OUR WATER RESOURCES

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India's water resources derive largely from rainfall within the country. The rainfall is generous but its distribution over time and place is uneven. This necessitates gigantic projects for the control, storage, and transfer of available supply.

The present book intends to acquaint the general reader with the problem. It examines the solutions being attempted and suggests fresh and possible alternatives.

DR RAMA is the originator of a conceptually new scheme for creating artificial underground reservoirs which are expected to be especially suitable for .the Indian environment. He has made original contributions in various other areas of research including the study of cosmic ray interactions, geochronology and the application of radioactive tracers for investigating problems in meteorology, oceanography, and hydrology.

Preface

This book is intended for a lay reader, that is, a person who is not connected with water professionally in any way. A professional should naturally feel disappointed if he cares to go through it.

Here, I have attempted to give, in brief, a perspective of India's Water Resources, the central theme being their availability for irrigation. The chosen theme, though admittedly mundane, is vital for us. Our future welfare rests on how well we succeed in harnessing the available water for 'irrigation'. Progress on other fronts such as hydel and transport is also important. But these and other aspects connected with municipal and industrial needs are not dealt in any length. Even in the main theme, only a brief account of the salient features is presented. Statistical data are given only when considered necessary to make a point.

The material presented here comes from various text books, reports of committees and commissions, talk heard in symposia and chance discussions with friends. I do not however wish to disown responsibility for mistakes and untenable opinions which must be there.

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1

Megh-Leela

The Only Source

We have just one source of fresh water. That is the rainfall, the water that falls from the sky. Free, and by itself.

Lakes, glaciers, rivers, springs, wells are all secondary; all fed by rain or snow. Important though they are for storing, transporting and moderating the flow of rain water, they are not primary. They are not very big either. In the absence of rain, they cannot last for long, not even our lifetime. Rain is the only everlasting resource we have. And we have it in good measure, else we would not be six hundred million.

All Indigenous

Almost all of our water is indigenous. Except for a small quantity that flows from Tibet and Nepal, the rest of our supply derives from rainfall within the country.

Geography has thus been kind to us, although we do have enough on our hands by way of inter-state disputes.

The Fifth Season

The world has four seasons; spring, summer, autumn and winter. We have one more. The *rainy season.* It bridges summer and autumn. But it is quite distinct. During this season, we witness a great drama, the drama of our destiny, played by the clouds.

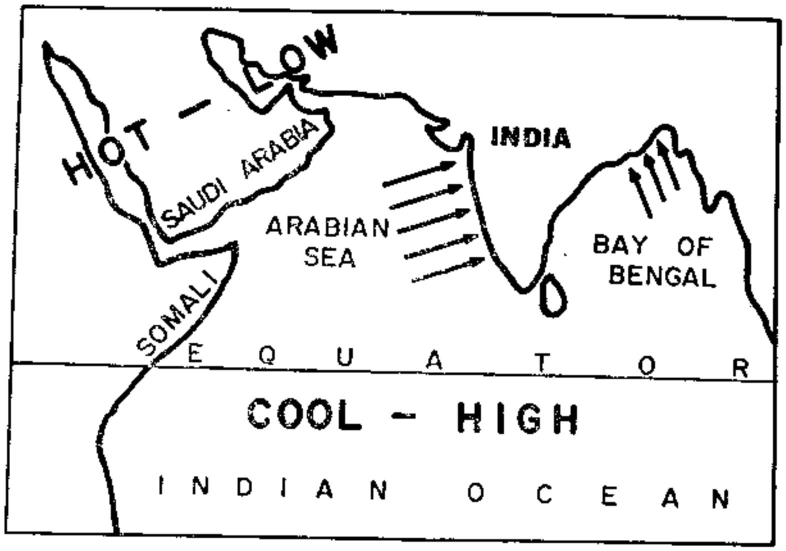
Act One: The sun shines for long hours all through April-May. This heats up the land areas of the north-west part of our sub-continent, Saudi Arabia and the north-eastern part of Africa, and this makes the air close to the ground hot. Since hot air is lighter, a low pressure develops over these areas.

In contrast, May-June is winter time in the southern hemisphere. The air there is comparatively cool and dense, and a comparatively high pressure develops over a large area here.

Thus we get high pressure south of us and low pressure north-west of us. This sends the air racing across the Arabian Sea. But nothing dramatic happens, except that the heat becomes unbearable, ponds and wells begin to dry up, and dust storms rise skyward. This is the time when we start yearning for the rains.

Act Two: Something happens. Perhaps something very subtle. Nobody knows exactly what. Suddenly, dark and dense clouds begin to appear from nowhere. They flash. They thunder.

Act Three: Gracefully, descends *Varsha* (rain) — vivacious and beautiful— dispelling heat, showering nectar. This is the moment that we await with intense expectation every year. The arrival of first showers of the reason!



The unique weather system that brings rain to our country

It is the privilege of Kerala to herald *Varsha's* arrival into the country, around the first week of June. Soon she moves northward along the western ghats and advances eastward over the peninsula and over central India. In another swift move, she drenches west Bengal and moves along Himalayas across the Gangetic plain right up to Sind valley. By July, she sweeps through the entire country. Often it is merely a hop-step-and-jump. But on occasions, she tarries over large areas.

Every bit of land becomes green with vegetation. Even the rocks become green with moss. Ponds get full. Mosquitoes multiply. The *koyals* sing. Frogs croak—peacocks dance—lovers yearn—spirits soar.

Act Four: Finally, all good things must end. By September, her visits become brief and less frequent. By October, she is gone, except for brief winter calls to a favoured few.

Unpredictable-Uncontrollable

As expected of any one so vivacious, *Varsha* is unpredictable and uncontrollable. Short term prediction, a few hours ahead, can be made by examining the cur-rent weather situation and its trends. This is useful for aviation, but inconsequential for agriculture. What agriculture requires is an accurate forecast at least a few days ahead. For example, we need to know whether a particular region, say six contiguous districts in Haryana, will receive five or more centimetres of rainfall during the next eight days. Or whether it will experience a dry spell over the next week or fortnight. If such predictions could be made, we could tailor our agricultural/irrigational actions accordingly, and the impact would be tremendous. But this has not yet been possible. There are valid reasons for this. The rainfall depends on numerous fast-changing interdependent variables in a system that is too free, too vast, too complex. True, there are numerous approaches. But, these are all on paper; nothing operational. Meanwhile, we are completely helpless. She comes, stays and goes; without our being able to tell. We may be able to explain subsequently how it all happened, but we cannot foretell. It is not therefore unusual that we see a farmer irrigating his field, and a couple of days later the rain also pours in.

Go, sow your fields, rains will come

Unpredictable does not necessarily imply uncontrollable. Scientists are engaged on projects in which they aim to induce her to come down. The inducement currently employed is called ‘seeding’. It attempts to introduce a large number of small particles of a suitable material into the cloud, in the hope that they will somehow induce the water vapour to condense and come down as rain. Materials generally used are common salt, silver iodide, solid carbon dioxide and a few others—some of them quite exotic.

Early claims of dramatic success have not been borne out. The results of a few preliminary experiments carried out in our country though apparently encouraging, are questionable. The claims made by most workers now are very modest. It is felt that seeding of certain favourable types of clouds may increase the rainfall by 10-20 per cent in the target area and may result in an equivalent decrease downwind. It is very difficult to prove or disprove such a modest claim. The reason is that the finding has to be established on a statistical basis and the experiments have to be completely free of any bias (since it does rain even without seeding). In such a situation, there is room enough both for ‘enthusiasts’ and for ‘critics’.

The principle of the method does appear to be sound, scientifically. We do expect the water vapour to condense around the seeded particles, and thus obtain some extra droplets in the cloud. But rainfall involves much more than making the cloud slightly denser. How and to what extent are these other processes affected by the seeding? When we begin to ask such questions, we start apprehending uncertainties. In any case, the actual experience so far has shown that dramatic modifications in rainfall are not at hand.

Even the modest claim, if genuinely realisable, can be very important for us. We can hope to change the distribution of rainfall, though only to a small extent. But even that is tremendous. Imagine pushing a few surplus clouds to deficit areas close by.

We are, in fact, in a dilemma. We have before us a potentially important development, but with uncertain results. We do not know whether to go all out for it or to ignore it. Questions of cost-effectiveness etc. can arise only after technical success. Therefore, a sizable investment on research in this area, although risky to the point of being a complete waste, is called for. The main cost lies in acquiring, operating and maintaining the aircraft required for these experiments; the rest is essentially organisational effort. We need to provide for all this since eventually we have got to prove to ourselves whether it works or not. Meanwhile, we are constrained to observe that *Varsha* is not only unpredictable, but uncontrollable too.

Moods

Truant, erratic, vagrant, kind, gracious, devastating, cruel. These are some of the adjectives used to describe her behaviour. Often, there are complaints, all the way. Some complaints are indeed genuine—sometimes. But often we tend to get worked up about minor aberrations. Her overall conduct is usually commendable. Else, we would not be so many.

Vital Statistics

Although we cannot foretell precisely what she will do on a particular occasion at a particular place, but we can certainly make statistical predictions since we do have written records of her past behaviour for more than a century. The gist of these records is also stored in the memory of the people who make their own predictions. However, a quantitative study of these records has been made by our meteorologists who have been able to establish the salient features and their likely explanations. They are also on the look out for subtler features and correlations which might be useful in making statistical predictions.

The salient features which have already been establi-shed are:

(1) A large part of our country receives most of its rainfall from June to September i.e. the rainfall comes in a pulse of three or four months' duration. Even this pulse is not very uniform, a couple of wet spells sometimes account for more than half of the season's total rainfall.

(2) The Western Ghats and the lower Himalayas get the most generous benediction. West Rajasthan and north Gujarat are the most deprived as are also the lofty peaks of the Himalayas.

(3) At any place, there occur variations in rainfall from one year to another. Percentage variations are largest in areas where average rainfall is low. This is not surprising. A variation of 15 cms rainfall at a place where average rainfall is 200 cms

means nothing, but the same variation of 15 cms at a place where rainfall is 20 cms can mean flood or drought. Thus critical conditions prevail in the arid areas.

(4) Not only are there variations in the season's total rainfall, but also in their distribution. Drought— flood—drought cycle can come in any given region during a single June-September season.

These variations are a matter of great concern to us, for obvious reasons. But we can do nothing about them, except to study them and intelligently adjust our perceptions to them. It is true that life would have been so much easier if the seasonal and geographical distribution of our rainfall were somewhat more equitable. Our agricultural production could have been much larger, even without any large scale irrigation works. Only if we knew how to push the surplus rain clouds from Assam to Rajasthan or from Konkan to Marathawada, or how to save some rain clouds of the Kharif season for use during the Rabi season. All this is beyond present day technology; the questions of economic viability and cloud ownership are therefore largely irrelevant.

The inequitable rainfall puts us into a difficult spot in another way. We get too much water in our streams during the rainy season, and very little afterwards. With the result that simple diversion canals (and small reservoirs) which are normally adequate to control and fully utilise the water of streams having relatively uniform flow are no longer adequate in our environment. We have to have big reservoirs (and therefore large dams) to store the large surplus flood pulse of the rainy season for later use. These are generally difficult and expensive propositions. But many of them do happen to be practical and feasible. And that is where human ingenuity and effort effectively step in.

II Ganga

Ganga is sacred to us irrespective of whether it were the efforts of Bhagirath or the simple geological processes that brought her to us. All streams carrying flowing fresh water are sacred to us. Indeed the names of many are suffixed or prefixed by Ganga. Traditionally, however, this sonorous and gracious name is reserved for the largest river that flows through the northern plains along the foothills of Himalayas.

Many of our rivers carry a substantial amount of water even after the rains are gone. They are vital for irrigation, power, transport and industry. On their banks stand great cities with beautiful architecture.

Water Availability

Our welfare, i.e., our prosperity and proliferation, is going to depend critically on the development of irrigation. It is therefore vital for us to know how much water we ha vein all and how much of it we can conveniently harness for irrigation. As a first step, we can assume that our entire water supply (which can ever be utilised for perennial irrigation) is that carried by our streams. How much is it? In order to answer this question, the obvious thing to do is to measure it. But the measurement of the flow of a stream is not simple or easy. It involves measurement of velocities of water at various depths in a given section of the stream, using a special boat fitted with velocity meter and other aids. The arduous procedure is long, tedious, and the task has not yet been accomplished. Pending this, we can use an alternate and indirect procedure which provides an approximate answer to the question.

Using the rainfall data (provided by the India Meteorological Department), we can compute the total amount of water that falls as rain in a given region. Some of this water evaporates away from the soil and is transpirated away (breathed out) by the plants. The rest of the water must be available in the stream that drains this region. Therefore, if we are able to compute the amount that is evaporated and that which is transpirated away, we can subtract this from the total rain-water, and thus obtain the value of stream discharge. Khosla (1) was the first to attempt to figure this out.

1. During the recent years, Dr A.N. Khosla has made outstanding contributions in the field of ‘water resources’ in our country. Although he is no longer commanding the current scene, our thinking in the matter of exploitation and assessment of our water wealth continues to be influenced by his thinking and achievements. He is a source of constant inspiration to our engineers.

We have approximately 330 million hectares of land area which receives an average annual rainfall of a little more than one meter. This gives us 400 million hectare meters {mhm) (2) water every year. Out of this, we have to subtract the amount that is evapotranspiratcd away.

Khosla argued that transpiration by plants and evaporation from soil depends upon the temperature of air near the ground. Mean monthly temperature in any region should therefore be related, in some way, to the monthly loss of water (as water vapour) in this region. He then evolved an empirical formula which bore this relation. Using this formula, he computed monthly evapotranspiration for each region separately. By add-ing twelve monthly values, he obtained the value of annual evapotranspiration for each region. By summing up the results for all the regions, he figured out that about 230 mhm water goes back into the atmosphere as water vapour every year over the entire country. We thus see that a little more than half (230 mhm out of 400 mhm) of our rainwater goes back into the atmosphere naturally. The remaining 170 mhm is supposed to be carried by the rivers to the sea every year, much of it during the rainy season. To be sure, the division of 400 mhm rainwater into two parts (i.e. evapotranspiration = 230 mhm, and river discharge = 170 mhm) is not known precisely. But it should be approximately correct. Khosla had to resort to this round about method because of lack of direct measurements of river discharge. Some measurements have since been made. These data are compiled by the Central Water Com-mission. They indicate that the actual river flow is perhaps not far from that computed by Khosla. Thus we have

Rain water - Evapotranspiration +River discharge

i.e. 400 mhm = 230 mhm + 170 mhm

(2) One hectare meter is the volume of water that will fill a field of one hectare to one meter depth. One million-hectare-meter will fill one million hectares to one meter depth. It is a big unit; it equals $I0^{13}$ litres or 10^{10} cubic meters (tons).

