickness over short distances and can be vesicular or amygdaloidal throughout the full thickness of the flow.

It is probably worthwhile describing the basic processes producing these features in the two types of lava flow. In the first type, which are also called simple flows, the lava spreads over the ground surface over an extensive front. Both the base and the upper part of the lava become chilled rapidly and solidify. Volatiles degassing from the lava are trapped as gas bubbles or vesicles in the chilled or solidified portion of the flow. The central portion of the lava cools very slowly and may remain fluid for many weeks, months or even years. In these types of lava flow three roughly parallel layers may be distinguished; an upper slaggy and vesicular portion, a central zone with irregular columnal jointing (cooling joints) and a basal layer of more rubbly basalt. The upper and lower margins of the flow become fractured, partly by shrinkage on cooling and partly because of distortion by the movement of the still liquid central portion of the flow.

The second type of flow called compound flow results from lavas which have lost much of their volatiles prior to extrusion at the surface. The lava is characterised by an exceedingly rubbly surface; the fragmented material is known as 'clinker' or as 'slag'. The fragmentation of the surface of the flow results from disruption of the very viscous crust by movement of the flow beneath it. The base of the lava is also rubbly and fragmented whilst the central layer generally forms a massive rock. The proportion of fragmented rock or clinker in a flow varies generally between 15-65%. The central part of the flow may be vesicular or amygdaloidal as any gas bubbles produced would be trapped by the rapidly solidifying lava. It must be stressed that there are gradations between the simple and compound flows. In fact a simple flow may become a compound flow since the loss of volatiles will increase the viscosity of the lava as the lava migrates away from the source vent.

## 3.2 Geology of Pabal Village

In Pabal village the basaltic lavas have been mapped by the staff of Poona University (Kulkarni, 1987) and the following sequence has been identified (see Figure 3.1):

(1) Compact basalt which underlies and forms the low hills,

(2) Amygdaloidal basalt which underlies much of the flat cultivated land. The upper part of this basalt is marked by a red tuffaceous layer which grades into a purple-grey weathered layer with a high density of amygdales, and

(3) A compact, almost black, basalt practically devoid of amygdales, immediately beneath the amygdaloidal basalt.

The boundary between the amygdaloidal and the compact basalts has not been clearly observed and it is therefore difficult to ascertain whether these basaltic lavas are separate flows or different parts of the same flow.

Perhaps from the hydrogeological point of view at least of greater importance is that the amygdaloidal basalt is cut by a large number of closely (1-10 cm) spaced horizontal-subhorizontal joints, referred to here as sheet joints. In contrast, the compact basalt is cut by very few horizontal joints and vertical joints are more frequent, although the spacing between vertical joints is much greater than that of the sheet jointing in the amygdaloidal basalt.

## 3.3 Hydrogeology of Pabal Village

A shallow water-table occurs within 1-4 m of the surface throughout the village area. The shallow aquifer itself probably does not extend beyond about 15 m in depth. This aquifer provides all the irrigation and potable water supply needs of the village since the only surface water in the village, a stream, ceases to flow after about January/February (except for a short period during the monsoon) the stream itself is fed by groundwater only.

Towards the end of the dry season and after periods of prolonged pumping the water levels in the wells are often so low that a considerable part of the aquifer is exposed

