PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

India: Underground Water Resources [and Discussion]

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India: underground water resources

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Irrigation is important in India where one-third of the land surface is semi-arid and the rainfall is seasonal and erratic. The irrigated area in the country has almost doubled during the last 25 years and now stands at 43 million ha. Groundwater contributes to 40 % of all irrigation. Apart from providing irrigation, groundwater has been contributing to irrigated agriculture in many other ways and has, therefore, become a vital factor in the country's plans for agricultural development.

The total usable groundwater resources of the country are assessed at 350×10^9 m^3. The factors contributing to these resources and governing their occurrence and distribution in different parts of the country are described. At present about 35 % of the available resources are utilized.

Different types of groundwater structures, typical to India and suited to meet the irrigation needs of small farmers, are being constructed to tap the available resources in various parts of the country. Their design and construction features, determined to a large extent by the local geological formation, are explained.

The first large-scale venture in scientific planning and the development of groundwater was undertaken in 1934. A major break-through came in 1965 with the advent of high-yielding varieties of crops. Two important factors, namely the expansion of the rural electrification programme and the development of the cooperative credit structure, have helped in sustaining a high tempo of development since then. The present dimensions and other features of the development programme are indicated.

A systematic programme of groundwater investigations is a must for scientific development and management of the resources. It has been greatly intensified during the recent years and investigations include hydrogeological survey, geophysical studies, exploratory drilling, pump tests, and water balance studies including the construction of mathematical models. The approach and methodology adopted to keep down the cost of investigations is described.

No amount of groundwater investigation and planning will help in preventing infructuous expenditure, unless there is legislation to control and regulate groundwater development. The steps taken in this direction are mentioned.

1. Introduction

The water resources of a country constitute one of its most important economic assets. The pattern of water resource development for various beneficial uses, however, differs from country to country depending on its climatic and physiographic conditions and socio-economic development. In India, at present more than 90 % of the total water usage is accounted for by irrigation (including associated hydro-electric power generation). This is so because 70 % of India's population is dependent on agriculture and, rainfall being highly seasonal and erratic, successful agriculture is not possible without irrigation. Although the irrigated area has almost been doubled since the inception of planning about 25 years ago, still about 75 % of the gross cultivated area is without irrigation. Moreover, agricultural production in the country is still short of requirement. It is, therefore, likely that while the requirements and priorities for industrial and domestic use of water will undoubtedly increase over the course of years, irrigation may still continue to claim the maximum share of water resource development.

The contribution of groundwater to total irrigation is 40 %. The most conspicuous development of groundwater for irrigation has been in the semi-arid region of the country. With the extension of cheap electric power for pumping, the old belief that because of the lifting of water involved, the economics of groundwater schemes is less favourable than of surface water irrigation projects, is no longer true. The higher cost of operation is more than compensated by the lower order of initial investment on the schemes. The latter, in fact, becomes a positive economic advantage when there is constraint of financial resources.

The rôle of groundwater in agricultural development is more important than merely increasing the irrigation potential. Most of the old canal systems in India were designed to provide irrigation of the protective type as an insurance against famine and scarcity. These systems are not able to meet the irrigation demand of modern productive agriculture. Groundwater development in the command of these projects has greatly helped to make good the deficiency of the irrigation supply. On many canal systems, it has been found to be a powerful tool in controlling waterlogging and salinization and in substantially reducing the need for horizontal drainage. Also, the experience during recent occasions when the country passed through widespread and severe droughts, has demonstrated to the farmers that groundwater is a more dependable and handy source of irrigation under such periods of stress. Moreover, the means of tapping groundwater, i.e. wells and tubewells, are generally owned by the cultivators themselves. With the control of water in their hands, cultivators have the incentive to make the heavy investment required by productive agriculture. Groundwater may thus rightly be said to be providing the basic infrastructure on which the edifice of modern agriculture is being built in India.

2. Groundwater resources – quantum and the contributing factors

The groundwater resources are dynamic in nature; they grow with the expansion of irrigation.

The main factors that build up the groundwater resources are: (*a*) rainfall; (*b*) seepage from the canal system including storage reservoirs and the return flow from irrigation; and (*c*) inflow from the rivers. It is obvious that the contribution from factor (*b*) will increase progressively with the augmentation of irrigation. The contribution of factor (*c*) is also likely to increase due to the lowering of the water table along the rivers as further groundwater development takes place and as a result of measures for induced recharge from the rivers.

The estimated contribution from these factors as at present and as may be obtained ultimately on full development of irrigation (the ultimate potential for irrigation development in the country is assessed as 107 million ha as against the present level of 43 million ha) is given in table 1 (Jain 1974*b*).

The total estimate of present and ultimate groundwater resources thus comes to 650×10^9 m^3 (650 milliard cubic metres) and 850×10^9 m^3 respectively. All these groundwater resources, however, cannot be utilized because of physiographic limitations, inevitable loss as evapotranspiration in some high water table areas and in view of the obligation to maintain the committed base flow in the rivers. Out of the present estimated figure of 650×10^9 m^3 for the

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total groundwater resources, the withdrawal use is estimated at 120×10^9 m^3. Assuming that the net annual change in groundwater storage is negligible, it is estimated that the remaining 530×10^9 m^3 is presently accounted for to the extent of about 80×10^9 m^3 by the loss due to evaporation from the water table and to the extent of about 450×10^9 m^3 by the effluent discharge to rivers and streams (the latter is the contribution of groundwater resources to surface water). On the presumption that the effluent discharge would be maintained ultimately more or less at the same level as at present (that is 450×10^9 m^3) but the loss by evapotranspiration may be somewhat reduced as a result of lowering of the water table due to further groundwater development (say from 80×10^9 m^3 to 50×10^9 m^3), the estimate of the ultimately usable groundwater resources is placed at 350×10^9 m^3.

Table 1. Assessment of groundwater resources (10^9 m^3)

contributing factor	at present	ultimate on full development of irrigation
rainfall	500	500
seepage from canal systems including return flow from irrigation	110	250
influent recharge from rivers	40	100
total	650	850

In comparison, the total surface water resources of the country are assessed at about 1780×10^9 m^3. The utilizable component, however, is estimated as only 666×10^9 m^3, of which about 250×10^9 m^3 are presently used.

It may be stated that all the above estimates are tentative and will be refined as more elaborate data are collected.

3. Occurrence and distribution of groundwater resources

While rainfall is the major source of groundwater recharge, infiltration and storage of groundwater are governed largely by the geological formations. These two factors together give a fair general indication of the occurrence and distribution of groundwater resources in different parts of the country.

(a) *Rainfall*

The average rainfall in India is about 120 cm, which is a little more than the global mean of 99 cm. However, it is highly seasonal in character and widely varying in distribution over the country. About 75 % of the total rainfall is received in the four-month period, i.e. June to September. Maximum groundwater recharge takes place during this period, and the groundwater contours are usually at their highest level immediately after this period.