We shall see later that the stream flow of 170 mhm is made up of two parts i.e.:

(a) Direct flow of 110 mhm from the land surface.

(b) Percolation of 60 mhm underground and its subsequent emergence into the streams.

Part (a) flows into the stream soon after the rain, or snow melt.

Part (b) continues to flow underground slowly and emerging into the streams much after the rains are gone.

A Point of View

The entire river flow of 170 mhm is available to us for irrigation. It is tremendous (at least as a thought). Instead of letting it flow to the sea, we can arrange to use it all. This will modify the natural balance radically, apparently to our advantage. In fact, we have already modified the natural balance to some extent. We have already developed irrigation to about 40 mhm (30 mhm canal water + 10 mhm well water), and are allowing the streams to carry only 130 mhm. We can possibly push it all the way. With 40 mhm, we are able to provide irrigation to 25 per cent of our cultivated land; with 170 mhm the entire cultivated area can be irrigated. And there may even be some further bonus in this. We know that the water used for irrigation is consumed mostly in transpiration. Plants breathe it out into the atmosphere. An increase in transpiration from the present 270 mhm (230 mhm natural f40 mhm irrigation) to 400 mhm should increase the humidity of the air substantially. It is conceivable that this should increase the rainfall somewhat. This presents a possibility for artificially speeding up the water cycle. Admittedly, this is a conjecture. But, not entirely a wild one. We shall not however consider it anymore.

Another Point of View

Under our present limitations, we are not going to be able to harness much more than is already underway. A development of 70-80 mhm is perhaps the ceiling. We do not have too long a rope. Our limitations apart, it may not be wise to go too far. Cutting the run-off to the sea drastically may not be desirable ecologically; there is the danger that the soil may eventually get saline if the run-off is withheld beyond a certain limit. Therefore, an irrigation potential of 170 mhm is merely a theoretical ceiling; the practical upper limit is far lower.

Unavailability

There are several practical reasons why only a part, and not all, of our stream flow can be made available for irrigation. The main reason lies in the basic fact that the rainfall, and hence the stream flow, is unevenly distributed in time and space.

TABLE I

	River Valleys	Annual Discharge (MHM)	Conveniently Utilisable (MHM)	Hard to Harness (MHM)
Himalayan origin	Ganga	50	20	30
	Brahhmaputra	40	5	35
	Sind	8	5	3
West flowing rivers	Narmada Tapti Sabarmati etc. W. Ghat streams	30	7	23
East flowing rivers	Godavari Krishna Kavery Mahanadi etc.	40	35	5
Desert streams	Luni Ghaggar	2	1	1
	Total	170	73	97

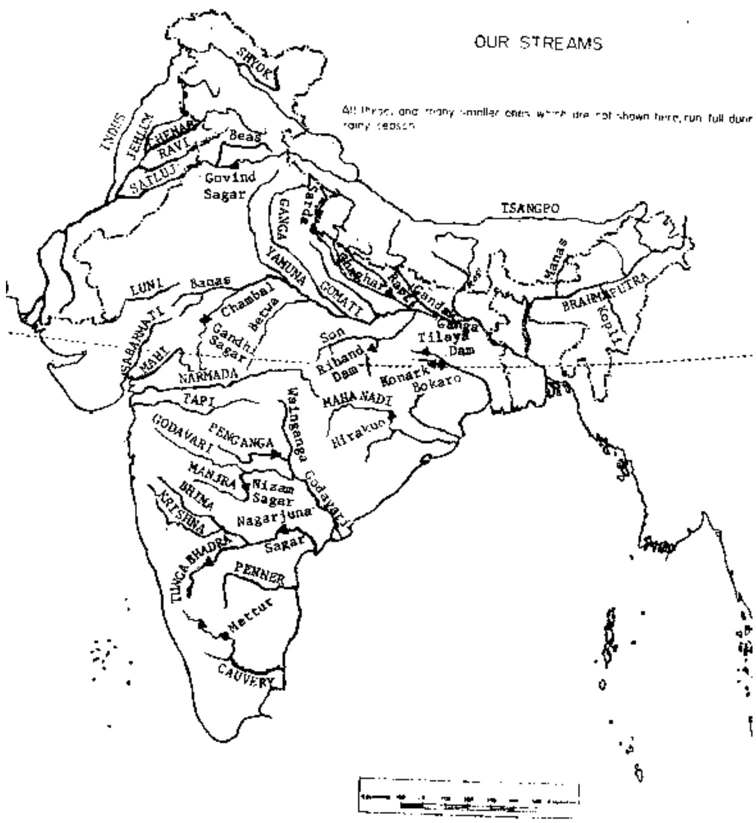
There is not much water in the rivers during the dry season when the irrigation demand is maximum. There is a lot of water in the streams during the rainy season when the irrigation demand is minimal. We must attempt to increase the utilisation of this water which goes waste during the rainy season. There are three courses open to us:

(1) Store this water for later use.

(2) Divert it to a far off region where it is needed immediately.

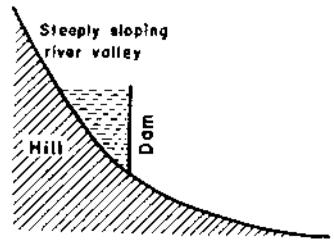
(3) Increase the local Kharif consumption by introducing new agricultural practices.

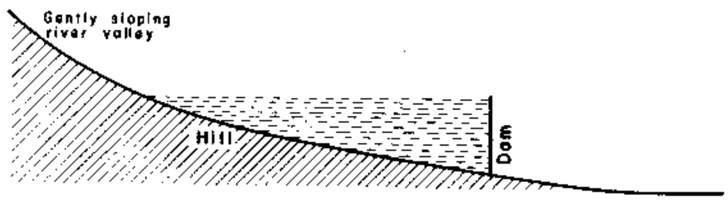
All three alternatives are currently in practice. But not on a sufficiently large scale, with the result that much of the stream flow runs into the sea during the rainy season. Even so, it has been possible to utilise the flow of some of the rivers almost fully. Waters of Sutlej, Beas and Kavery are completely committed, while those of Ravi, Narmada, Tapti, Krishna, Godavari and several others will soon be. But the waters of the two major rivers, Ganga and Brahmaputra, continue to present the greatest challenge and also the greatest opportunity. In order to get an idea of the problem, let us look at Table I. The numbers in the table are not intended to be precise, but they do provide a perspective. We notice that a large fraction of the water of the Brahmaputra. The Ganga and small rivulets of the Western Ghats is difficult to impound for one reason or another.



The Brahmaputra valley is mostly mountainous and prone to earthquakes. There are not many sites suitable for impounding the waters of Ganga and its northern tributaries in the Indian part of the Himalayas; there are some suitable sites in Nepal though both countries could benefit from such works.

The impounding of the waters of the rivers is however a complex task. Not only technical, but economic, social and political considerations also come in. The size of the reservoir (i.e. the volume of water impounded) should be large even for a dam of reasonably small height, i.e. a deep, large and relatively flat valley should be available. The rock boundaries of the reservoir should be strong to withstand the water pressure with no chances of leakage. A narrow gorge should be available at the dam site so that the dam is not too long and hence not too expensive. Not many people should be living in the proposed reservoir site so that rehabilitation of displaced people does not become a severe problem. These and several other factors restrict the choice. Further, fair size reservoirs can be built only in the hills. Therefore, the water coming from rains in the hills only can be impounded. The water coming from rains in the plains has to be used concurrently (as in canals or flood irrigation). Fortunately, this is beginning to be more and more feasible now. The demand for paddy irrigation, during the rainy season itself, is now growing. The effort therefore reduces to merely increasing the canal network. These canals will run only during the Kliny season. This may not be appealing from the point of view of earning revenue since these canals will cater only to the Kharif crops. But they have a sufficiently attractive benefit-cost ratio. It would thus seem that the utilisation of Ganga water can be pushed above that indicated in Table I.





Steeply sloping river valleys are less suited for impounding water economically

The utilisation of the water of rivulets in the Western Ghats is complicated by the fact that the ghats have a steep slope towards the Arabian Sea. The water thus runs away quickly via numerous small rivulets and no big river is formed despite heavy rainfall. We can therefore undertake only small projects in the ghats. Even these have to conform to the restrictions mentioned earlier. Further, only a small breadth of coastal strip (Konkan) is available where impounded water can be used for irrigation; cutting canals, distributaries and field channels also is not so easy in the region.

It thus seems that in the short run (i. e. a couple of decades) we can increase the irrigation from the present 40 mhm to about 80 mhm It is hoped that a good part of the remaining 90 mhm will also become available for irrigation as the technology improves and the value of irrigation water appreciates (both are bound to happen with time, certainly the latter). But we do not, at the moment, know how we are going to harness the remaining 90 mhm. We are not even thinking or discussing this seriously. The surplus water of Brahmaputra would need to be brought to western and southern India. The flood waters of the Western Ghats would need to be stored or transferred. These would involve bold engineering and ingenuity. We must not, however, forget to recognise and respect the individuality of each stream that we wish to harness. We must also not forget that irrigation water has to be very cheap, in fact it should be dirt cheap'. Therefore, imagination should not be divorced from feasibility.

Misleading Average and Meaningless Totals

Averages of very different numbers often give misleading impressions. For example an average of 200 cms and 20cms rainfall is a perfectly respectable 110-cms rainfall. But, to achieve the results of 110 cms rainfall from 20 cms and 200 cms rainfall is no easy matter; 20 cms rainfall means aridity and 200 cms rainfall can mean floods. We club the numbers together in order to obtain some perspective, without losing sight of the drawbacks of the procedure. We have indeed clubbed very different numbers to obtain averages and totals. We did this in order to assess what may be possible, not necessarily what is feasible immediately. In order to work out the feasibility of any project, it is necessary to investigate it in all aspects, in detail. This is a job for the experts. We are fortunate in having an adequate number of experts. They are only too eager, and are always on the lookout for undertaking developmental projects. Some of them prefer challenging jobs. There are hurdles, of course.

Hurdles

The main hurdle is lack of resources which, in this context, means 'skilled men, materials and machines'. We do have all three available indigenously but not abundantly. There are priorities on them and there are some other constraints also. This is not to say that there are no projects now in hand. The food output has been doubled during the last two decades, in a large measure due to irrigation works completed during this period. Several projects are underway and nearing completion, while some new ones are being discussed and examined. All that seems needed at the moment is a change in priorities, and shedding a little bit of our lethargy. Both are on the anvil.

Then, there are political hurdles. But they are likely to succumb to the social pressure that is mounting in favour of quick development of irrigation. The pres-sure is mounting because we have already extended cultivation to about half of our geographical area and the scope for bringing more area under cultivation has shrunk. We have therefore to take recourse to increasing the yield. The most important input for increasing the yield is water. That means increasing irrigational facilities. Luckily, we can do that. We have not reached the end of the line. We do not have to wait for any breakthrough either. In the short run, we just have to do more of what we are doing i. e. divert the river water into canals and build reservoirs and tanks (bhandaras) by damming the rivers and streams, wherever feasible. The plan is to bring an additional 1-2 million hectacres under irrigation every year; this is needed just to feed the extra mouths added every year. A little spurt in this plan can make all the difference between near-sufficiency and easy-sufficiency. The tempo is already building up.

III

Khwaja Khizr

If we dig a pit in the ground, we first meet a thin layer of dry soil at the top, then somewhat wet soil for seve-ral meters underneath. If we continue digging deeper, we meet oozing-wet soil and the water begins to collect in the pit. The depth at which the 'water begins to collect is called spring level or water table level. Below this depth, the pores of the soil are completely filled with water; there is no vacant air space. If we continue to dig deeper and deeper, we eventually meet a hard compact rock which may have no open space and hence no water.

The behaviour described above is generally observed everywhere. There are, of course, considerable differences in the depths and thicknesses of different strata. At some places, in fact over half of our country, the soil cover is very thin and we meet the rock just at a depth of a few meters or even less. This region is called 'hard rock area'.

There can be, and usually there is, some water even in the hard rocks, particularly at shallow depths. Most rocks have cracks, fractures and fissures which get filled with water if water is available. Sometimes, weathering of rocks creates pore space in their body. This pore space likewise gets filled with water if water is available. Some rocks, like sandstones, are structurally porous and can accumulate water in the pores. However all sandstones are not equally porous; some are very compact.

Most peculiar are limestones. Some of them are easily attacked by the action of rain water. Such limestones are, therefore, infested with caves and tunnels, of all sorts of sizes and shapes carved out by the water flowing for ages. If sufficient water is available, the entire mesh can get filled with water. It is only in this type of rock that we can hope to locate underground flowing channels or large cavities full of water. If such formation (cavernous limestones) is close to the sea, its underground mesh can discharge a large quantity of fresh water to the sea. We do not have much cause for worry; in our country, the area covered by limestones is relatively small and is far away from the sea. *For the most part, we have no underground flowing streams or underground water lakes of the kind we see at the surface.* When we do talk of underground reservoirs in our country, we shall mostly be referring to water resid-ing in the pores in soil or in the cracks in rocks. It is this water that seeps into our wells and tube wells when we draw on them.

The northern plains (Sind and Ganga valleys) are covered by thick alluvial soil, which can store a large quantity of water in its pore space. About ten to forty per cent of the soil volume is empty pore space which can get filled with water. In contrast, the volume occu-pied by cracks and fissures in a rock is usually very small.

About half of our country is covered by basalt, granite and sedimentary rocks. They can usually store only a small quantity of water. But, it is often enough to go by. Whatever be the case, we can, and we do, find some water underground everywhere. Its profusion, quantity and quality however differ from one place to another. There are valid reasons for this. We must understand them. Not merely for the sake of academic knowledge, but because groundwater is so much a part of our life. An individual may not be able to put a dam across a river or dig a canal privately, but he can always dig a well in his property and draw water. What a boon. More reliable than anything else. But there are limita-tions to this too. It is, therefore important that we understand the situation correctly.