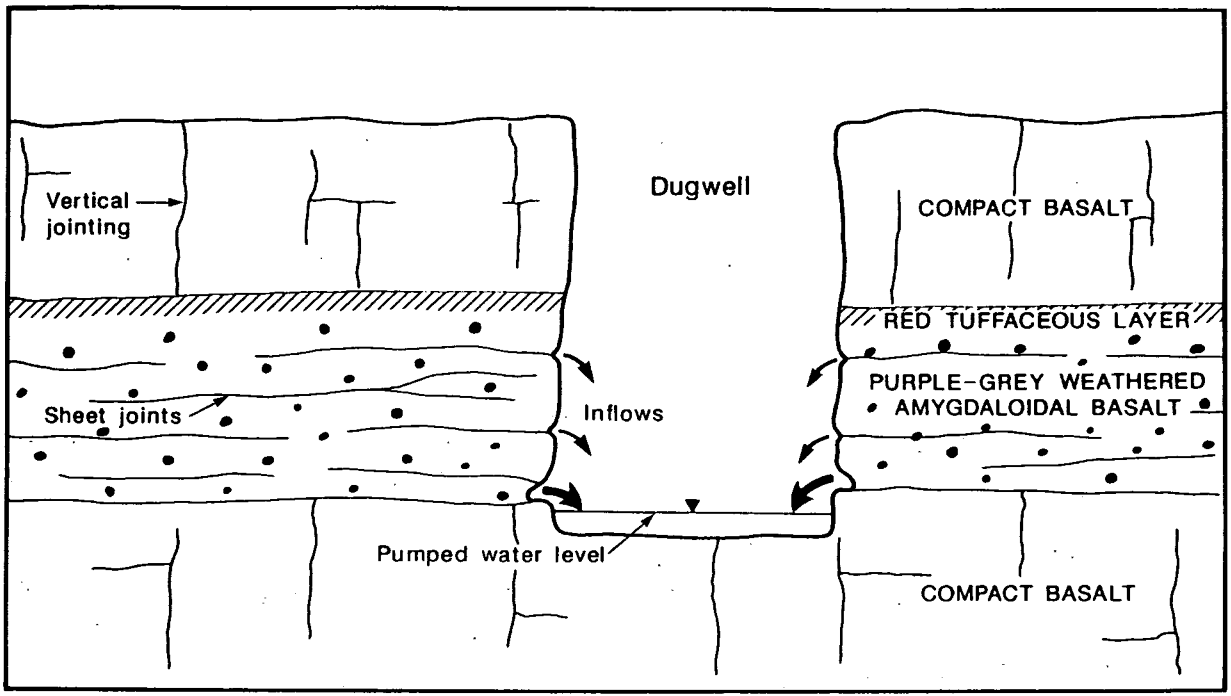

Figure 3.1 Idealised basaltic lava sequence, Pabal village.

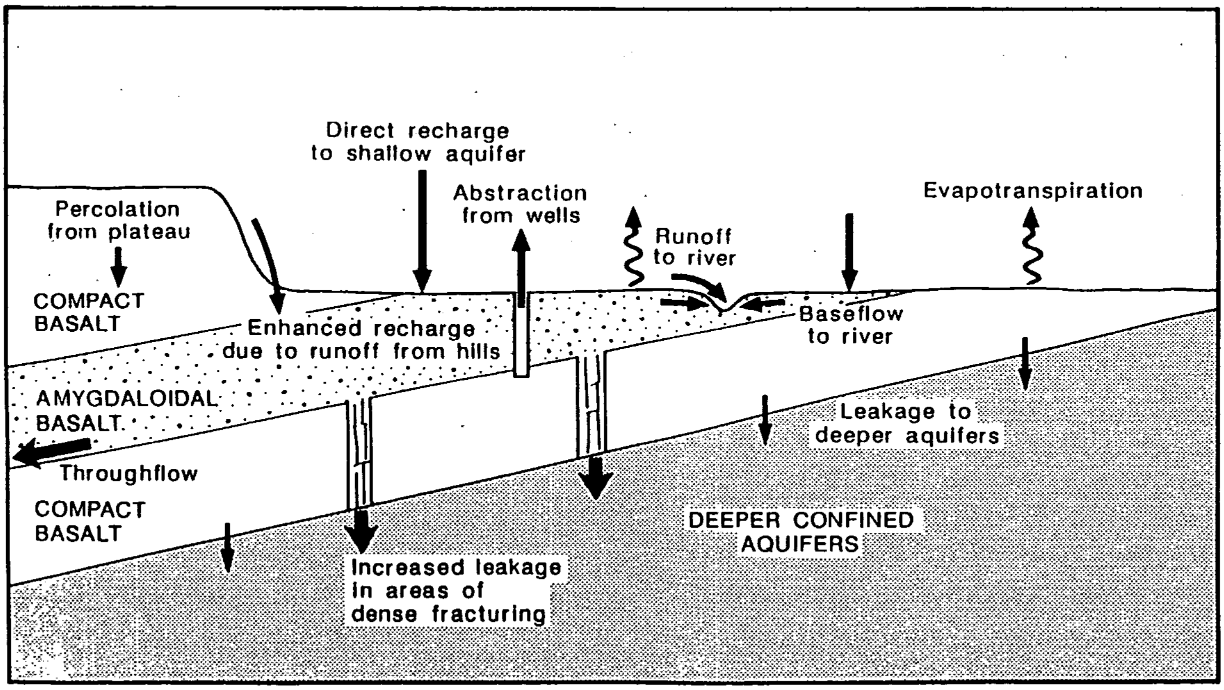

Figure 3.2 Schematic illustrating recharge and discharge processes within a basaltic aquifer.

within the wells. On these occasions water can be clearly seen flowing into the well from discrete fissures. Visual evidence of this type was used to suggest that the most prolific inflow zones in the Pabal region occur within the sheet joints although other inflows occur particularly at the contact between the base of the amygdaloidal basalt and the upper part of the underlying compact basalt. This evidence was supported by water level versus time data collected during the recovery period of a well which showed that wells in the amygdaloidal basalt recovered faster, and were therefore more permeable, than wells subject to similar pumping conditions, in the compact basalt (Kulkarni, 1987).

The term shallow aquifer is widely used but is difficult to define precisely in the Deccan basalts since the shallow weathered layer cuts across individual permeable horizons within the basaltic lava sequence.