The rainfall map of India (figure 1) shows that an average rainfall of the order of 100 cm and more occurs in about 50 % of the total land area of the country covering the Eastern Region, the Himalayan Region and the coastal areas. An appreciable portion of this region in the northeast and along the western coast receives rainfall of more than 200 cm. This region accounts for about 55–60 % of the total usable groundwater resources of the country.

On the other hand, the bulk of groundwater development that has taken place and made a significant contribution to stepping up wheat production in the country has been in the region receiving less than 100 cm of rainfall. A major portion, comprising about 60 %, of

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this region, towards northwest and covering the rain shadow area formed between the mountains, called the Ghats, along both the coasts in peninsular India, receives a rainfall between 40 and 75 cm and may be categorized as semi-arid. Most parts of this region, however, happen to be under heavy canal irrigation from snow-fed and other rivers and have good groundwater potential in spite of low rainfall.

The fringe area in the extreme northwest is an arid region receiving less than 40 cm of rainfall. Groundwater availability is by and large chequered in this region and the groundwater encountered is frequently of poor chemical quality. Saline and fresh water zones are

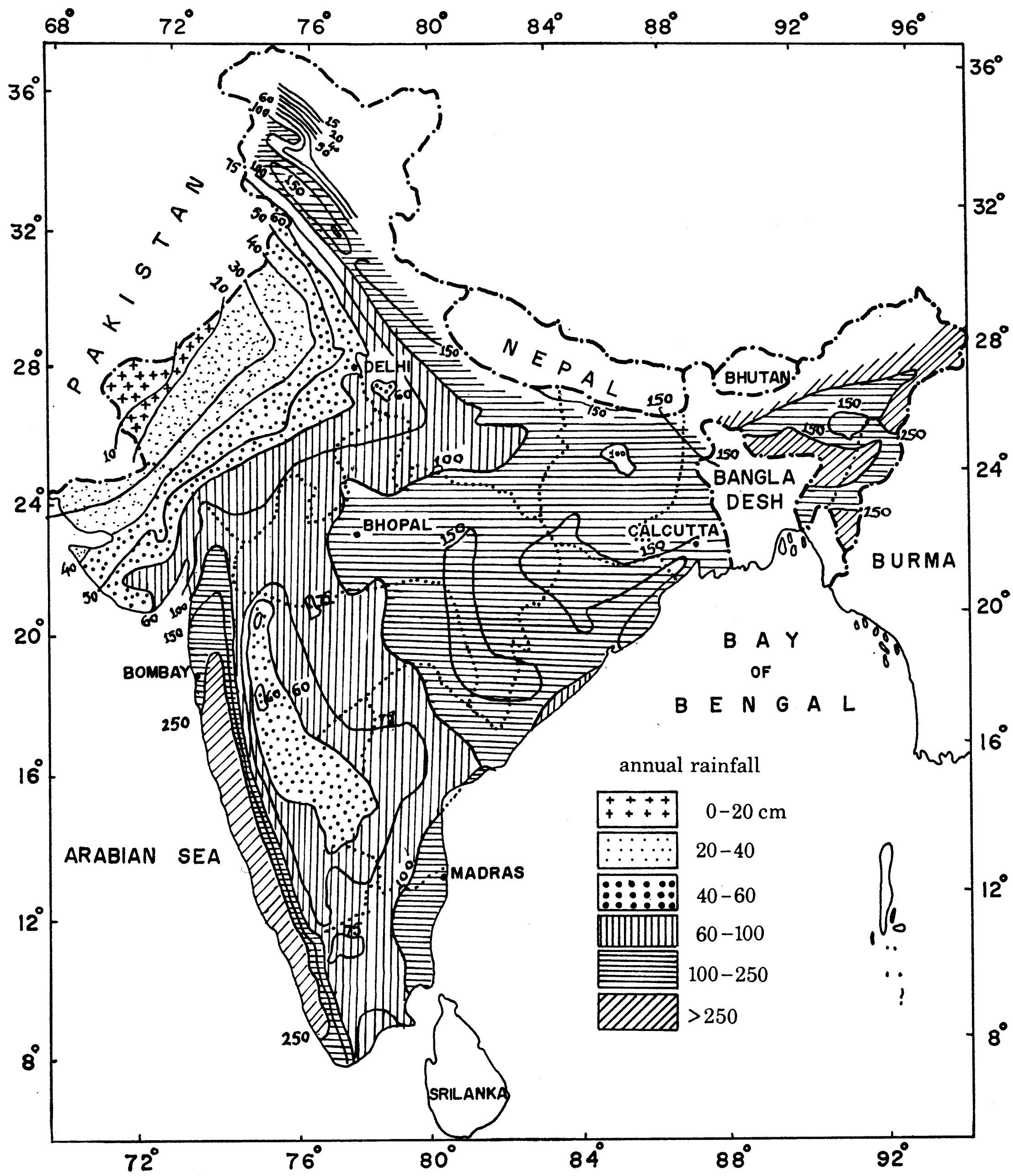

FIGURE 1. Rainfall map of India.

intermixed in a complex manner and this becomes a serious problem in the utilization of the available groundwater resources. In a part of this region, there has been located a sandstone formation of Jurassic age which holds a reserve of good quality groundwater (about 28×10^9 m^3). The water is estimated to be 7000 years old and has no current recharge.

(*b*) *Geological formations*

Groundwater availability is largely governed by the state of cementation and compaction of the formation. From this point of view, the geological formations encountered in the country may be broadly divided into three categories (Deshmukh 1975), namely, the unconsolidated; the semi-consolidated; and the consolidated (figure 2).