Source

If we pour some water on the ground, we can see it sink in the soil. Likewise, we can often see the rainwater also sink in the ground. Further, we often observe that the water level in the wells comes up after the rains. All this goes to show that rainwater is the real source of the groundwater. Exactly how the rainwater proceeds towards the water table is a subject of research, but we already understand the phenomenon broadly; there are no great mysteries in it.

Percolation

A question of great, practical importance is, 'how much of the rainwater flows from the land to the streams immediately and how much sinks into the ground?' What fraction of the water that sinks into the soil is evapotranspirated from the top soil and how much is the remainder that manages to percolate deep down to the water table?

There is no single answer to these questions. It varies from one place to another. There are several factors which have a bearing on the answer. Firstly, the water can percolate downwards only at a limited rate; the soil offers resistance to its flow. And if the percolation rate happens to be less than the rate at which rain is falling, the excess water begins to collect at the surface and then flow away to the neighbouring stream. Thus the fraction of the rainwater that sinks into the soil is criti-cally controlled by these two factors i.e.:

(1) The rate of percolation permitted by the soil.

(2) The rate of rainfall.

The downward percolation rate depends very much on the nature of soil. Coarse sandy soil permits fast percolation of water. Fine clayey soil permits very slow percolation. There exist all grades of intermediate varieties. Cracks and fissures are a different class. Water can move very fast through them.

Permeability (ease of flow) is thus a major factor in controlling the amount of rain water that sinks underground. But not always. In order that the water may sink, we must have not only permeable soil but also empty space underneath in which water can go. If all the available space is already full with water, no more can go in. We have three distinct situations in our country where this condition prevails.

(i) Western Ghats (Konkan) and a few other hard rock areas

The first few showers of the season fill up whatever empty space is available in the rock underground. After that there is no empty space left. What a pity. There is plenty of rainwater available, soil is fairly permeable and hence there is no serious impediment in the downward journey of the water. But, no space to store it in. Consequently, most of the rainwater flows away from the surface.

(ii) Water logged areas

Some low lying area and some areas irrigated by an excessive amount of canal water have their entire underground storage full. The water table is very close to the ground surface. Irrespective of how permeable the soil, very little rain water can sink in this area. There is no empty place underneath for it to go in.

(iii) Beds of Streams

Stream courses, as a rule, run along the low lying points. The pore space in their beds is usually full of water. Therefore, no water can sink underneath even though the beds may be sandy and the streams may carry a lot of water.

Evaporation from Top Soil

As mentioned earlier, not all the rain water that sinks into the soil reaches the water table. Only a small fraction does; the rest is evapotranspirated from the top soil. In fact, out of the 290 mhm rainwater that sinks into the soil, 230 mhm is evapotranspirated away from the surface soil; only about 60 mhm is able to percolate down to the water table. This is the picture on a countrywide scale. What about individual regions; for example, the arid regions?

If the rainfall is scanty, it barely wets the top soil. The entire moisture is evapotranspirated before the next rain comes. Thus there is hardly any excess moisture at anytime in the top soil that could be heading to-wards the water table. It does not matter how perme-able the underlying soil or the rock is. Such conditions prevail in the arid regions. Since very little water flows through the soil, both the soil and the water are saline.

We thus see that in order to have a prolific supply of groundwater, there must be sufficient rainfall, strata should be permeable and there should be sufficient empty storage space available underground.

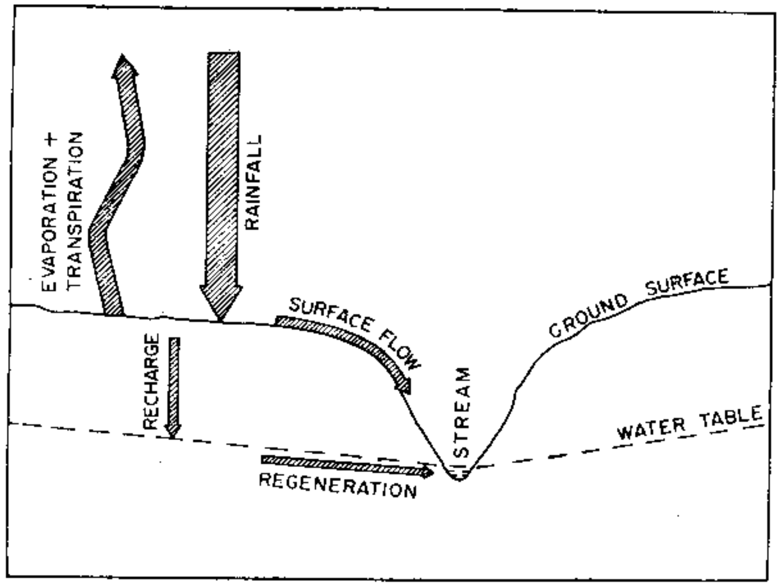
Fate of Groundwater

We know that some water may be a little or may be a lot, is able to percolate down to the water table every-where. We may ask, 'what happens to all this water which, year after year, keeps going into the ground?'

Well, a little bit of it we take out for irrigation and for drinking. A small fraction is transpirated by the trees whose roots happen to extend deep down to the water table. The remainder, which is most of it, emerges into our streams. This sounds strange, but it is true. Let us consider the following illustrations:

(1) There is no rainfall over the Western Ghats for eight months, but the Krishna continues to carry a sizable discharge even during these dry months. This water obviously comes from the ground. The water that entered into the ground during the rainy season keeps slowly emerging into the stream, because the stream bed is usually lower than the spring level around. The groundwater that thus emerges into the streams is called 'regeneration water' or 'effluent water'.

(2) During the dry season, we divert almost the entire water of the Ganga into the Upper Ganga Canal. This leaves the Ganga bed almost dry near Hardwar. But at Narora (Aligarh District) we again get a sizable amount of water in the Ganga although there is no tributary meeting it between Hardwar and Narora. This water has obviously seeped into the Ganga from the ground, because the Ganga bed is lower than the spring level around it. This kind of regeneration takes place in many of our streams, Much of the regeneration perhaps takes place during the rainy season itself or soon after, when the level of water in the ground is high and therefore the seepage to the streams can be expected to be more abundant. In most streams, we are not able to utilise this regeneration water; it merely adds to the flood water, and runs to the sea. We can however easily pick up the dry season regeneration water, from the big streams. There is hardly any water, regeneration or otherwise, in small streams during the dry season.



Much of our water, both overland and underground, flows into the streams and then to the sea

It is possible to eliminate (or reduce drastically) the loss of groundwater due to seepage into the streams, if we so desire. We merely have to lower the water table below the stream beds by pulling out a sufficient amount of groundwater during dry seasons and use it for irrigation. We can certainly use this method in areas where sufficient demand for irrigation exists or can be generated. But, in hilly and forested areas where there is no demand for irrigation, the groundwater will continue to seep out into the streams. There is no great harm in this. The dry season seepage (regeneration) water can be easily picked up from the streams for utili-sation. It is the rainy season seepage that we may conti-nue to lose along with the flood water unless we impound or divert it.

Water Logging

If, for any reason, the water table rises close to the ground surface, it can prove very bad for the crops and the soil. The crop roots like to breathe air. If the water rises enough to drown the root zone, the crops do not grow well. Even if the water table stays somewhat below the root zone, it can cause enough damage. It can seep up to the surface by capillary action in the soil, evaporate there and leave behind salt residue. There is always a little bit of salt dissolved in groundwater. If a large quantity of groundwater evaporates from the surface a sizable quantity of salt is left behind in the soil. Unless this salt is somehow washed away or washed down, the surface soil becomes too saline to grow good crops. The solution lies in attacking the root cause of the problem i. e. in reventing an excessive rise of the water table.

It is observed that water-logging (rise of water table close to the surface) occurs in some of the areas where canal irrigation is introduced. We know that a sizable quantity of water can seep from the canals, distributaries and water courses into the ground. This is in addition to the rainwater that percolates naturally. Further, a part of the irrigation water that is applied in the fields also seeps down. Thus we get excessive percolation. This makes the water table rise, which in turn, causes increased seepage loss of percolated ground-water to the streams. If there are a sufficient number of streams in the area, the water table stabilises fairly below the ground surface and nothing untoward happens. However, if there are not enough streams (which drain the groundwater away) in the area, the water table may rise dangerously close to the surface. To prevent this from happening, we have three courses open to us.

(1) We can attempt to prevent seepage from canals etc. by lining them and also possibly reduce the seepage of irrigation water in our farms by resorting to better practices and techniques of irrigation.

(2) We can dig artificial streams (drains) in the affected area and connect them to natural streams. These will drain away the excess groundwater and thus prevent the water table from rising dangerously.

(3) We can just pull the excess groundwater out and use it for irrigation in addition to the canal irrigation. This is now beginning to be a feasible proposition and is considered to be a better solution inspite of the operational complication arising from the fact that canal water is far cheaper than the well water. Well water needs to be pulled out of the ground while canal water flows by itself under gravity. The canal water is therefore very cheap, and hence the farmer's preference for it. But the situation is now changing. Canals are not able to meet the increasing irrigation demand, particularly the peak demand. The canals are designed to carry a certain steady maximum discharge, not to meet the peak irrigation demand. It is too expensive to construct canals which will cater to the peak irrigation demand, even assuming that sufficient water is available at the source which is often not true in the case of diversion canals. Therefore, the present day farmer is not assured of meeting his full requirement at the right time. On the other hand, a private well water supply, though considerably more expensive, is convenient, reliable and at his own command. These advantages become all the more valuable in case high yielding varieties are grown. The high yielding varieties require larger investment in inputs and have critical water needs. In the absence of an assured water supply, they become high risk ventures. Therefore, an independent and flexible well water supply (standby or exclusive) is very much in order. This is just as well, because a proper mix of canal and groundwater supply can enable us not only to avoid the water logging problem but also to derive optimum benefits from the available water at minimum national cost. The two systems are complimentary in several respects, and need to be developed as such.

Ground-water Supply

There is a fairly large amount of groundwater under our feet. This water is stored in the pore space in the soil and in cracks in the rocks. This is a great asset. But this is an asset which we have inherited. We must pass it on to our children, in a healthy state. We must not cause any undue reduction in it. This is possible if we limit the withdrawal of water from the ground to less than that percolating into it every year: So what we need to assess is 'how much water percolates deep into the ground every year rather than how much total collection there is.

An accurate determination of this quantity is difficult. But we can assess it approximately in several ways. And that is usually good enough.

We can get an idea of the quantity of deep percolation (recharge) by measuring the rise in water level in the wells during the rainy season. We need several other pieces of information, other than mere knowledge of the rise in the water table, before we can estimate the percolation quantitatively. Despite some uncertainties, the method provides a fair estimate.

There are some direct methods also which we can use. One of them employs the lysimeter which attempts to simulate the natural crop-soil-water condition; but, in effect, it is similar to growing plants in a big pot and observing the water that trickles to the bottom of the pot. Lysimeters can be very large and elaborate. They can provide reliable information but are inconvenient and expensive. We have, therefore, generally shied away from developing this method.

Another method employs radioactive (tritiated) water. It is possible to trace the movement of this water through the soil by pursuing its radioactivity.

This method, though believed to be fairly accurate, has been used only in a small part of the country. Therefore, at the moment, we go by plausible guesses. But this presents no serious handicap since our present style of development does not rest on any serious consideration of prior knowledge of percolation recharge. Although, ideally it should. The next best thing to do is to continue to increase the usage of ground-water, but gradually. As soon as we notice signs of a progressive recession of the water table, we should put a stop to further increase in groundwater usage. This is a practical approach, but it does not permit complete pre-planning.

We are presently using the groundwater to the extent of only about 10 mhm every year on countrywide scale. How much more can we draw? It is difficult to answer this question precisely, because we do not know the percolation rates precisely in the different regions of the country. Some workers have attempted to make intelli-gent guesses, and they estimate a total annual percolation of about 60 mhm over the entire country. Can we extend the annual groundwater withdrawal to 60 mhm then? In principle, yes. But in practice, no. The annual total of 60 mhm includes the percolation over the hilly and forested areas also, which is more practical to utilise as 'regeneration water' rather than pump it out as groundwater. The percolation that occurs over the agricultural areas only can be profitably pulled out for the purpose of irrigation. Even here, it may not be wise to pull out all, and thus deprive the streams of the regeneration water completely. The already existing works which depend on the regeneration water partly or wholly will suffer. Thus it would seem that our ground-water exploitation ceiling is far lower than 60 mhm; perhaps only 20-30 mhm.