The shallow aquifer as defined in this report is the unconfined aquifer that exists within the upper 15-20 m of weathered and fractured basalt. It is a dynamic system with water entering and discharging from the aquifer. Figure 3.2 shows the main components of recharge and discharge to the system. Groundwater abstraction is almost certainly the single largest component of discharge from the shallow aquifer and can be reliably estimated. For Pabal it has been estimated that the average abstraction for an irrigation well is 860 $m^3$/week and that the irrigation period is approximately 24 weeks, thus a single well would pump some $2.0 \times 10^4$ $m^3$/yr. With a well density of 10 per $km^2$ this is equivalent to 200 mm over the irrigated area. Taking into account that some 30% of irrigation water is likely to be recharged and that some groundwater is "lost" from the shallow aquifer to streams and to deeper groundwater, the volume of recharge required to sustain groundwater development over the total catchment, including the low hills is 100 mm. This is a significant percentage of the total average annual rainfall of about 1000 mm. This recharge to the aquifer must balance the loss in groundwater storage through the dry season. On this basis with an average seasonal fall in groundwater levels of 4 metres the specific yield would equal about 5%, not an unreasonable estimate for weathered basalt.

These calculations are rather crude and serve only as a likely indication of the order of magnitude of the various groundwater components. However three important observations follow from these calculations:

(1) The recharge required to sustain the present level of groundwater development is high and it is unlikely that greater recharge could be induced by increased abstraction.

(2) The component of discharge to the deeper groundwater systems is quite small and that the potential for development of the confined aquifers is probably limited.

(3) The total quantity of groundwater stored in the shallow aquifer is probably less than two years' 'average' recharge. A value which in the future could reduce with the effects of a changing climate.

The quantity of groundwater required for potable supplies is quite small - equivalent to about 10 mm/yr (assume population density of 700/$km^2$ for Pabal village, excluding hill areas, and a per capita consumption of 40 l/d) or about 5-10% of the groundwater stored in the shallow aquifer. This quantity of water is small in comparison with the groundwater storage and water pumped for irrigation. Therefore the benefit of intensively irrigated crops must be weighed against the possibility of having to provide alternative high cost water supplies during drought periods. The key question is what will happen if abstraction for irrigation is increased, will it result in individual wells drying-up or a regional water level decline affecting potable supplies as well?

## 4. SITE INVESTIGATIONS

### 4.1 Previous Work

A substantial amount of work has already been done in and around Pabal village by the Geology Department of the University of Poona. Groundwater levels were measured on a seasonal basis over the period 1984 to 1986. A well inventory was also established during this time and a geological survey undertaken. Local agricultural practices, described earlier, were studied. Work has continued in the region since. The sustainability study to be undertaken is to be built upon the hydrogeological understanding already attained. A smaller area of the Pabal region has been chosen to allow a comprehensive study to take place within the staffing and budget available.

### 4.2 Work Programme

A number of wells have been dug since the initial surveying of the area. Geological and hydrogeological information mainly on lithology and fracture patterns will be obtained from these wells to add to existing knowledge. This information will be used in conjunction with measurements of the vertical variation of storage coefficient and transmissivity to better understand the storage and flow system of the aquifer. Storage coefficients will be obtained by carrying out recovery tests on dug wells at periods throughout the year as the water table declines following the rainy season. Double packer-tests will be performed on newly drilled boreholes. The method allow sections of the aquifer to be isolated and pump-tested. Analysis of the resulting pressure data will give the transmissivity of the aquifer in the vicinity of the well over the depth interval of the packer-test. By moving the packers down the borehole in steps the variation in transmissivity with depth can be measured. It is believed this will be the first attempt to carry out this type of aquifer-testing on the Deccan Basalts and will allow hypotheses on the most productive layers of the aquifer to be tested.

A groundwater monitoring scheme will be introduced to measure water table fluctuations throughout the year. Observation boreholes will be drilled both near to and distant from irrigation wells to investigate: the radius of influence of the pumping wells, the effect on regional water levels and any long-term background decline.

The boreholes for the packer-testing will also be used for performing pumping-tests on the deeper confined aquifer while monitoring the groundwater levels in observations boreholes completed in the shallow aquifer. This will show the connection between the two and demonstrate the effect of exploitation of the deeper aquifer on the unconfined aquifer above.

The great majority of the work will be carried out by the staff of the Geology Department of the University of Poona with the help of research students. The packer-testing work will be carried out initially by a BGS member of staff with the aim of training the university staff in the use of the equipment.

## 5. CONCLUSIONS

The recent trend in increased abstraction from the Deccan Basalt aquifer to meet, in particular, the rising demand for irrigation is likely to continue. This has heightened concern in India that current groundwater abstraction from the shallow aquifer in certain areas may be exceeding that which is sustainable from limited groundwater resources and that water levels are declining as a result. The possible reduction in recharge due to climatic changes would exacerbate this problem. The cost implications of over-abstraction and depletion of groundwater resources are potentially very serious, both in terms of wasted investment in agricultural development and in loss of cheap potable water supplies to many rural communities.

Few studies have been undertaken on the shallow aquifer within the Deccan Basalts to understand the groundwater system, to quantify recharge or to assess the influence of pumped irrigation wells on the regional water table. There is therefore a clear need for such research if sensible planning for sustainable development of groundwater and agriculture is to be made.

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