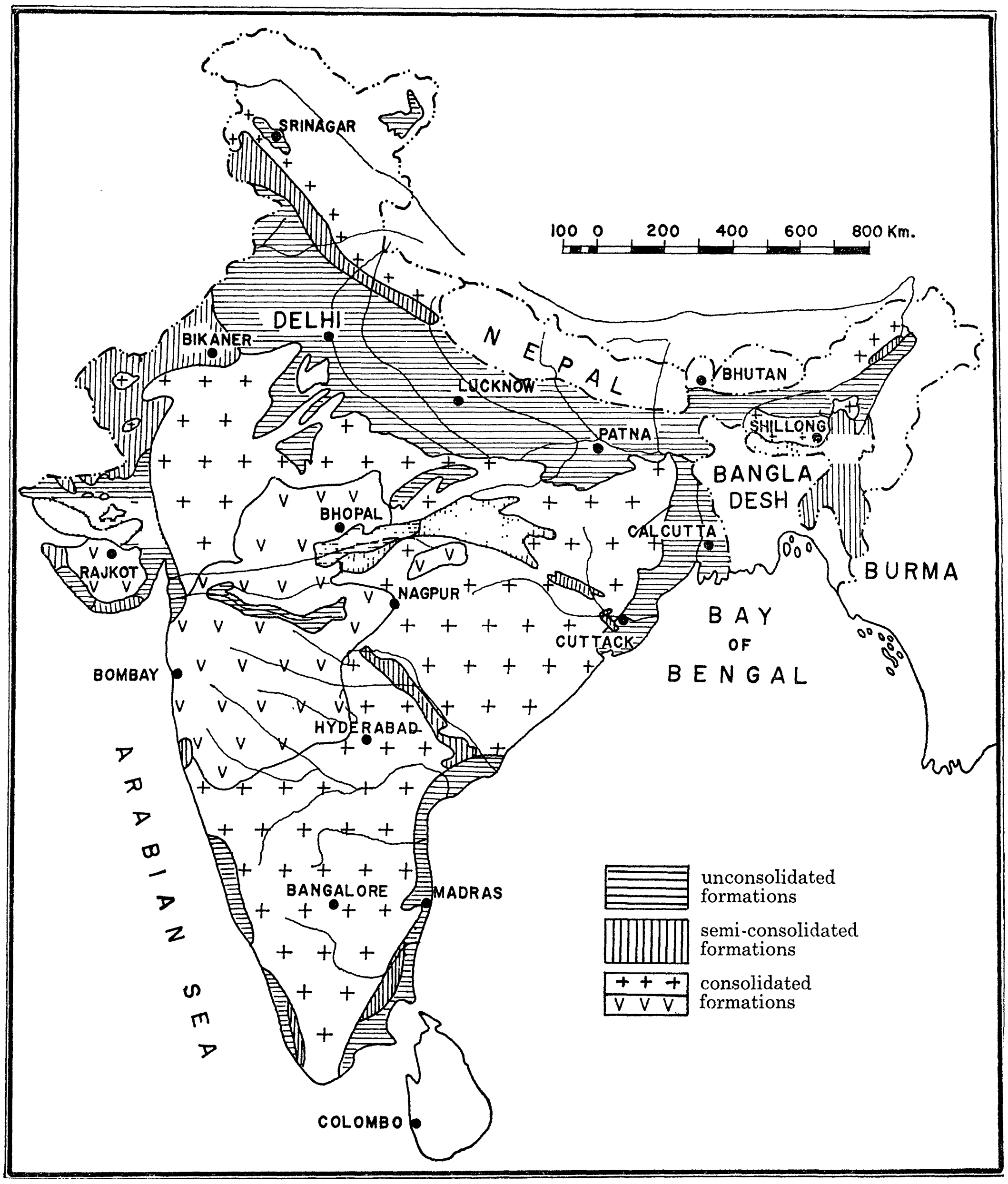

Figure 2. Hydrogeological map of India.

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(i) *Unconsolidated*

These include: the alluvial plains built up by the Himalayan rivers, namely, the Indus, the Ganga, the Brahamputra and their tributaries; the inland valleys of the rivers Narmada, Tapi and Purna in central India; the coastal alluvia – of east and west coasts and plains of Gujarat; and the aeolian sand-tracts of western Rajasthan. These formations are richest in groundwater except in parts of the northwestern arid and semi-arid zones not served by surface irrigation canals. They comprise about one-third of the total land area in the country (which is 3251200 km²), but account for about 50–60 % of the total usable groundwater resources. The lithology includes zones of sands, gravels, pebbles, etc. which not only store large quantities of groundwater but are also favourable from the point of view of groundwater extraction.

(ii) *Semi-consolidated*

These include the semi-consolidated sandstone formations of Mesozoic and Tertiary age, interspersed in different parts of the country, such as Western Rajasthan (Lathi series and Palana and Nagaur sandstones); east coast (the Cuddalore sandstones and Rajamundri sandstones); the west coast (the Warkalli formations in Kerala and the Himmatnagar sandstones and the sandstones of the Bhuj and Katrol series in Gujarat); and the rocks of the Gondwana systems (which have sandstones and shales) in Andhra Pradesh, Bihar and Orissa.

These formations are next in importance in groundwater availability, but hardly cover 5 % of the total land area. The lithology is generally favourable for groundwater storage and extraction.

(iii) *Consolidated formations*

The major part of the country including almost the entire Indian peninsula consists of hard rock formations. These comprise: crystalline rocks, granites, gneises, schists, etc. of Archean age; basaltic formations of Upper Cretaceous to Oligocene age; and compacts sedimentary formations – the Cuddapah, the Dehlis and the Vindhyan system which belong to the Precambrian age. Nearly two-thirds of the total land area is covered by these formations, of which about one-fourth is accounted for by the basaltic formations.

The rocks in these formations have no primary pore spaces and only hold limited quantities of groundwater in the weathered and the fractured zones. However, sizeable quantities are available at some locations in vesicular lava flows, intertrappean beds and cavernous limestones.

4. Groundwater structures – salient design and construction features

Diverse geological formations require different types of structures for tapping groundwater to meet irrigation needs. The choice of the structure in an area is also influenced by the size of farm holdings and the relative preference given to private, cooperative and public wells. Broadly, groundwater structures commonly constructed for irrigation in India (Jain 1973) may be divided into three categories: (*a*) dug wells; (*b*) dug-cum-bore wells; and (*c*) tube-wells.

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(*a*) *Dug wells*

These comprise open surface wells of varying dimensions dug or sunk from the ground surface into the water bearing stratum. Usually two types of wells are constructed: (i) masonry (lined) wells; (ii) unlined wells in hard rock.

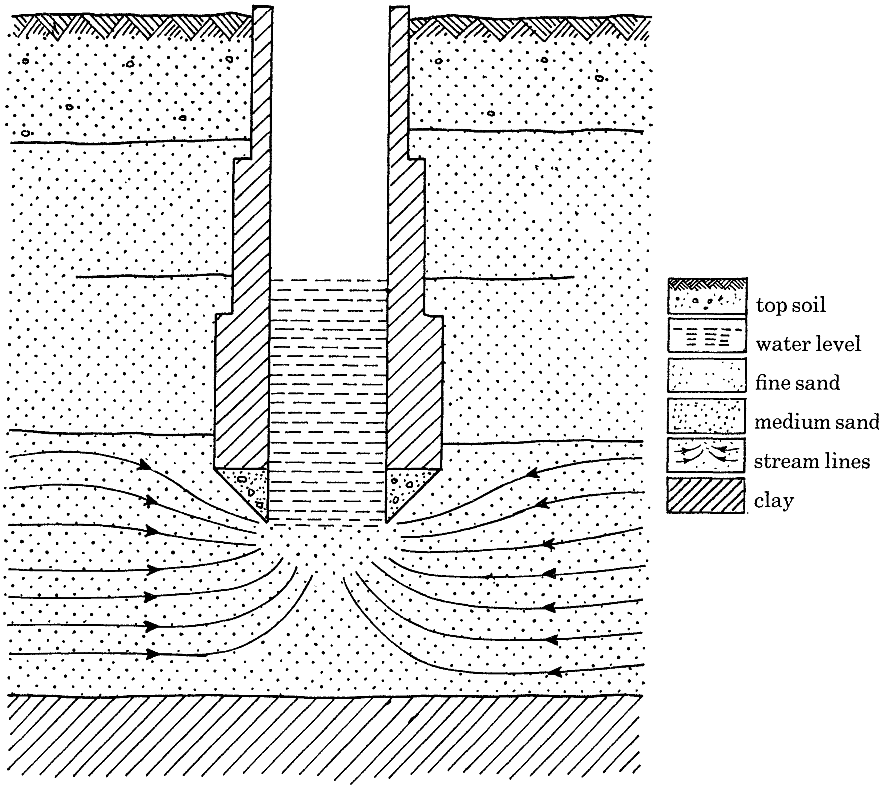

FIGURE 3. Masonry well in alluvium.