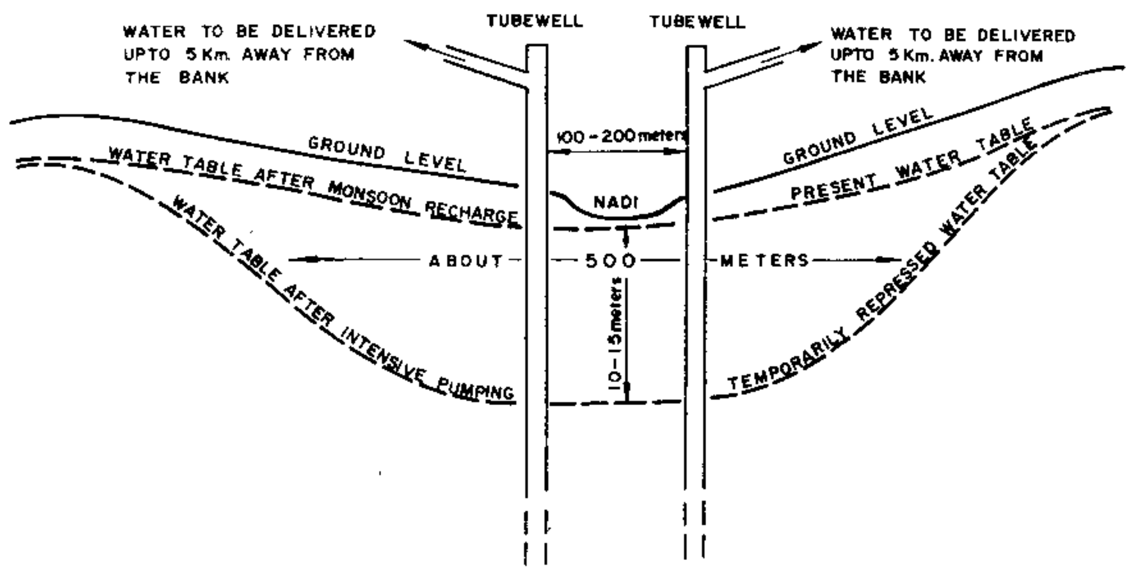
Overdraft

We have been using groundwater for irrigation since ancient times. The technology involved is quite simple and has been improved considerably during the recent years. We can now pump out large quantities of water even from very deep levels. This enables us to avoid the problem which our ancestors had to face occasionally due to the drying up of shallow wells during summer. But this also equips us with the option of drawing extra groundwater, more than that percolates in. We seem to be heading for this option. There are several advantages in developing groundwater irrigation exclusively and complimentary to canal irrigation. Ground-water supplies are well suited to meeting peak demands of irrigation. Further, they can be installed in no time and start giving returns immediately. These (and a few other) advantages cover the cost factor adequately. That is why groundwater utilisation is fast increasing. This is very nice we shall have more food. But there always exists the possibility that we might overdo it. In fact, in some pockets (in Punjab, Haryana, Western Uttar Pradesh, North Gujarat) we are already overdoing it i. e. we are pulling out too much ground water for irrigation; somewhat in excess to what goes into the "ground. This has resulted in a rather frightening phenomenon; an extreme opposite of water logging; i.e. the water table keeps receding deeper and deeper. One may argue 'what is wrong in this as long as the irrigation water pays for itself in terms of higher agricultural pro-duction?' This argument, apparently valid, loses ground when viewed from a long term prospect. As the water table continues to fall deeper and deeper, we have to make a bigger and bigger effort to bring the water out. Finally, a stage will come when we shall be forced to restrict the withdrawal rate to less than (or at most equal to) the percolation rate. But then the water table is unnecessarily too deep; why not restrict the withdrawal rate right now so that the water table does not recede too much. To achieve this, we require to work out policies which are socially just and enforceable. But can't we manipulate something so that the water table does not recede despite a large groundwater draft? For example, by increasing the percolation artificially during the rainy season. There are several methods which may be used to achieve this objective. Impounding of water, spreading it over large areas, artificial injection in wells are some of the possibilities. But they all suffer from technical snags and prohibitive costs, particularly in the context of climate and cultivation patterns prevalent in our country. Therefore, as a general rule, an overdraft leading to progressive recession of water table must be avoided. However, there are situations (we have discussed three of them) in our country where an enhanced draft in a restricted area can automatically lead to enhanced local percolation. We can certainly take advantage of these. These situations arise when the water is not able to percolate because of the pore space below being already full with water. In this case, we have merely to empty out the pore space during the dry season, and use the water for irrigation. During the rainy season water will automatically fill the space below. No extra engineering is required. This procedure can be (and has been) applied in water-logged pockets, it has already brought relief in several places. It can also be applied with some advantage, in Konkan— where we can possibly pull out as much water from the ground as is available or as is economically feasible, lowering the water table by several tons of meters during the dry season. But the underground reservoir (cracks and fissures in the rock) is expected to fill every rainy season, since there is plenty of water available and percolation is expected to be quite fast. The main drawback in this scheme is the expense on deep tube wells in the rocky terrain. But it is not unbearable.

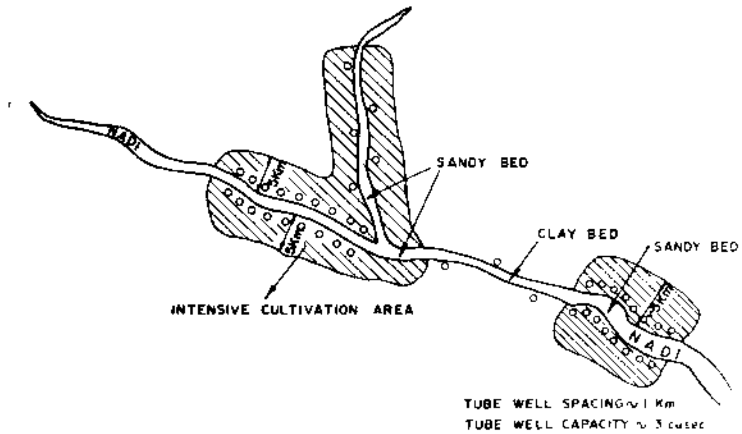
The third possibility is to try the same procedure in areas contiguous to our seasonal streams. We have a very large number of seasonal streams which carry plenty of water during the rainy season but carry very little water afterwards. Many of them have sandy beds which go dry at the surface, after the rainy season. But, if we dig a little bit below the surface, we meet the water table. This means that the sandy beds (and the adjoin-ing sandy layers under the banks) are full of water. We can take this water out, and use it for irrigation. This will lower the water table under the beds. But the beds will fill again, by themselves, during the rainy season when the streams go in spate. Plenty of water can percolate down through the sand. Since a part of the stream water will sink in the bed, there will be less water in the stream channel; this will mitigate the floods. The scheme appears to be so attractive that we may like to push it to its feasible limit, deliberately. But there is a price to pay.

Underground Reservoirs and Intensive Cultivation

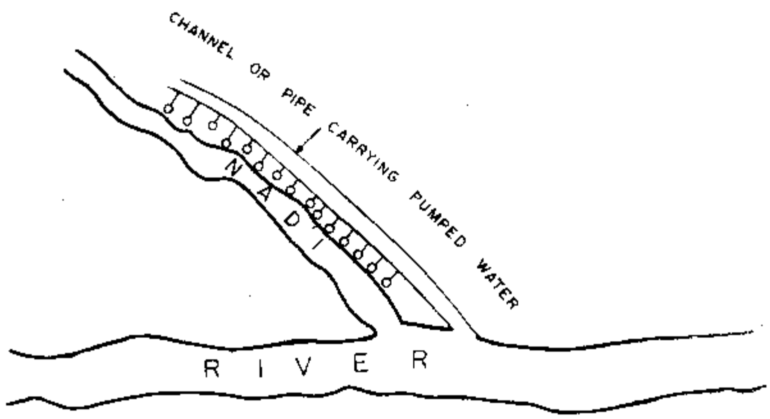
We can approximately estimate how much water is likely to percolate through the bed of a given stream over the entire rainy season. We can then install suffi-cient number of wells along the banks of this stream and pull out the right quantity of water during the dry season. If we pull out less, the bed will be full before the rainy season is over. If we pull out more the bed will get filled only partially, not to the brim. It is possible to adjust correctly. Rough estimates show that we should be able to pull out a large quantity of water safely. It will all be replenished. The question that now arises is 'what can we do with this large amount of water that we are free to pull out?' Obviously, we can use it for irrigation. In order to be able to take advantage of the entire tappable water, we shall need to encourage intensive cultivation deliberately, and may even need to transport the extra water to areas close by. This is the artificial part of the scheme. Another new situation that will arise is a 'highly fluctuating water table'. The water table will go down by ten or twenty meters during the dry season and rebound back to the surface at the end of the rainy season. This means that all wells in this area have to be deep. The scheme however does appear to be feasible.



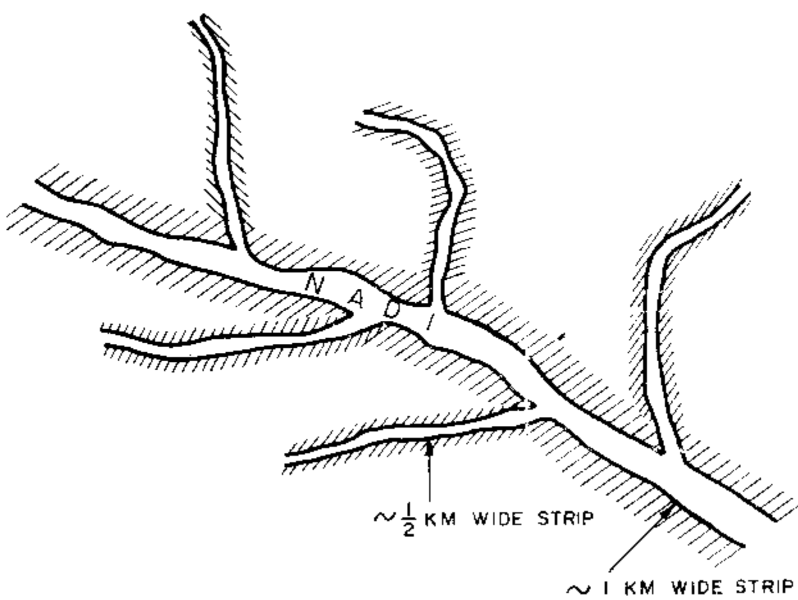
A schematic drawing of proposed underground reservoir



A schematic diagram for intensive cultivation by tubewell irrigation



Augmenting river discharge (canal supply) with water pumped from Nadi bed during dry season



Areas suitable for intensive cultivation based on local pumping
by tube wells (no piped transport involved)

It must be stated that this scheme, aimed at creating replenishable underground reservoirs, is merely an idea as yet. Although apparently attractive, its practical demonstration, even on a pilot scale, is yet to come. If successful as envisaged, we should be able to withhold 10-15 mhm water in the Ganga valley alone where the scheme appears to be most suited. This does not seem much compared to the 50 mhm that the Ganga system carries, but compare it with the current total utilisation of ground water which is just about 10 or 12 mhm.

Conclusions

(1) We should increase the groundwater utilisation gradually till it matches the recharge, from all sources. This will cut on the regeneration even during the rainy season, and thus assist in limiting the floods.

(2) We should next exploit the groundwater near the banks of the seasonal streams to the appropriate maximum feasible limit. This will provide for extra storage of flood water underground, and thus mitigate the floods too.

(3) We should not over exploit the groundwater along the banks of major rivers whose dry season flow is already committed. This restriction can however be withdrawn when we find that we must create underground reservoirs even under the beds of these rivers. We may then need to build alternate works to cater for the current commitments. But these can wait.

(4) We must not withdraw a large quantity of ground-water very near the coast. It is well known that all along the coast, a small amount of groundwater keeps seeping into the sea. This bars the saline sea water from intruding landwards into our groundwater. It is necessary to keep this balance intact. We must continue to develop more irrigation facilities but only after ensuring that we can keep them going indefinitely. Water is a special com-modity. Once supplied, it should be continued undiminished. Adjusting to reduced supply is very painful, if not disastrous altogether.

VI

Extremes

Cherapunji gets a bumper 11 meters annual rainfall while Jaissalmer gets a measly 0.2 meters. This is their usual share and they have learnt to live with it. However, a further problem crops up sometimes. The shares go too high or too low, causing floods or droughts.

In some region or the other in our country there are floods every year. If there are no floods, then droughts. Sometimes both; flood in one region and drought in another. Occasionally, flood and drought in the same region, one after the other. In recognition of this, we have the Prime Minister's Relief Fund operating on a continuing basis.

We have no control over the basic cause of flood and drought. We do not know how to prevent *deluge* and *rainlessness*. But it is certainly possible to moderate the severe effects that follow. The methods are well known; we have only to choose the appropriate combination for a given situation and put it to work.

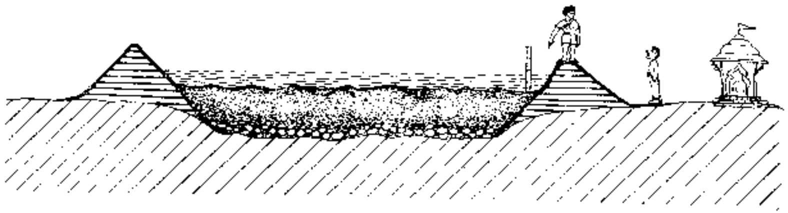
When there is too much rain in too short a period, then the natural processes that moderate the flow and those that drain the water away are not able to cope with the collection of water. The water level in the stream rises above the channel boundaries and spills over to the adjoining area where it was not normally expected to. Occasionally, the main flow of the stream itself changes its course and a large quantity of water gushes where it was not expected to. Under these circumstances, water can be very cruel; it can wipe life, property and vegetation in a moment. And, it does that almost regularly, somewhere or the other, in our country. The annual loss of crops has been estimated to exceed 1 million ton food (which can sustain several million people for one year).

Northern plains are more prone to floods than the rest of the country. Assam, Uttar Pradesh, Punjab, West Bengal and Bihar suffer most; Madhya Pradesh and Karnataka are affected least.

It is possible to reduce the flood intensity by putting in a reasonable effort. The most practical method is to put dams across the streams and impound the water in multipurpose reservoirs, and to divert it in an extensive network of irrigation canals, wherever possible. What could be better than taming the angry water and putting it to work. However, the method has its price and its limitations. The method can be used to im-pound the water in hilly regions only. There are occasions when the rainfall in the plains itself is excessive and the drainage gets overtaxed. To meet this situation, several engineering solutions are in practice. We build embankments to contain the flow and thus prevent spill over. Thousands of kilometres of embankments have already been built. But that is at best a partial solution to a local problem. Often it merely transfers the problem to a downstream area, in a more severe form. We cannot possibly go about building embankments at all the vulnerable stages of all the streams. Therefore, the flood problem stays.

In certain situations, it may be more acceptable to have moderate floods over a large area than to have severe floods over a small area. Light floods may even be welcome since they may bring in new rich fertile allu-vium in addition to the irrigation water and flush away any accumulated salts from the soil. Flood irrigation is however a sort of gamble since it is difficult to control it and it may bring coarse sand instead of fertile clay. The emphasis therefore has been on controlling the streams as far as has been practical.

Occasionally, flood occurs if a stretch of the stream gets silted and the flow is retarded. In such cases, dredging (an expensive effort) is resorted to.



Good news. Sir, this is full with sand again; contracts for dredging and for raising embankments should soon be coming.

The topography of some regions is very flat and the water does not find a quick exit, with the result that a large area gets flooded. In this situation, artificial drains are constructed with the aim of leading the water quickly downstream. More than ten thousand kilometres of drains have already been constructed. This does not appear to be a very satisfactory solution however. We grudge the effort and the cost involved in building the drainage which we expect nature to have provided us.

Ponds and ditches can hold some water. They are of some help in containing flood waters in the beginning of the rainy seasons.

Vegetation can impede the flow as do the roads and train tracks. Thus they can moderate the flow resulting from sharp showers. But they themselves become vic-tims if the showers last for long.

Habitations and other artificial structures reduce, though only to a small extent, the area available for water to percolate down. This adds a little extra water to the overland flow, thereby increasing the chance of flooding. Then there is deforestation which leads to not only bigger erosion but also quicker flow of water down the slope.

The eroded mud gets dumped in the flat parts of stream channel, and thus the water carrying capacity of the stream gets reduced. This enhances the chance of flood. After all, water that causes damage is usually only a small fraction of that which passes through easily and without spilling. By the same token, it has been possible to operate the reservoirs, canals and drains in such a way as to minimise the damage.

Another possibility, though yet untried, exists in creating underground reservoirs where the water can sink. We have discussed this possibility already; its effectiveness for mitigating floods yet needs to be ascertained. If it works as expected, flood problems would stay solved, to a great extent.

It appears that our major thrust, therefore, should be directed towards building multipurpose reservoirs to contain the run-off from the hills. In order to contain a part of the run-off from the plains, it appears likely that the underground reservoirs may turn out to be practical.

Flood Forecasting

If warning about the coming flood be issued sufficiently in advance, then it is often possible to take some protective and evasive measures to save life and property. Flood forecasting, a specialised activity, is nevertheless an operational science. One tries to esta-blish the relationships between the rainfall and the resulting run-off in the catchments of each stream. Obviously, the details of area and time distribution of rainfall are very important for this purpose. Further, the surface conditions of the catchments (area from where the stream catches its water) prior to the rainfall are also of some consequence. The situation, therefore, is complex. But not intractable. Often the flood fore-casting can be done merely by observing the discharges upstream and then making some intelligent extrapolations for the downstream region.

Admittedly, our understanding of the various factors which are responsible for floods is far from complete. There are mutual interactions between them. Better drainage at one place can be the cause of a disastrous flood downstream. We must therefore try to understand the system as a whole. We must collect the necessary observational data and model it intelligently. Hopefully, this will enable us not only to make more reliable forecasts but also to decide on optimal actions for flood control.

Cyclones originating in the Bay of Bengal and the Arabian Sea, which cause considerable damage in the coastal areas, can be located and traced using radars. The Meteorological Dept. issues warnings about their probable strike. These warnings have certainly been very useful, particularly to the fishing and shipping community.

Long range forecasting of floods, other than on statistical basis, is not feasible in as much as the long range forecasting of rainfall is not operational.

Droughts

Drought simply means ‘less than expected* rainfall. Less than 75 per cent (or perhaps less than 50 per cent) of normal rainfall may be defined as drought. This kind of definition, though arbitrary, is generally adequate. We may however, bear in mind that not only the total rainfall but its distribution in time is vitally important for the crops. Small deficit (or surplus) in rain is not necessarily directly related to agricultural productivity.

Therefore, it is desirable to evolve indices for performance of rains over the entire season, which are appropriate to agricultural productivity. Whatever these indices, large deficit in rainfall does undoubtedly cause drought. When crops begin to wither, it is drought.

This happens when there is insufficient moisture in “the soil. The farmer is therefore more concerned with soil moisture rather than the amount of rainfall. That is why he does not care to put a pot in his farm for measuring the rainfall. His decision and actions are based on his experience in relation to the wetness of the soil which he tries to assess in his own crude way (which is often adequate).

We know pretty well which areas are prone to frequent droughts. In general, they are the areas which have low average rainfall. An excess or deficit of mere 15 cms in an area of average rainfall of 20 cms can mean severe flood or severe drought. Surprising, but floods do occur in deserts. Because of low average rainfall, the deserts do not have well developed drainage i.e. they do not have many natural streams. Sharp showers therefore can cause inundations. A deficit of mere 15 cms in the rainfall, on the other hand, causes the familiar drought.

Crop Protection

In the absence of any effective method of making artificial rain when desired, the only workable solution for saving crops is to develop the irrigation facilities which can be stretched to the maximum during the drought period. That this works is quite evident from the way Punjab and Haryana are able to tackle their droughts, largely by drawing on their irrigation facilities.

The real problem arises in the arid areas which have no large scale irrigation facilities. Here, over the years, people have devised ways and living habits which enable them to cope with the situation as best as the envi-ronment permits. They attempt to harvest a maximum amount of usable water, reduce waste to minimum and then attempt to get the maximum out of the stored supply. Modern research is making further inroads in these areas. Attempt is made to collect water from hill slopes by removing any obstacles in its way and guiding it to a place close to where it is to be stored or consumed. Research is going on for developing and improving the methods for reducing evaporation from open water bodies, reducing seepage in water courses, reducing evaporation from soil surface and even reducing the water consumption of the crops. Methods of irrigation which involve the least wastage and yield maximum benefit are being evolved. This whole new field of management of available water for maximising crop production is drawing the attention of very many talented scientists. New technologies for cropping system are being investigated; these may enable the use of brackish (a little saline) water for irrigation. Green houses (air-inflated plastic bubbles) are being installed in energy rich arid regions.

These are all very good. We shall have to resort to some of them when easier options are exhausted. In some pockets, where transport of water from surplus areas is not feasible, some of the technologies mentioned above are probably already called for. It may however be mentioned that, in general, these technologies are very expensive, in materials and in effort. Some of them require sophisticated management. They are therefore our last resort. Many of them are mere research curiosities and are very limited in their application.

A practical and more effective solution lies in importing water from surplus areas. For example, excess Himalayan run-off can solve the problem of the Thar Desert. The Rajasthan canal is an attempt in this direction. More is possible. It may well turn out that our methodology is not the most appropriate one, but the basic policy appears to be certainly right, scientifically.

Irrigation of desert areas does bring some problems. The excessive percolation of irrigation water, in the absence of adequate natural drainage, causes a progressive rise of the water table and eventually water logging. At the same time, excessive evaporation of the irrigation and capillary water from the soil leaves ever increasing salt residues behind since the rainfall is inadequate to wash them away. Eventually, the soil becomes too saline to support a good crop. These are familiar problems. But there is no need to get scared of problems that may arise after fifty years. Many of them are amenable to built-in solutions. For one thing, these problems can be delayed considerably by banning reckless use of irrigation water and by simultaneously initiating the use of ground water before it rises dangerously close to the surface.

Conclusion

Floods and droughts arise from excess and deficit rainfall. We need to create works by which excess in time and space could be adjusted against the corresponding deficits. This is difficult, but it has got to be done. Our engineers know how to. Feasible engineering solutions exist. It is merely a matter of fixing priorities for these works to be executed.

V

Devouring the Potential

Lack of development was probably the main reason behind our poverty in the past. But the present status quo, despite the reasonable pace of development, is due to our continuously increasing numbers. The increasing numbers is a hard reality that is going to stay with us for a while; it cannot be wished away.

One thing that people need most is ‘food’. It is therefore imperative that our food production must increase in step with our growing numbers. For producing more food, we need land, water, labour, skills, science, engineering, administration and management. During the last three decades, we have advanced on all these fronts, but have merely been able to maintain per capita consumption constant. We have brought under cultivation 60 million hectares extra. The total area under cultivation now is about 180 million hectares i.e. more than half of our geographical area. The rest is forests, hills, pastures or barren land. The scope for bringing more area under cultivation, without upsetting the ecological balance is now very limited, except perhaps in parts of Rajasthan. We have therefore to depend mainly on increasing the yield from our existing farms. The most important input for increasing yield is water i.e. irrigation. Admittedly, irrigation alone is not a complete guarantee for food sufficiency, but it is the most essential requisite. The advantage of higher yields from other inputs like fertilisers and improved seeds can be realised only with assured irrigation. Fortunately, there still exists a sizable potential for making more water available for irrigation. Our emphasis during the next two decades is therefore going to be on developing this potential, and thereby extending irrigation to about half of the cultivated land.

Past Performance

Irrigation has been practiced in our country since ancient times. It was necessary, given the kind of weather we have. It was easy, with the kind of physiography we have. The methods of irrigation developed in ancient times are widely used even now. The well water is drawn using manually operated or animal operated mechanisms of various kinds. Tank irrigation is practiced wherever it is possible to impound water in a natural depression or a stream course. Flood irrigation, a somewhat risky operation, is also practiced in some areas, by blocking the path of a seasonal stream by a mud bund so that the water spills over the banks. Diverting the water of big streams into inundation and perennial canals has also been in practice. But the construction of major multipurpose reservoirs by damming large rivers is a rather recent development.

During the last three decades, our performance in developing irrigation has been commendable in all res-pects except one i.e. it has always fallen a tiny bit short of the requirements of our growing numbers, necessitating an import of food grains to the tune of a few million tons annually, on the average. The strides in food production have nevertheless been remarkable. Food production has gone up from less than 50 million tons to more than 100 million tons. This is partly the fruit of a large number of irrigation projects major, medium and minor, that were undertaken and completed by our engineers. The area under irrigation has thus been doubled from 20 million hectares to about 45 million hectares. The development has not however been uni-form in all regions of the country. There are several reasons for this. The major reason of course is techno-economic i. e. cost/benefit ratio of the irrigation works. This, in turn, depends upon a number of physiographic factors, which happen to be very favourable in the Indo-Gangetic plains. Here, the Himalayan Rivers carry substantial amount of water perennially (though the discharge is maximum during the rainy season). We put an obstruction (barrage or weir) in the path of the river and divert the water in a canal. The gentle slope of the plains makes it possible for the canals and their distri-butaries to run under gravity and spread the water over large areas of thick fertile alluvium. Cutting the canals, and the distributary system, in the alluvium is a relatively easy matter. Many of our canals and distri-butaries run for hundreds of kilometres and provide a perennial irrigation supply. Sirhind Canal (Sutlej), Upper Bari Doab Canal (Ravi), Western and Eastern Yamuna Canals, Agra Canal (Yamuna), Upper and Lower Ganga Canals. Sarda Canal (Sarda and Ghaghar) are some of our major diversion canals. The capacity of these canals, large though it is does not take full advan-tage of the enormous quantity .of water that is available in our rivers during the rainy season and for several months after that. Their capacity was designed on the basis of an adhoc criterion that they should always run full, even during most of the lean period when discharge in the rivers is small. This makes good sense from the point of view of earning maximum revenue per unit cost. But this also implies that the designed capacity of the canals is too small to take full advantage of the flood discharge during the rainy season. This handicap is particularly noticeable for the canals taken from the Ganga and its tributaries on which no dammed storage has yet been built. Ignoring this aspect, the fact remains that the diversion canals provide the cheapest water for irrigation. Hence, our preference for them. In certain situations, it has been found expedient to pump out the water directly from the river into small canals which irrigate the nearby fields. Such lift irrigation schemes offer the advantage of quick installa-tion but are considerably more expensive.

The situation is very different for non-Himalayan Rivers. They are not snow-fed; therefore they tend to dry up during summer. In order to feed perennial canals from these rivers, we need to impound the flood waters of the rainy season in tanks and reservoirs. Irri-gation by small canals fed from tanks has been popular in Andhra Pradesh, Karnataka and Tamil Nadu, and to a lesser extent in several other states also. However, major perennial canals can be fed only from major dammed reservoirs like Tungabhadra or Nagarjuna-sagar (which is yet to be completed). On the other hand, irrigation by well water can be undertaken any-where if the ground water is conveniently available. That is why there has been a phenomenal increase in the exploitation of groundwater during the last decade. The most intensive development has taken place in western Uttar Pradesh, Punjab, Haryana, Tamil Nadu and Gujarat, and to a lesser extent in eastern Uttar Pradesh, Bihar, Maharashtra, Madhya Pradesh, Rajasthan and West Bengal.

In the post-independence era, several major multi-purpose river valley projects were undertaken and completed. Bhakra-Nangal, Damodar Valley, Hirakud, Rihand, Kosi, Tungabhadra and Chambal are some of the projects we often hear about. They are outstanding engineering feats. These projects serve three main pur-poses i. e., irrigation, power generation and flood control. Several other beneficial aspects like fish culture, water transport, recreation, soil conservation, afforestation etc. are also included as objectives of these projects.

The main problem in undertaking the major projects is the requirement of heavy resource commitment (also involving a sizable foreign exchange component) over a long period. The major projects usually take ten years or more to complete. After they are completed, they bring prosperity (relatively speaking) to the region. If, for any reason, some of our major works go out of commission, millions will have to starve.

Of late, there has been some concern about the rapid siltation of some of our major reservoirs. Efforts are afoot to identify the causes. Meanwhile some conventional remedial measure (such as afforestation and soil stabilisation) have also been initiated.

Underutilisation

One would think that the irrigation projects are so planned that every drop of water made available for irrigation would indeed be utilised. But, our experience in the past has shown that certain bottlenecks make this realisation difficult. The reasons are both technical and economic. The technical snag arises from the fact that all aspects of the scheme do not get completed simultaneously. The canal and distributaries may all be ready, but the field channels, which take the water to the farmers' fields, may not be ready or the fields may not have yet been properly levelled by the farmer to permit irrigation by gravity flow. It takes a while before these problems get straightened out.

The underutilisation due to economic factors arises mainly from the farmer's inability to pay for the water. The authorities try to get over this problem by spreading the distribution network (command area) over a large number of fields. This enables them to sell more water, but this policy has its own disadvantages. Firstly, it leads to increased loss of water due to seepage and evaporation over an unnecessarily large network. Secondly, it renders the supply somewhat uncertain and unreliable since it is promised to more customers than it can be delivered to. The situation has however changed recently. The demand for irrigation water has increased immensely and the utilisation has become quite high. It is now due more to technical factors that utilisation may sometimes suffer rather than due to want of customers who are willing to pay.

The operation of groundwater supplies wells and tube wells is at present, by and large, in the hands of private individuals. They do try to get over all the technical hitches (in fact, by an unnecessarily large margin). But the utilisation of their installed capacity is very poor since the private well or tube well is used mainly for meeting the relatively small demand for private irrigation. Most of the time, the well is idle. Thus the certainty and reliability of the private ground-water supply is acquired at great national cost. This luxury will continue to proliferate until the State tube well programme becomes widespread, and becomes more efficient. Alternatively, the existing private wells (with and without pump sets) and tube wells must start catering to the demands of the neighbouring community and thus run much longer than they do now. Or, perhaps completely new thinking in groundwater technology is called for.