A typical masonry well usually constructed in the alluvial or semi-consolidated formations (figure 3) has a masonry steining wall sunk in subsoil by applying a static weight of sand bags and simultaneously scooping out earth from inside. In locations where it is not possible to sink masonry steining by ordinary methods due to the presence of hard clay or boulders, it is built in a dug pit from the bottom upwards. The diameter of the well ranges between 2 and 6 m, and the depth of the well between 8 and 15 m.

Research work is in hand in the country (Jain 1971) to improve the design of these wells in two respects. The draw-down and therefore the yield of these wells has to be restricted to prevent sand movement from the bottom so that the masonry steining does not collapse due to settlement. Attempts are, therefore, being made to design suitable inverted filters that may be provided at the foundation of the wells to control sand movement. Secondly, the flow in these wells is through the bottom only. This results in the congestion of stream lines and considerable loss of head. The wells are, therefore, hydraulically inefficient. Efforts are being made to evolve suitable cheap designs for pervious steining which should improve the efficiency and water output of these wells.

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In alluvial formations with a shallow water table, both dug wells and shallow tubewells (described later) are feasible and the latter are generally cheaper in terms of cost of per unit of water produced. Dug wells, however, have the advantage that they permit a phased development to the poor farmer. In the first instance he goes in for the well only and then after earning some money he gets it bored and subsequently gets it fitted with a pumpset – which arrangement practically becomes a tubewell with the well steining serving as a pump house.

A typical dug well constructed in the hard rock formations is usually an open excavated pit through the top soil and the weathered rock. The top portion through the soil mantle is usually lined with masonry or dry stones. Pneumatic rock blasting equipment using jack-hammers and explosives is employed for excavation of the well through the hard rock. The well taps water from the sides as well as from the bottom and is generally constructed in a large size (6 m × 6 m or more) to provide storage.

The diameter and the depth of these wells is often decided arbitrarily. Case studies are in hand to assess the relative advantage of having a larger diameter (which increases the percolation area as well as the storage capacity) versus greater depth (which increases operational draw-down and therefore the yield and also the storage).

Persian wheels, rope-and-bucket lifts and sometimes counter-poised lifts are used to lift water from dug wells. The present trend, however, is in favour of using power pumps, preferably electrical but otherwise diesel if electric power is not available. The water output of these wells is of the order of 50–100 m^3/day and their cost ranges between $250 and $1000.

(*b*) *Dug-cum-bore wells*

Dug wells are frequently bored through the bottom to augment their output. These are referred to as dug-cum-bore wells.

In sedimentary formations, boring essentially consists of drilling a small size bore of diameter usually ranging between 7.5 cm and 15 cm, through the bottom of the well and extending the bore down to a layer of good water bearing medium with a view to tapping this aquifer. The boring is usually done by the percussion method, using hand boring sets or percussion rigs (Jain 1962). Bores are of two types: either cavity or strainer.

The dug-cum-bore well of the cavity type (figure 4) taps a water bearing medium, which is immediately below a hard impermeable layer, through a cavity formed in the medium as a result of gradual over-pumping. The bore is fitted with a plain pipe, extending down to the cavity. This type of boring is economical but is not feasible at all locations. An essential requirement is that the impermeable layer overlying the water bearing stratum should be sufficiently thick and strong.

In the dug-cum-bore well of the strainer type the water is tapped through a screen provided opposite the vertical depth of the water bearing medium. The rest of the bore is lined with unperforated pipe.

In hard rock formations again, bores are of two types: (i) bore tapping an embedded layer of water bearing medium; and (ii) bore tapping joints, fissures, fractures, etc.

Figure 5 shows the first type. The size of the bore is usually 7.5 cm or more. It is normally drilled by percussion or calyx rigs. Recently in some cases down-the-hole rigs have also been used for faster drilling.

In the second type the practice is to drill a number of slim holes, 4–5 cm in diameter

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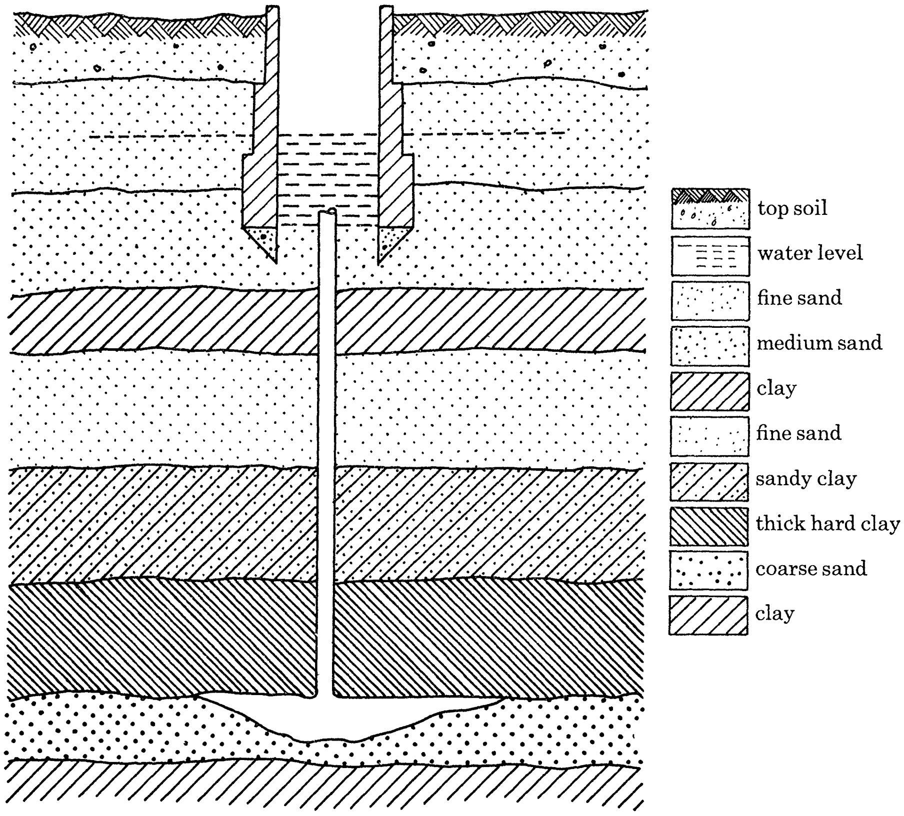

FIGURE 4. Dug-cum-bore well in alluvium (cavity type).