An extremely cheap low draft groundwater supply suitable for meeting the requirements of small farms (one hectare) needs to be invented. Ideally, it may be powered by wind or solar energy. But wind and solar energy have the disadvantage of being diffuse and intermittent, and therefore the contraptions using wind and solar energy are, in general, unwieldy, inconvenient and expensive. These contraptions have not proved very practical so far. Muscle power appears to be our best bet. An evil thought, though.

Availing the Potential

We seem to have succeeded very well in developing irrigation by minor schemes like wells, tube wells (shallow and deep), tanks and lift schemes. This is going to continue, on private, community and govern-ment levels. In certain regions, groundwater develop-ment is proceeding very rapidly. Mainly because of its appropriateness under the existing conditions. The governmental policy also has a lot to do with this. Indi-genous and readily available technology has made the installation of wells and tube wells an easy and quick matter. Further, the pump-sets, both electric and diesel, are also readily available. The extension of electric power in rural areas and availability of diesel and easy credit are making pump-wells and tube wells a feasible proposition for an average farmer. This trend is likely to continue and catch on. We can therefore expect that during the next twenty years, or perhaps even earlier, 30-40 million hectares will come under groundwater irrigation. And that is perhaps the end of the line.

At present, the backbone of groundwater irrigation is the dug well, notwithstanding a spurt in tube well construction. The situation may not be radically different in time to come except that the future wells may be somewhat deeper and a larger number may be operated by pump sets rather than animal power. In either case, we shall be able to push the groundwater exploitation to its ultimate optimum limit.

There are no ready estimates available as to how much extension we can ultimately achieve on irrigation by large and small tanks. Many of the existing ones are reported to be silting and their storage capacity is thus running down. Desiliting operations, despite some practical difficulties, must be carried out.

We have recently constructed a large number of tanks in drought affected areas. Some of them are termed ‘percolation tanks’, implying that they help in increasing the recharge of water underground and thus making more water available in the wells in the down-stream area. Their normal storage capacity is however generally too small to justify the effort, except as a relief measure.

Another practice in Konkan is to put small bunds across the streams towards the end of the rainy season. This is indeed helpful in restraining the loss of ground-water by effluent drainage. The water collected in the stream is picked up for irrigation, manually or by using pump sets. Such mini-schemes are likely to become more popular. But it is difficult to estimate their total impact quantitatively. They are undoubtedly beneficial and cost effective.

Scores of major and hundreds of medium irrigation works are likely to be completed in the next two de-cades. We have not yet exhausted the potential for building even simple diversion canals, from the Himalayan Rivers. The Sarda Sahayak project now underway would utilise the waters of Ghaghar; its irrigation potential is almost double that of the upper Ganga Canal. In addition, the diversion of flood water for irrigation of Kharif crops can be taken up. This is comparatively less attractive, but has an immense poten-tial. While the development of works on Himalayan streams will continue, a great spurt in development schemes will be witnessed in the valleys of Narmada, Godavari, Krishna and other interstate streams in the peninsula. The projects held so far due to interstate disputes on sharing waters are bound to be cleared, with appropriate modifications wherever necessary. A large number of multipurpose projects, involving the construction of dams, a network of canals, power houses and lift schemes will betaken up. The concerned State Governments have already drawn the schemes. The demand on national resources will be tremendous and will have to be met by some sacrifice elsewhere. When we enter the 21st century, we would have about 100 million hectares under irrigation and our annual utilisation of water will be stepped up to 80-90 mhm. This formidable task will be achieved by the engineers, administrators, managers and the nation as a whole. We cannot afford to fail in this. In addition to patriotic fervour, the ‘will to survive’ will continuously propel us to work towards the goal. Extension of irrigation and the intensification of agriculture is the only way for providing gainful and stable employment for our growing millions. It will be decades before voluntary (and even compulsory) family planning stabilises the population and its pressures. Meanwhile, we cannot afford to let the lack of food take over the control of our numbers. There is only one direction, in which we can now go, that is forward. We cannot afford to overplay the ‘ecological scare’ either. Irrigation facilities must grow, and grow fast. However the growth must be judicious.

VI

Elixir

When we feel thirsty, we take a glass full of water and gulp it down. It quenches the thirst, and performs seve-ral other vital functions inside the body. It collects the toxins and expels them on its way out.

Since we gulp water, and it is taken straight into the body (unlike food which is first examined, sorted and cooked), its cleanliness is vitally important. It should be free from pathogens (disease causing organisms), it should not contain excessive amounts of salts or toxic elements. Many diseases, epidemics and deaths result from bad water. It would thus seem that making provision for clean drinking water is even more important than providing for irrigation. But we discussed irriga-tion first, only because of its much larger quantitative demand. It takes several thousand drops of water to produce one grain of wheat or rice. Man’s daily requirement of food needs the consumption of several tons of water while his daily direct intake of water is trivial, in comparison. If we succeed in providing water for irrigation, drinking water supply is only a minor step further. But the requirements of drinking water is of a critical nature, and therefore cannot be deferred.

That is why it has been found feasible to transport drinking water by trucks, when necessary. We never transport water by trucks for growing food.

Some source of water (well, pond, stream, spring, lake, canal) is generally available wherever there is habitation. Sometimes this source runs dry, and accessibility of even drinking water becomes difficult. Sometimes the water is bad. People manage to live through both the problems. But it is certain that their vitality heath and productivity would be far better if they had easy access to clean water. The Government and numerous social organisations are very aware of this, and they are sincerely trying to do their bit. But they have so far been able to tackle the problem only superficially. The problem is too big. About six lakh villages are scattered all over the country; more than one lakh runs into serious problems during summer when the local source of water dries up. The problem can be solved in certain cases by installing deep wells. There is no easy solution in certain others. What can one do for fifty families living on a hill slope or on hill top?

Drinking water

We obtain our drinking water from all sorts of sources; some good, some not so good, some bad and some which are outright dangerous. These are reflected in the health, vitality and longevity of the people.

Scientifically distilled water is the cleanest. But it is not good drinking water. It is flat in taste. So is rain-water. Since rainwater too has very little dissolved minerals. We can get good drinking water from rain-water if we adulterate it with requisite amounts of various minerals from the soil. This is what we are adapted to; this is what we get, anyway.

There can be some controversy on what constitutes 'ideal' drinking water. But there is no controversy on what 'acceptable water' is and what 'bad water' is. We can say that any water free of pathogens, excessive amounts of salts and toxic elements should be accept-able. By the same token, presence of these in excessive amounts is bad. However what amounts can be termed excessive, what acceptable and what beneficial? Ap-proximate answers to these questions are known to Public Health Engineers. There are international standards set on these. But as far as we are concerned, the international standards are merely in books, rarely met fully in our water supply. If the available water happens to conform to these standards, well and good. If not, it is rarely feasible for us to treat the available water supply to bring it up to so called international standards (distillation, reverse osmosis, chemical treatment are too expensive for our pocket, even for the restricted drinking water supply). We are not sure what price we are paying for each individual lapse. In some cases, the damage is visible. In others, it is hard to assess or it may not even be there.

It seems that good quality water should have a delicate balance of chemicals. For example, it is claimed that fluoride is good for teeth; therefore 1 milligram of fluoride per litre of drinking water is recommended (provided we do not get enough already in the food). On the other hand drinking water containing about 5 or more milligrams of fluoride per litre is considered the cause of a debilitating disease, aptly named 'fluorosis'. It is surprising that man has acquired only a small latitude of safety.

Not everyone who consumes fluoride water is a de-finite prey to fluorosis. But a substantial fraction (10-20 per cent) of adults do suffer from this to a varying degree. The existence of this problem in some areas is therefore real.

Fluoride is just one example, though a glaring one. Excess or deficit of anything can be upsetting. It would thus seem that each local problem has to be solved individually. An unnerving prospect. But there is no need for panic. No fresh disaster awaits us. Our ancestors have lived with it. Therefore any action taken by experts can only be an improvement.

It is not possible to discuss here individual cases of drinking water supply. We shall therefore consider only some general aspects.

Rural Alluvial Areas

If water passes through a few meters of clayey soil, all the particulate material (including pathogens) are filtered away. The groundwater in alluvial areas should therefore be safe for drinking, particularly if it is drawn from deeper zones. If the area receives adequate rainfall, the salt content of the water generally conforms to acceptable limits (our own). Only in arid and semi-arid regions does the salt problem arise; and one can discern this merely by tasting the water.

Toxic elements in trace quantities present a special problem. The problem is usually identified when we notice an unusual incidence of some disease in any locality. Ideally, it should be the other way around, i. e. water should be tested, treated if necessary or alternative supply located. This is a mere pious hope since this is beyond our present means. But, there is no need for getting nervous. We have lived with the problem for generations. It is reasonable to assume that groundwater has not become any worse than what it was for our ancestors. The worst that can happen is that we shall be beset with the same handicaps as they were. The only difference is that we are perhaps more aware of it now. We can, on the other hand, look forward to some improvement, certainly if we bring canal water to this region or if energy becomes cheap enough to enable us to treat the local groundwater.

There are several things which we can do ourselves right now, with some guidance from the public health people. We often mess up what normally ought to be a safe drinking water supply. Many open wells give bad water because they are subject to pathogenic contamination from the surface. Covering them adequately and leading the waste water away so that there is no cesspool close by should help. The refuge dumps can be located at some distance from the well. Installing hand pumps, with the same general precautions, may even be better.

Hand pumps are coming in increasing use in certain areas. Lucky ones are able to afford hand pumps right in their homes. They usually allow their less fortunate neighbours to draw water from their pumps.

Any toxic element, if present in excessive amounts, is best handled by experts. They can treat the water. Treated water is however expensive. Its consumption “therefore has to be restricted to the necessary minimum. We need not use treated water for bathing and washing as a little excess of some salt’ in bathing water is not expected to be very harmful.

Another alternative is to store enough rainwater and use it for drinking and cooking after mixing it with an adequate quantity of local well water. In these matters, guidance from experts is necessary. This is an area where research can pay rich dividends.

Rural Hard Rock Area

Position of drinking water supply in rural, hard rock areas is less comfortable than that in the alluvial areas. There are several reasons for this.

As we noticed earlier, only a small fraction of the rock volume is open from where water can enter. As a result, if a sizable amount of water is taken out of the ground, the water level in the wells goes very deep. In fact, it may hit the bottom of the fractured rock, and the rock beneath this may be solid and may contain no water. Consequently shallow wells tend to dry up during summer. To hedge against this, people try to impound water in tanks, natural depressions and stream courses. Many of these also run dry before the summer is out since they are usually shallow and evaporation takes its toll. Deep wells and tube wells if located in a water bearing zone yield more reliable supply but they are expensive.

Water requirement for domestic purposes in the rural area is so small, that this can be met even in the poor-storage rocks. But when the irrigation also starts drawing from the same source, problems crop up, particularly in the areas which have low rainfall, low recharge or poor storage. Very few villages draw their domestic requirements from canals or big reservoirs; we just do not have enough of them yet. The problem will automatically ease when we are able to complete more irrigation works on our streams.

Not only is the supply problem difficult in the hard rock area, the quality problem is also more severe. Since the soil cover is often thin the filtration of surface water is not efficient. The shallow depth of open wells is further conducive to contamination from the surface.

In the areas with sufficient rainfall (for example, Konkan), salts and toxins are rarely a problem. It is the lack of storage which creates problems of availability during the summer.

We often draw domestic water requirement from open tanks. When judged from usual standards of hygiene, the open tanks are anything but hygienic. How much the drinking supply from these tanks hurts us is not known. Filtration wells located at some distance from the tanks can provide a safety factor.

There is a general feeling that the problem of scarcity of drinking water in the hard rock area has become more acute during recent times, say in the last ten or twenty years. This feeling may partly be just a manifestation of enhanced reporting by the information media. Partly, it may also be true.

The requirement of drinking water has approximately doubled during the last two or three decades. But, this by itself can not be the reason for acute and recurring scarcity. The real reason perhaps lies in the enhanced withdrawal of groundwater for irrigation. But, irrigation is essential for producing food, and cannot be dispensed with. The only sensible course open to us is to tap the deeper levels and to restrict the usage of this water for drinking only, Water from deeper levels is expected to be more hygienic too.

However, initial cost, uncertainty in locating the water bearing zone at depth, maintenance and running costs are inhibiting factors. This is another field where research can pay rich dividends. The real solution lies in impounding flood water, and distributing it for irrigation; all round improvement will follow.

Rural Arid Areas

That is where we do have serious problem and see no easy solution. Soils in arid areas are usually highly saline. The rainwater percolating down through these soils also becomes saline.

No one ever likes to drink highly saline water. People have therefore always struggled to devise suitable alternatives. In parts of the Thar Desert, people gather the rain water from an adequately large area and store it in fair size tanks right in their homes. This takes care of their drinking demand. Other domestic and stock demands are met from tanks in which the surface run off from large areas is impounded.

In certain years, there is no rain at all. Therefore, no water collects in tanks. People have to perforce fall back on groundwater which they have to pull out from depths of 30-100 meters. The camel has to make two rounds to complete a pull. This water procured after hard labour, though usually saline enables the residents to meet emergencies.

During the last fifteen years, Government agencies have discovered potable water in some formations (Lathi) in Thar Desert. This water is brought out using deep tube wells, and distributed among the residents. This has helped in reducing the migration of people that used to occur because of water shortage.

Thar is an extreme case. But there are large areas which are semi-arid. People in these areas also face serious shortage of drinking water during summer, particularly when the rainfall has been scanty. The shortages seem to have become more frequent recently, probably because of enhanced withdrawal for irrigation. The problem of salinity also exists. Here too, the deeper aquifers, wherever possible, offer the solution, provided they are not over exploited for irrigation. Good quality, of course, is desirable. However when this is not available, there is very little that can be done except to depend by and large on the resilience and resistance of the human body. Better days will come only when we are able to conserve and divert the flood waters to these areas. Good drinking water alone is not sufficient; food is also essential.