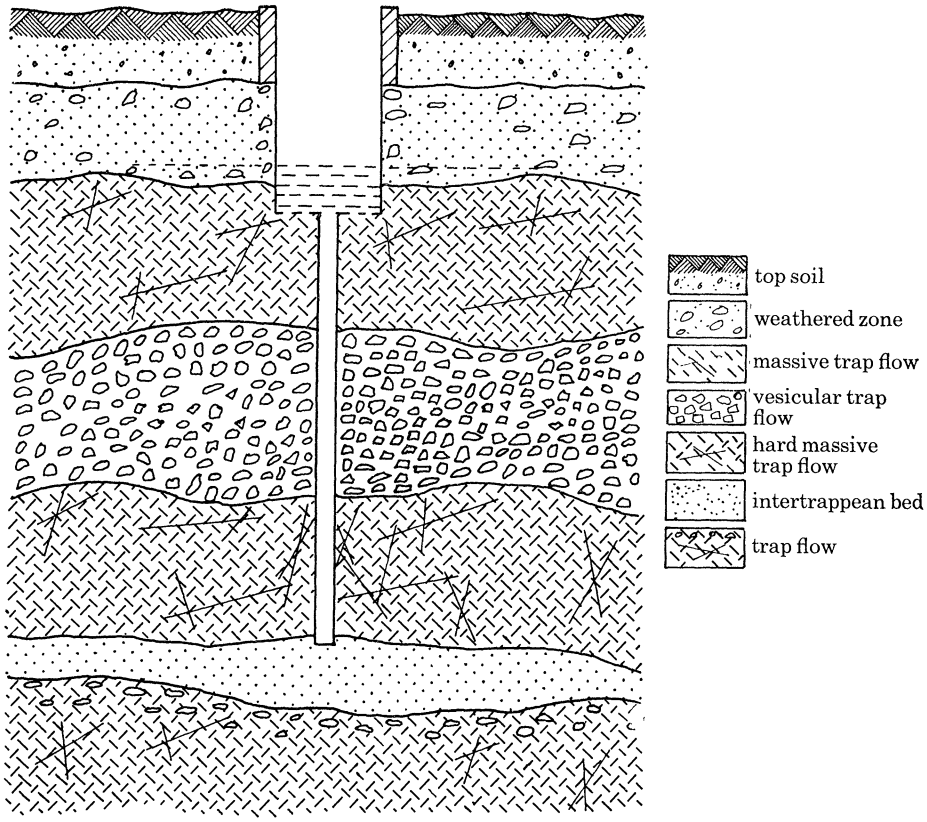

FIGURE 5. Dug-cum-bore well in hard rock (tapping intertrappean bed).

instead of one big central hole, in various directions perpendicular to the inclination of the water bearing fracture planes by using rock drills with extension equipment.

The water output of the dug-cum-bore well is considerably higher than that of a simple dug well. It is usually much more economical to operate these wells by pumpsets than by man or animal operated water lifts. The depth of the bore seldom exceeds 50 m and the extra cost involved in boring usually ranges between $100 and $600.

(c) *Tubewells*

A tubewell essentially consists of a borehole drilled into ground with the purpose of tapping groundwater from the pervious zone. Tubewells constructed in the country may be broadly divided into three categories: (i) shallow tubewells; (ii) deep tubewells; and (iii) bore wells. A tubewell in sedimentary formations not exceeding 60–70 m in depth is called a shallow tubewell. Shallow tubewells are of two types: cavity tubewells; and strainer tubewells.

In a cavity type shallow tubewell the water is directly pumped from a cavity formed at the bottom of the bore, which is provided only with unperforated pipe. Cavity tubewells are cheaper but a durable cavity is feasible only where there is a strong roof of hard impermeable stratum, immediately overlying a good water bearing medium, and the water bearing medium is comparatively thin.

In a strainer type shallow tubewell the bore hole is installed with a pipe assembly including plain pipes opposite non-water bearing formations and a perforated screen opposite the water bearing medium or media.

Shallow tubewells are usually drilled by percussion methods using hand boring sets and sometimes percussion rigs. They are generally operated by the centrifugal pumps (volute type). They normally operate for 6–8 h per day during the irrigation season and giving a yield of the order of 100–300 m^3/day – roughly 2–3 times that of dug wells. Their cost ranges between $500 and $1500.

They are usually privately owned by the individual farmers. Their success and popularity depends on how cheap they are. Research and development efforts are therefore being directed to evolve cheap strainers for these tubewells. Perforated PVC pipes and pre-gravel pack filters are some of the promising designs that are presently under trial. Meanwhile, coir strainers formed by winding coir string over an iron frame have become very popular, because of their low cost, and have replaced, to a considerable extent, the brass strainers that were formerly in use. In the shallow water table areas, even the use of the iron frame in the coir strainer has been replaced by the bamboo frame. Also, attempts have been made to replace the steel pipe casing with pipes constructed by wrapping bitumenized gunny bags over the bamboo frame. These are called bamboo tubewells and are very cheap.

The deep tubewells constructed in India usually extend to depths of 100 m and more, and are designed to give a discharge of 100–200 m^3/h. These are usually drilled by direct rotary or reverse circulation rigs except in the bouldery formations where percussion or rotary-cum-percussion rigs have to be used. They operate round the clock during the irrigation season. Their total annual water output is roughly 15 times that of an average shallow tubewell.

Their cost is as high as $10000–16000. They are, therefore, beyond the means of individual farmers and are usually constructed as public works, owned and operated by public corporations or Government departments. Water rates are charged for the service rendered to the farmers.

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Usually deep tubewells in the country are constructed as artificial gravel packed wells (figure 6). There are situations where straight or naturally developed wells (strainer tubewells) will be more economical and efficient but still the practice is to go in for gravel packed wells. The important reason for this is that suitable screens with fine slots are not available in the country. Slotted steel tubes are mainly used as screens and it has hitherto not been possible to cut satisfactory slots of less than 1.6 mm size on these tubes.