Urban Supply

The problem of water supply in the towns is essentially similar in all regions, alluvial or hard rock. In large cities, lots of people are packed over a limited area. So much so that the locally available groundwater is not sufficient for meeting their domestic and industrial demand. The city corporations therefore import groundwater or surface water from adjoining areas. Sometimes the water is brought from distant places. Groundwater is generally put into the taps straight, with little or no treatment. Surface water is chlorinated[1] (adequately if the town corporation is rich; psychologically if the corporation is poor) for killing pathogens before the water goes into the taps.

The corporations have to attend to the reverse prob-lem also. They are supposed to dispose the sewage water so that it does not cause health problems. The small town corporations straightaway sell it to the farmers who grow vegetables on the outskirts. The big town corporations attempt, or appear to attempt, to remove the pathogens before they let the water loose some-where, usually a stream or a *nullah* or the sea. Now, there are plans afoot to utilise the city sewage and waste for making compost fertiliser.

Chlorination may create its own problems. If the water already contains some organic pollutants, chlorine may react with some of them to form chloroform and other chloro-organic compounds which are suspected to be carcinogenic (cancer causing).

We notice that the water supply in big towns now is completely different from the traditional well water supply that our ancestors used. The departure from the traditional well water supply is necessary, because of a high density of urban population.

It is in the big towns that the services of the experts are continuously available. They try to maintain quality to some acceptable standards. But failures can occur, and do occur. What comes in the pipe, the residents drink? Convenience of the piped supply thus comes at the price of some risk.

The treated water is supposed to be better. But it is new to our physiological system. Its slow side effects, if any, will be known only after generations.

Occasionally, serious shortages in city water supply also occur. But the cities are inhabited by a very large number of people. There is always sufficient number of influential, resourceful and authoritative persons among them. They somehow arrange to tide over the problem; they get the water released, transported, or tapped from somewhere else. The total requirement, quantity wise, is rarely prohibitive despite the fact that many town dwellers keep the tap running while shaving.

Our per capita investment in the urban water supply has been roughly ten times that for rural domestic supply. It has got to be that way: a town dweller has to have water in the tap; he has no chance of locating an independent well water supply by walking a kilo-metre or two. There are too many users over too small an area.

Summary

We are living in a fairly big country with unique weather. Shortages of drinking water develop in some region or the every year, particularly during the summer time. Since the drinking water requirement is usually small quantity wise people manage to live through the difficulty somehow. The exact toll on their health due to lack of good drinking water (in certain pockets) is not known. But the problems have been identified and their magnitudes assessed by the Health Ministry. A general easing of these problems will automatically come about from an increased network of irrigation canals, leading to better availability of ground water too. This can bring our pipe dream of piped water supply in the rural area closer to realisation.

During the last three decades, there has been a very fast increase in the urban population resulting in a rapid increase in the demand for domestic water supply. In some cases, the sources close by are already tapped and are not sufficient to meet the growing demand. A sizable amount of water now needs to be brought from far away sources. This is beginning to be a sort of a mini-challenge.

The fact that we are still alive and that our numbers and longevity continues to increase may indicate that the maintenance of international standards in every detail, though probably very desirable, is not a must. The lapse perhaps does affect our vitality and longevity adversely. But we do not know exactly to what extent.

We also do not know which factor will dominate in setting a ceiling on our longevity; will it be the non-availability of drinking water of international quality or will it be the non-availability of other health services, or will it be merely malnutrition?

VII

Trisul and Lonar

The laws of atmospheric science say that the air at high altitude should be cooler than the air at the ground level. And, indeed it is so. If we go up in an open helicopter, we find that the air gets cooler and cooler. At a height of about 5 km, the air becomes ice cold. Higher up, it becomes cooler still, freezing subzero. That is what makes the hills cooler than the plains. Besides the height, the temperature of air depends also on season; winter air is cooler. There are other factors as well, but they are less important. We shall not worry about them.

Glaciers

If we take a trip to one of the popular hill stations (2-3 Km altitude) in Himalayas during summer, we meet pleasantly cool weather there. Our stay there is punctuated by frequent and heavy rain. These rains send large quantities of water hurtling down the Himalayan streams. Quantity wise, this water is much more than what comes from melting of Himalayan snow and ice. Major source of Himalayan water are the rains, not snow or ice. In any case, large amount of water flows down during the rainy season.

If we continue to stay at this hill station during winter, we observe that now we are more likely to get snowfall rather than liquid rain. But the snowfall is generally not very heavy; quantity wise it is much less than the summer rains. This snow melts away during early summer from most of the area and adds some water to the flow of the rivers,

Now we move farther north to a higher altitude; let us say, to 6 km. height. Here, the weather is much chillier. During winter; the temperature stays below zero. Even during summer, it stays below zero for most of the day. Only in the afternoon, it may warm up a bit and melt some ice. At this height, rarely do we expect to get any rain. Whatever little water falls from the sky, it is mostly in the form of snow, even during summer. The total snowfall (winter + summer) is thought to be meagre as compared to rainfall at lower hills. And so rarely does the air temperature rise above zero that it takes almost a full summer to melt an equivalent of even this meagre amount.

We observe another strange thing here. We see large masses of ice lying on the ground all the time; in the valleys between the hills, in the depressions and on hill slopes. We call them glaciers. These large masses of ice collected on the Himalayas during ancient times when the Himalayas (and the world in general) were much cooler. At that time, the climate over the Himalayas was so cold that the annual melting of snow was less than the annual snowfall, with the result that gradually large masses of snow gathered there and got compressed into ice. In fact, the glaciers were much larger then. They covered more area and were thicker. Many of our present day hill stations were under ice. The glaciers extended down to 2-3 km. altitude; we can see their tell-tale remains at 2 km. altitude now.

At present, the climate is comparatively warm; it has been warm for several thousand years. It has been warm enough to melt away every year an amount of ice which is equal to the entire year's snowfall. In fact, a tiny bit more. That is why the ancient glaciers have been slowly melting away and thus becoming smaller in size. They are still getting smaller, slowly but perceptibly.

We may now ask that if the climate stays as warm as it is today, will all the glaciers melt away from the Himalayas, some day in the distant future. The answer is, no. Not from the loftiest peaks, anyway. The loftiest peaks of the Himalayas are too cold even during summer for any ice to melt away. But the glaciers (ice masses) do slowly slide down to lower altitudes where they melt. In the meantime, an equivalent amount of snowfall takes place at these lofty peaks, so that there exists a sort of equilibrium between the gain of ice by snowfall and the loss by sliding down and subsequent melting of the ice. Thus it seems that the high Himalayas will always retain their peaceful whiteness.

Availability

What is the relevance of all this to the main question that we have been asking all along, i.e., the availability of water?

Firstly, the fact that a part of the precipitation over the Himalayas falls as snow rather than liquid rain is very useful. Unlike rainwater, the snow does not start flowing immediately. The winter snow melts gradually. Thus the melt water from the ice starts flowing after a considerable delay after the snow fall and usually flows at a moderate rate. This is what makes the Himalayan Rivers carry a substantial flow during early summer. Although this flow is small compared to what arises from rains during the rainy season, it is a very important and useful flow since it reaches the plains when it is needed most and can be utilised fully in the canal system which has already been partly built.

The part played by permanent glaciers is thought to be still smaller quantity wise, but again very vital because of the convenient timing of ice melt. The glacial-melt water becomes available at the height of summer when most of the winter snow has already melted away from the low altitudes.

Some melting of glaciers continues even when rains have set in i.e. during July-September. This glacial melt water joins the flood waters at lower altitude and is lost to the sea if not impounded somewhere.

Speculations:

It is useful to get quantitative information on the extent and volume of permanent glaciers. With this information in hand, we can attempt to examine some speculations; in perspective.

During winter, the snow-bound area over the Himalayas covers about 500,000 sq. km. (2500 km length x 200 km. width). The permanently glaciated area however is much smaller, i.e., about 50,000 sq. km.(2500 km. x 20 km.). We do not have precise information on the quantity of total water locked as ice in these glaciers. But a rough guess can be made. It should be somewhere around 400 mhm i.e. equal to one year's rainfall over the entire country. This cannot last long if artificially tapped extensively. Fortunately, nobody yet knows how to. However, if we do develop some feasible method to tap it, we could use this reserve selectively during emergencies. More important is to devise ways to hold back the flood waters of the rainy season. One possible way (not necessarily a desirable one) is to convert the rainfall of lower and middle Himalayas into snowfall. Then the flow in the rivers can be made more uniform in time. But, fortunately, or unfortunately, nobody yet knows how to convert rainfall into snowfall. We have therefore to fall back on conventional methods of impounding the flood waters; big dams and large reservoirs. They are known to work.

Lakes

We do not have very many large natural lakes. We have a few medium sized ones in Kashmir (Dal, Wular, Tsomriri, Pangkong etc.), small ones in Kumaon hills (Naini Tal, Shim Tal), in Sikkim (Yamdrok Tso, Chamtodong). There are a few small ones in the peninsula also. Rajasthan has a few shallow depressions, Sambhar salt lake is the largest. It is about 250 sq. km. in area, gets filled to about one meter depth during the rainy season, but dries up soon thereafter, leaving a salty crust behind.

All of these lakes are important locally, and are a source of tourist attraction. The Lonar Lake, a crater-like depression of about 100 metres depth and 2 km. diameter, in the Deccan Basalt has got a rim like structure. This lake has recently attracted some atten-tion since it is now considered that it was cratered by meteorite impact. If true, this is the only known meteorite crater in basaltic formation.

More important and more numerous are perhaps our artificial lakes from the point of view of storing and regulating the flow of water. They are made by impo-unding stream water with the help of big and small dams.

VIII

The Fork

It is nice to have a water tap in the home. When it is opened, water should flow so that the domestic requirements can be met conveniently. It is also nice to have a canal supply in the farm. When it is kicked open, water should gush out so that the farm can be irrigated as and when needed. Failing this, one can wish for the next best, i.e., a water well or hand pump at home and a water wheel or tube well in the farm. Basically, there is no inherent difficulty in getting these. Certainly none in the alluvial areas such as the Indo-Gangetic plains which have sufficient rainfall. Wherever we make a hole, we can hope to get an adequate amount of ground-water. There may be some variations in the quality and profusion of the supply, but no holes end up dry. Thus there is no real need for water diviners in these areas, and there are none.

In the semi-arid areas, however, the situation is some-times somewhat different. We may easily locate holes which yield sufficient water, but the water may be too saline. Salinity can be widespread, or confined to small pockets. We would therefore appreciate it if someone could tell us where we should make a hole so that we strike sweet water and avoid the saline water.

This is not a very difficult task. Scientists can usually provide a satisfactory answer. They use an instrument which measures the electrical resistance of the soil in a farm and of whatever else lies underneath the farm. In other words, they can measure the electrical resistance of deep layers, without making any deep holes. The electrical resistance of any layer depends on the physical and chemical nature of the layer material and also on the fact whether there is water in it or not. Further, the electrical resistance of water itself depends upon the amount of salts dissolved in it. The more the salt content, the less the resistance. Thus the measurements of electrical resistance can, in principle, provide the answer whether there is or isn't water available underneath; if there is, whether it is sweet or saline. The divining is not however always very simple. Some experience in the field and in interpreting the measurements is essential.

The real challenge and the real usefulness, of divining lies in the rocky areas. More than half of our country is covered by rocks which have very thin soil cover above them. The peninsula is covered with basalts and granite. Here, if the borehole or dug pit meets a fractured or weathered rock, it can yield a good supply. If it passes through solid rock most of the way, it may yield very little water. We would like to avoid drilling these dry holes. Has science something to offer?

Yes; again, the electrical resistance measurements. But, the method meets only a limited success. Sometimes, other methods are also combined with the resistivity method, with the hope of improving the divining a tiny bit. The limitation of the electrical method arises from the fact that often the change in resistance caused by presence of water is rather small and only comparable to that which may arise due to change in composition of rock itself from one place to another.

The intuition of a trained and experienced geologist, equipped with resistance measurements and their probable interpretation, is about the best that science can offer at the moment. And this is not very cheap. Much cheaper is a water diviner who uses nothing more than a twig and his own experience and intuition. He is thus able to compete inspite of the fact that the twig business may be a complete hoax. He thrives because he provides cheap, quick and dramatic service. He charges only a couple of hundred rupees while the boring may cost as much as five thousand. The client, in his wisdom, decides to throw a couple of hundred to the diviner, just in case it works. The cost is just equivalent to a meter or two of extra drilling. The scientist faces a tough job. He must improve the prediction and cut the costs. He can drive out the 'hoax' only if he is able to offer something which is demonstrably much better, not by something which is marginally better. It is a very worthwhile research area. The economic impact can be tremendous. Imagine the saving if no unproductive holes are bored.

IX

A Calamity?

Our ancestors did not have it. Not in any appreciable measure. It is new. It is called 'pollution'. Some people call it 'slow suicide'; some accept it as a 'necessary evil'. Most ignore it until personally affected. Then, the emotions run high. Why not? Because it can kill.

Let us attempt to look at it somewhat dispassionately.

What is pollution? It is the presence in our environ-ment (let us confine our consideration to water only) of certain materials, some of them completely new, in large enough concentrations which affect us immediately or eventually in an adverse way. These materials are put inadvertently by us through the various activities which we have taken up in a big way in recent times. These materials are called 'pollutants'. Some of these pollutants, like municipal waste, were introduced by our ancestors too. But we have started putting a bigger load because we have increased very much in number, especially so in the towns. However, this by itself is not an unmanageable problem. As discussed earlier, municipal waste can be converted into useful products like fertiliser and fuel. This is beginning to be a feasible proposition in our country. Efforts are already afoot in this direction.

The problem of pollution arises mainly from the dumping of industrial wastes into the streams and from the usage of certain new industrial products. Even this problem appears to be a manageable one. But it is certainly there. The root cause of all pollution (and glittering progress) appears to be the direct or indirect consumption of coal and oil (and natural gas). Coal and oil have made large scale mining, extensive industrialisation and gigantic civil works possible; they have also provided sustenance for an ever increasing population. Of course, this fete will not last for ever. Nor will it end tomorrow. Oil is expected to last two or three generations and coal many more. There is very little that we can do at the moment to restrict the main engine of progress and pollution. We shall therefore merely take a look at the individual maladies, and consider some palliatives.

Industrial Waste

There are large quantities of minerals buried underground. They have remained buried for millions of years. We are now digging them out. We sort them, keep the desired ones, and dump the rest. Dumping causes a minor environmental upset.