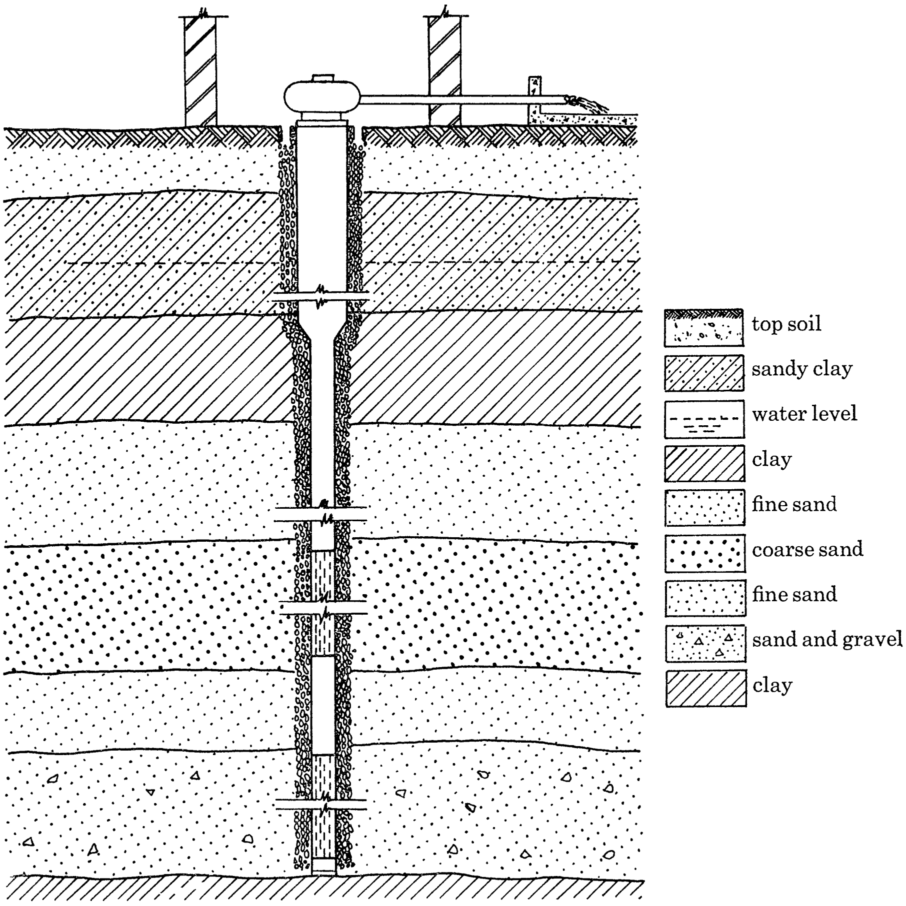

FIGURE 6. Deep tubewell.

Some far-reaching improvements (Jain 1973) have recently been effected in the design of these tubewells. These include:

(i) Designing the gravel pack and the slot size in relation to the aquifer material – definite criteria, based on research, have been evolved for this purpose. Further research work is in hand.

(ii) Designing the well for a high operational draw-down (the former practice was to limit the draw-down to about 6 m) so that the same well is able to deliver much more discharge at practically the same cost.

(iii) Increasing the open area of the screens from the previous 5–6 % to 15–25 %, as it is found that this improves the efficiency of the screens without endangering their structural stability.

(iv) Increasing the diameter of the screen assembly from 15–20 cm for wells discharging between 100 and 200 m^3/h in order to reduce the head loss.

(v) Reducing the area commanded by these tubewells so that they are able to provide intensive and assured irrigation required by the improved crop varieties now used.

The main criterion for the tubewell design still continues to be that the entrance velocity through the screens should not exceed 3 cm/s to control sand movement, encrustation and corrosion. Research work is in hand to evolve more refined criteria in this respect. Efforts are also being made to develop suitable alternative materials for the screens, particularly for use in formations where quality of water is a problem.

Tubewells in the hard rock areas are called bore wells because in such wells the borehole is stable without a lining in the bottom portion and a tube is put in only in the upper weathered zone.

These wells usually depend on the joints, fissures, fractures, etc. for their water supply. Even with a heavy draw-down of 20–30 m, such wells are usually not able to yield more than 5–10 m^3/h, except when they tap some embedded water bearing strata. Their operation is possible only with submersible pumps. Their cost ranges between $1200 and $1600 and is comparable to that of an average dug-cum-bore well fitted with a pumpset. Their advantages are that they do not occupy any agricultural land and can be completed in a very little time by hammer drills. Due to their meagre yield, however, they have not become popular for irrigation use in comparison to dug wells or dug-cum-bore wells, although they have established their merit for meeting drinking and domestic water requirements.

5. Programme for groundwater development – dimensions and policies

The use of groundwater in India through dug wells and indigenous water lifts dates back to ancient times. The first large scale venture in scientific planning and development of groundwater was undertaken in 1934 when a project for construction of 1500 deep tubewells was initiated by Sir William Stampe, the then Chief Engineer, in one of the important States of India, Uttar Pradesh. All the available knowledge on groundwater at that time was pooled and fully used in planning. The success of this project led to the extension of similar activity to other promising areas of the country. A significant breakthrough in groundwater development, however, came around 1965 with the appearance of high-yielding varieties on the agricultural scene and the realization that groundwater development is essential to provide the controlled and assured supply of irrigation needed to reap the full benefit of these varieties. The progress of development, in terms of important parameters, up to 1965 and afterwards, is set out in table 2.

Two major factors, namely, the expansion of the rural electrification programme and the development of the cooperative structure for financing privately owned irrigation works have played an important rôle in sustaining the high tempo of progress after 1965. During the fourth Five-Year Plan electric connections were provided to 270000 pumpsets every year. Progress slowed down during the last two years due to shortage of power and the limitations of main transmission and distribution lines. This, however, was a temporary phase and the programme has already started to regain its original pace.

The present annual expenditure on the programme of groundwater development is of the

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order of \$400 million. About 60 % of the total amount is now mobilized through cooperative sources including land development banks and cooperative banks, which extend long-term credit (period 7–15 years) and medium-term credit (period up to 5 years) respectively. The remaining funds are partly provided from Government sources and partly arranged by the cultivators themselves. Financial support of the cooperative credit structure has indeed been a big factor in the expansion of the programme during the recent years.

Table 2. Progress of groundwater development (millions)

	1950	1965	1975
dug wells	3.50	5.00	7.25
tubewells	negligible	0.10	1.00
pumpsets	0.08	0.90	4.75
area benefited (10^6 h)	6.50	9.50	17.00

The annual programme presently embraces construction of about 300000 new groundwater structures. In addition, about 100000 existing dug wells are bored or deepened to augment their water output and fitted with pumpsets (in place of existing man or animal operated water lifting appliances) every year. In terms of volume of water, utilization of groundwater resources was of the order of 120×10^9 m^3 at the end of 1973–4, which marked the last year of the fourth Five-Year Plan. Utilization is presently increasing at a rate of about 5×10^9 m^3 per annum.

Although the programme of development has now been picking up momentum in all areas, the rate of development hitherto has been much faster in the areas receiving rainfall of less than 100 cm. In fact, a stage has been reached in many parts where much more sophisticated planning and development of groundwater resources in close integration with surface water development is necessary to avoid situations of overdraft, saline contamination, reduction of committed flows, etc.

About 85 % of the total groundwater development is taking place through dug wells, dug-cum-bore wells and shallow tubewells, which are cheap enough to be afforded by farmers on an individual basis and have enough water to meet the irrigation requirements of small farm holdings – the average size of holding in India is about 2.3 hectares. If any farmer owning a well has some surplus water, he sells it to his neighbours. Deep tubewells are much more expensive and are generally beyond the financial means of individual farmers. These are, therefore, generally owned and operated as public works. The policy adopted is that public tubewells are usually constructed in areas where the water level is deep or aquifers are deep seated or otherwise difficult to tap by shallow tubewells or dug wells. In areas where both deep tubewells and shallow structures are possible, deep tubewells are constructed as public works in such pockets as have a predominance of small farmers who cannot afford structures of their own.

The management of public tubewells had suffered from some administrative problems. These have been identified and serious efforts are being made to remove them. In several states the construction and management of public tubewells has been transferred to public corporations who are expected to give single-minded attention to these problems. These corporations are also able to mobilize institutional credit, in addition to the budgetary allocations by the Government, for undertaking the construction of additional wells.

For private works, in addition to the cooperative loan, grants up to one-third from

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Government sources are also made available to small farmers having holdings less than 2 ha and up to one-half in cases where the small farmers combine together in a group to own and operate a well. Custom service in boring and drilling of wells as well as technical guidance in design and construction of wells is provided to the farmers by the State ground water organizations. There are also many small private agencies available to do the construction work and the farmer is free to choose between the departmental or a private agency.

Altogether the development of new irrigation potential, the problems of irrigation water management, and better utilization of existing irrigation potential are now receiving the serious attention that they deserve. A special programme called the Command Area Development Programme has been initiated for this purpose during the current Plan. This programme, however, will mainly cover public irrigation systems. As far as private wells are concerned, the standard of land levelling and shaping, constructing and maintaining farm distribution channels and crop planning, is already much better than on public irrigation systems. Further efforts to improve standards are being made by the lending agencies and the Extension Service.

6. Groundwater investigations – approach and methodology

That systematic groundwater investigations are essential for scientific development and management of groundwater resources hardly requires any elaboration. In fact, modern agriculture emphasizes the need for integrated development of ground and surface water resources (Jain 1974*a*) and this further increases the importance of scientific groundwater investigations and planning. The need is particularly urgent in areas where a critical stage has been reached and the hazards of over-development are in sight.

A systematic programme of groundwater investigations started in the country in 1954, with the launching of an all-India Exploration Project under the Technical Cooperation Programme of U.S.A. This project envisaged geophysical investigations to supplement the available geological data in regard to the structural disposition of the water bearing strata; and test drilling, including electrical logs of the bore holes and pump tests, to study the hydrogeological parameters in selected alluvial and sedimentary areas considered to be geologically favourable for the large-scale production of groundwater. This led to the setting up of the Exploratory Tubewells Organization (E.T.O.) under the Ministry of Agriculture and the creation of an exclusive wing in the Geological Survey of India (G.S.I.) for groundwater investigations. The two organizations did spade work in opening out new and promising areas for large-scale groundwater development. However, when the programme of groundwater development gained momentum around 1965, it was felt that there were deficiencies in groundwater investigations and planning (Jain 1975). It was noted that there was not a sufficient tie-up between exploration and the development programme. Exploration was mainly directed towards planning deep tubewells and was, therefore, largely confined to alluvial and sedimentary areas. Development on the other hand was taking place in almost all parts of the country and about 85% of total development was through dug wells, dug-cum-bore wells and shallow tubewells. Secondly, the main focus of the investigations had been on exploration and prospecting and the quantitative aspects of groundwater availability had lacked attention. Thirdly, while under the Indian Constitution, responsibility for the development of groundwater devolves on the States, they had no organization of their own for investigations and the planning of projects. Both the E.T.O. and the Ground Water Wing of the G.S.I. were located at

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the central level. It was further realized that the needs of the development programme were urgent and it would not be possible to wait for the results of very detailed and comprehensive groundwater investigations, which are not only expensive but also time consuming.

The programme of investigations has been intensified in the recent years and several corrective measures have been undertaken. It has been decided that no scheme or project will be sponsored by any financing agency unless it has been technically evaluated. In the absence of elaborate information, the project, unless it has some complicated implications, will be appraised on the basis of empirical norms and short-cut procedures. A guideline has been formulated for this purpose. The norms and procedures will be gradually refined as more data become available. To facilitate the use of data in formulating and appraising schemes, it has been agreed that compilation of data and information will conform to the district boundaries, which are the administrative units for planning. The two organizations at the central level, namely, the E.T.O. and the Ground Water Wing in the G.S.I., have been merged to form a unified organization, called the Central Ground Water Board, in order to bring more cohesion into the activities. Since the basic responsibility for development of groundwater resources devolves on the State Governments under the Indian Constitution, organizations have been set up in nearly all the states for planning schemes, collecting data that is relevant to planning from different sources including the on-going production programme, and undertaking short-term investigations to fill up gaps in the information.

A blue-print has been prepared for long-term investigations in the country to serve the increasing needs of the development programme at minimum cost. This visualizes extension of the basic programme of hydrogeological investigations to all parts of the country, including the areas under consolidated formations which had earlier been left out. These investigations include surface geological reconnaissance, photo-geological studies, geophysical investigations, well canvassing, water level measurements, and chemical testing of water. About half the total area of the country is expected to be covered by these studies by the end of the current Five-Year Plan. The programme will be of a continuous nature and the area once covered will be reappraised at regular intervals for up-dating the information. Expensive activities including exploratory drilling, geophysical logging and pump tests are to be undertaken in limited areas where these are essential to supplement other information. The need for water balance studies and special hydrological studies to provide quantitative assessments is fully recognized, but since such studies are expensive and time consuming, they are to be undertaken in limited representative basins so that the results achieved can be applied to larger areas. Nine projects for such studies are presently in hand. The scope for applying more refined techniques like remote sensing, radioactive tracer studies, mathematical models, etc. is being assessed under these projects.

The maximum emphasis under the strategy of investigation is on setting up grids of observation wells for continuous monitoring of the water levels and changes in the quality of water. These studies are expected to give most reliable information at minimum cost on the status of the water balance and the chemical régime of groundwater systems in a region at any particular time.

This strategy of investigation, coupled with research and development efforts in the engineering design of groundwater structures, has brought about considerable improvement. There is, however, full awareness that as groundwater development reaches a more critical stage (in fact it has already started doing so in some limited areas), much more sophisticated

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investigations and planning will be necessary. With the foundation already laid, it is hoped that the capability for the same will also be built up over time.

It is obvious that no amount of groundwater investigation and planning will help in preventing overdraft, saline infestation, reduction in committed base flow in the rivers and other hazards, unless there is legislation to control and regulate groundwater development. Realizing the importance of such a legislation, an important step has been taken in this direction, in that a model bill has been prepared and circulated to the states. The states are being urged to process it through their Legislatures at an early date. Fortunately, under the Indian Easement Act 1882, all groundwater vests in the government and no right to groundwater can be acquired by prescription. It is, therefore, felt that the proposed groundwater legislation should not pose any serious legal or constitutional problem.

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Discussion and replies by the author

B. H. Farmer (*Centre of South Asian Studies, University of Cambridge, Laundress Lane, Cambridge CB*2 1*SD*). May I first congratulate Mr Jain on his interesting and important paper. I was particularly glad that he emphasized the fundamental difference between the groundwater resources of the alluvium on the one hand, and of the crystalline tracts on the other; for I have often been depressed by the ignorance of this distinction shown by academics, administrators and others, who have imagined that the abundant groundwater resources of the Punjab are replicated in other areas of India, and that the Punjab agricultural miracle can be repeated by tapping underground water. In thus underlining the limitations on India's ground water resources, I would, however, like to take the matter a little further than Mr Jain did and to draw a distinction between alluvial areas like the Punjab where groundwater is fed by inflow from large snow- and monsoon-fed rivers and from irrigation canals, and those in the Rajasthan desert where these conditions do not obtain and where the water table over wide areas lies too deep to be tapped.

As for the crystalline tracts, Mr Jain has explained why and how underground water resources are limited and shown why careful investigations are necessary. Work done by our research project, based on the Universities of Cambridge, Madras and Sri Lanka, has shown, further, that in North Arcot District of Tamil Nadu (South India) increases in rice production owe more to electric pumps on open wells (old ones newly dug) than to 'high yielding varieties' (this varies a point made by Mr Jain): but that greatly increased pumping has led to a secular fall in the water table at an average rate, over the last few years, of not less than 0.3 m per annum. In other words, underground water is being used at a rate generally exceeding the recharge rate. Similar results have emerged from the crystalline areas of South and Central India. These facts underline the limitation on the extraction of groundwater and the need for careful investigation and monitoring.

Reply: I agree with Mr Farmer about the distinction between alluvial areas in the Punjab and those in the Rajasthan desert. His remarks about the over draft situation developing in the crystalline areas of the south and Central India and about the need for careful investigations and monitoring in this region are also pertinent.

H. Rush (*Science Policy Research Unit, University of Sussex*). Mr Jain refers to the building of private tubewells among Indian farmers as a means of giving the farmer greater control over the agricultural infrastructure. While the increase in private ground water exploitation has been extremely rapid the rate of well utilization, as reported by I. D. Carruthers, is often extremely low. With the constraints of shortages and high prices for electric power, oil and spare parts for pumps, private farmers operate their wells at the bare minimum and are rarely prepared to sell water to neighbouring farms. Until complementary facilities are improved the constraints to economic utilization of both private and public tubewells will remain and farmer control over the agricultural infrastructure is illusory.

Reply: It is true that in many areas in the country, private and public tubewells are underutilized but private tubewells give a greater confidence to the farmers as regards the assurance of the irrigation supply when they need and this induces them to make higher investment on other complementary inputs necessary for productive irrigated agriculture.

H. W. West (*Wolfson College, Cambridge*). I would like to draw attention to a linkage between arguments put forward this afternoon by Mr Jain concerning groundwater development and mention of the fragmentation of holdings made this morning by Professor Dharma Kumar.

Such fragmentation will introduce diseconomies in groundwater use and hence disincentives working against private investment in the sinking of tube wells, because of difficulties in surface distribution. In such circumstances the need to develop groundwater resources must provide an added motive for the prior consolidation of holdings.

Reply: I fully agree with the remarks of Mr West.

J. A. Allan (*School of Oriental and African Studies, Malet St, London WC1E 7HP*). India is a 'huge parish' as suggested by Professor Kumar earlier today, so I hope that I may be forgiven if I refer to that part of it with which I have some familiarity, namely the districts of western Uttar Pradesh drained by the Ganga–Jamuna river system. This is an area which was affected a century or more ago by the development of canal irrigation, precipitating what some have referred to as 'the first green revolution'. As a result of the canal building water tables rose rapidly with all the attendant problems of waterlogging and soil deterioration.

The recent 'green revolution' has been associated with an even greater extension of water utilization made possible by the massive well drilling programmes of the State Tube Well Organization and especially through the privately developed tube wells of the progressive farming community of western Uttar Pradesh. The aquifers of the deep alluvium of the area are presumably interconnected and clearly have up to now been equal to the massive withdrawals of water witnessed up to 1975. I believe, however, that there is evidence that the water supply in the region of Delhi may not be sufficient to meet the agricultural needs of local farmers. Is this because of the urban demand of the nearby capital or is there some other explanation?

Reply: Groundwater availability in Delhi region is very much limited, because of the presence of hard rock in the sub-strata, as compared to the dynamic reserve of groundwater available in the alluvial areas of Uttar Pradesh.

B. Dasgupta (*Institute of Development Studies, University of Sussex*). I would like to make four points regarding the use of tubewells or irrigation pumps. First of all, their use is dependent on an adequate supply of electricity or diesel fuel. In a country like India, where the indigenous supply of diesel fuel, and the capacity to import are limited, and where the electricity facilities are non-existent in a great majority of villages, the scope for the use of pump irrigation is limited. Secondly, in the case of those villages with electricity, where the supply of electricity comes from hydro-electric projects, the availability of irrigation water largely depends on weather conditions. Thirdly, due to lack of coordination between the electricity and irrigation authorities, irrigation pumps do not receive electricity connections for many months. The conflict of interest between the two authorities lies in the irrigation authorities wanting to space the tubewells in a way which minimises the depletion of groundwater, while the electricity authorities would prefer them to be bunched for reducing costs. Fourthly, tubewells being costly are usually owned by the rich farmers with adequate financial resources, credit-worthiness and access to credit institutions; even when water is sold to poorer farmers, the latter pay a higher price than and remain dependent on the former. A major consequence of tubewell irrigation in Punjab (of both India and Pakistan) is the increasing disparity of income and resources among the farmers.

Reply: In spite of the limitations pointed out by Mr Dasgupta, a programme of groundwater development has been progressing very satisfactorily in India. Public tubewells and private wells owned by groups of farmers are being specially encouraged to meet the needs of the small farmers.

W. H. Boon (*Formerly Plant Protection Ltd, Godalming, Surrey*). We have heard some excellent descriptions about the provision of water supplies. I wonder whether as much attention should be devoted to the utilization of their supplies by modification to traditional cultivation methods. I have in mind, in particular, some work done by my former company in South India which showed that the use of chemically assisted minimum cultivation of rice could lead to a substantial reduction of the water required for crop establishment.

Reply: I completely agree that apart from development of irrigation, the economic use of irrigation water also needs to be given adequate attention.