Industry processes the sorted minerals further. The processing generally involves some sort of chemical treatment. This generates large quantities of waste materials which need to be discarded somewhere. If they are discarded in water or in soil in large enough concentrations, they can prove very harmful. They can render the water unfit for drinking, and even for irrigation. They can also make the soil infertile.

How serious is this problem in our country? Not very. Industrialisation in our country is not very widespread or intense as in other countries. The pro-blem is therefore proportionately less severe. But it is certainly there, in localised pockets. When present, it is usually visible.

Recently, a fertiliser factory was ordered to close down because it was discharging large amounts of harmful ammonia and arsenic in a nearby stream. A fertiliser factory in our country is on a very different footing compared to, say, a caustic soda or a dyes factory. We need the caustic soda and the dyes, but we need the fertiliser even more since it helps us in growing more food which we need so desperately. That the authorities saw it fit to order closure of the fertiliser factory, though temporarily, brings out a very disturbing fact i.e. industries are only a mixed blessing. The resulting pollution can sometimes bring more harm than good, at least locally.

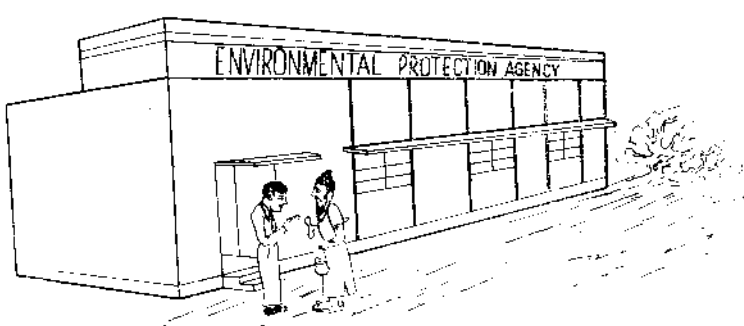
There are several other visible examples. Pollution of Ulhas River (near Bombay) and Damodar River (Durgapur-Asansol near Calcutta) is often quoted. The industries in Baroda have thought it fit to embark on building a 65 km long lined drain to carry the industrial effluents from Baroda to the sea. It is only to be hoped that effluents are dispersed adequately in the sea water, and cause no problem there.

The Invisibles

Certain industrial effluents can be dangerous even in .small quantities which are not easily observable. Mercury, lead, arsenic and some organic compounds (weedicides and pesticides) are the classic examples. No actual hazard to human life from the use of these chemicals has so far surfaced in our country. But it will, if we are not careful.

Challenge

How can we meet the challenge? Firstly, we can try to treat the effluents to remove the dangerous com-ponents. This is the favoured solution for the industries already in existence although the treatment usually involves direct and indirect usage of more coal and oil some where else. If the treatment is too expensive, (which often it is), we can take recourse to the siting of new industry and shifting the old one to a place where large quantities of water are available for diluting the effluents, and where life and vegetation exposed to the onslaught is minimal. If this is also not feasible (which usually it is not), we have to evolve alternate technology through further research for achieving the desired end product but with less dangerous consequences. If we fail, we have to learn to live without this particular industry. This stage has not yet come. We are busy attempting half-way solutions with the hope that they will be semi-acceptable.



Our experts sire unable to perform the miracle, trill you please take over

There can arise severe and widespread problems which are not easy to discern. They are subtle and potentially far more serious. For example, intensive large scale industrialisation puts large amounts of gaseous oxides of sulphur and nitrogen in the atmosphere. These gases dissolve in rain drops and come down as very dilute sulphuric and nitric acid. The effects of this slightly acidic rain on soil fertility may become visible only after a long time. Such problems, if genuinely there, can be much more disastrous than what we have discussed so far. However, we are not yet industrialised heavily, and our coal is low in sulphur. Moreover, rainfall comes only for four months and is usually heavy. Therefore, our rains are expected to bring down only a small amount of acid and that too extremely dilute. There are further possibilities of siting the industries judiciously, keeping in mind the air movement during the rainy season.

The pulsed nature of our rainfall is both a disadvantage and an advantage. A disadvantage because there is very little water in the streams during dry season, and even a moderate load of effluents causes a high pollutant concentration in the water. An advantage because the stream gets flooded during the rainy season and all pollutants are wiped off and thus there should be no progressive build-up of pollutants in the bed. However, we cannot afford to be complacent and depend merely on hypothetical thinking. A countrywide network of water quality analysis needs to be routinised. It is already operating, in a way.

Industrial products

Not only the manufacture but also the usage of certain industrial products can create problems of pollution. Here again, except for a few pockets, the problem is not severe in our country. Not yet. It may never be. The usage of industrial products on a country-wide scale is quite small. But we do need to keep a watch on two products, i.e. the fertilisers and the pesticides; their usage may be increasing in future. Both can, under certain circumstances, affect the water adversely. Pesticides even tend to enter the food chain. But we are being forced, by economic compulsions, to apply only minimally necessary quantities of the two, and to revert to the usage of traditional biogenic materials. The problem may therefore never assume worrying levels. What are our options anyway? If we have to extract enough food out of our land using today's established technology, we have to have certain industries going. We need to apply fertilisers and the pesticides. In order to build irrigation works and agricultural implements, we need steel, cement, oil, coal and other materials. We therefore must have the industries, and we also must attend to the local problems caused by these industries. We face no immediate impasse on this score.

Manufacturing process for certain industrial products are known to be very dangerous for the health of workers in the factory. Some of the rich countries therefore prefer to buy these products rather than manufacture them themselves. It is deplorable to go into the export of these products for earning high profits and ignoring the costs in terms of the health of our workers. The scale of such operations is fortunately not large as yet. We must guard against their possible expansion in future and attempt to gradually wind up these exports.

Limited Options

Sufficient nutritive food for every one continues to be one of our immediate goals. For this, we need to raise the production of food above the present level and continue to raise it in step with the increase in our numbers. Expansion of certain industries would therefore be inescapable. But their siting, choice of processes and treatment of effluents which were not a major concern earlier would require to be judiciously looked into. This can go on for a while, but not indefinitely. Eventually, slippage and failures will start due to several serious constraints unless science makes a new break through, in the field of energy and agriculture. If cheap energy is available, almost anything is possible. On the other hand, if the going gets tough, philosophy always provides the shelter. There is hope. Non-polluting alternate technologies are being worked out. Possibilities of tapping solar, wind, oceanic and geothermal energy are under investigation, as are new biological possibilities in agriculture and waste treatment. But they are all cosmetics; none of them has really clicked yet; coal and oil continue to rule the commercial energy field. But the game is on.

In the meantime, our action should be cantered towards assessing the magnitude and severity of visible (immediate) and invisible (long term) problems, and then take necessary remedial and judicious preventive steps. We are in no position to call a halt to the expan-sion of essential industries. We can however close down the factory which manufactures shoes for dogs. It is easy to close this factory because it does not yet exist. But we have thus established the principle that unnecessary things can go. It is going to be very painful to decide what is more unnecessary. But eventually the exercise may become inescapable. Must we refine *gur* to obtain sugar or can we do with *gur?* It may become necessary to ask such questions and react accordingly. Since our acts are deliberate, the remedial measures can (and should) also be deliberate. If we do not care to react, the system will continue to move towards extreme position and cause pain, but not necessarily a holocaust. Most systems are self-adjusting and self-regulating. These mechanisms automatically come into play when things go to the extreme. We see them at work in various spheres of our activities, all the time.

Conclusion

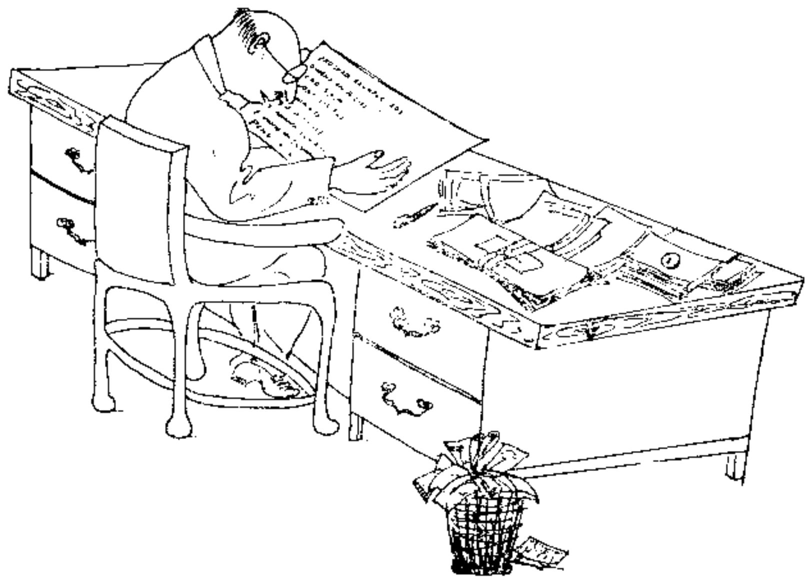
We have to keep our eyes open and minds alert so that we do not overlook the dangers ahead. We have borrowed the technology; we can also borrow the remedies and adapt them, wherever and whenever needed. This will provide us a short term stop-gap solution. And that is what matters most at present since we need time to think and adjust towards the long term options. Much will depend on what turn the energy problem takes.

X

Planning

Development, control and utilisation of water resources cannot be carried out on adhoc and piecemeal basis for long. Eventually, the different pieces will start coming in each other's way. Therefore, it is necessary to work out an integral plan. But this is a complex task. We have already discussed some aspects of this, broadly. But the 'in' thing these days is the so-called 'total system' approach to planning. By that we mean any decision or plan on utilisation and control of water should be arrived at by considering all possible factors. Any new project (or any modification of the existing water use) we wish to undertake should be a part of a much bigger plan in which appropriate consi-deration has been given not only to technical factors like water, land and energy but also to other diverse factors; social, economic, political and ecological. The grand plan should be a comprehensive long term plan for an entire river basin; may, it should cover the entire country including inter-transfer of water and other resources between different basins. This is not all. Various alternative profiles of actions we can possibly take should be examined in detail. The projections of future demands should be prepared, and various constraints under which we have to operate should be identified and quantified. Then priorities and time schedules on individual actions (such as construction of canals, drilling tube wells) should be examined and matched in the big scheme. All this may appear rather complicated, which it is. But this type of planning can be accomplished, certainly on paper (though the execution is a different matter). This approach to planning is not entirely new either. The planners always keep diverse factors in mind, and often take them in to account intuitively. But the 'total system' approach attempts to take them into account quantitatively, presumably in an objective way.

Viewed simply, planning for water (or anything else) is not very different from what the housewife does all the time while managing her household. She takes into account scores of factors, variables, probable, incidentals and accidentals; chalks out courses of objective oriented action for herself and other members of the family; lays priorities and time schedules on these; attempts to accommodate conflicting demands; makes projections; keeps various alternatives open. She sometimes commits mistakes and tries to rectify them in mid-course. Occasionally, she lays unrealistic goals, and faces disappointment. However, most*of her realistic plans do materialise. The experience in water management is essentially similar. The only difference is that an attempt is made to consider the system in all its complexity in a quantitative way. Laudable though it is, even the 'total system' approach cannot take into account all conceivable factors irrespective of how sophisticated the computation and how powerful the computer. This is because the influence of water is so "pervasive in our life and in every thing around us that the number of possible variables is much too large. Further, it is not by any means certain that we can take into account all possible technical factors. Some extraneous, hitherto unrecognised, factors sometimes begin to affect the execution of a project in a vital way and jeopardise the whole plan. Some factors which cause ecological imbalance become visible only after a long time. Therefore, 'total system' planning is no guarantee for completeness and success. But it is certainly better than no planning or inadequate planning. Just to give an idea of the kind of factors that go into the system, a few may be mentioned:



This must be one of the unfathomable creations of our computer

Rainfall, its distribution in time and space; its possible modification by seeding; stream flow and its variation; groundwater and its interconnection with stream flow; land and its use; soil types, their moisture retention characteristics and their suitability for various cropping patterns; people, their skills and culture; regional economy and fiscal policy; cattle and their utilisation pattern; industries, agro and others; irrigation already in practice and its modifications; pattern of available energy; inland water transport and fisheries; ecological balance. All these (and many more) constitute one system. A change in any one affects all others. It is extremely complex. This is a job that only experts can handle on a fast computer. But they also have to restrict themselves to important questions relating to technical and policy matters and proceed to answer them with the help of a modern computer. The answers can be very useful as a guide for taking an appropriate decision. The answers should not however be taken as 'dictates' for any particular policy. For the simple reason that they have been arrived at under some unavoidable limitations. Sometimes compromises are made even with respect to input technical data which may be sparse or even faulty. The game however must be played since in the process we begin to understand the system better and may even locate some new possibilities.

Though advisable, the 'system analysis' is not a prerequisite for every action. Often there is so much latitude available for a particular action and the situation so compelling that one can, and has to, go ahead straight-away. In fact, that is how we have operated so far, and that is how we can perhaps continue for some more time. For example, we can continue to build both the diversion canals and also use the ground water for irrigation in the Ganga basin for some more time to come. There is latitude available in both, and both are desirable and feasible. At the moment, nothing more than the usual considerations may be warranted. But after a while, conflicts will begin to appear since the two sources are parts of the same system and they interact with each other. Then we shall need to take an objective decision on limiting our action on one in preference to the other, depending upon the local and overall situation in which many factors will need to be considered. It may be wise to start gathering the requisite information and develop methodology right now. Once the methodology is ready, it can also be applied to the existing water supply to maximise (or optimise) the desired benefits.

The fashionable thing these days is to make demand projections for the year 2000 A.D. and to work out a plan for meeting these projected demands. One starts with the population. What would be the population (under different assumptions) in A.D. 2000? What would be their requirements of water and food? How can these requirements be met? What would be the impact on ecology? This goes on. And it should go on. Not because the projections will come true, but because certain problems will come into focus and remedial steps can be initiated.

All plans and projections seem to go awry for a while when some unanticipated events start exercising an over riding control. But that possibility is always there, planning or no planning.

Conclusion

A total system approach to planning is very desirable.

Care must however be taken that the very process of planning does not become so unwieldy that no specific plan ever emerges; nor should it become so expensive that it starts eating into the execution of the plan itself.

XI

Investigations and Research

Water is used for so many diverse purposes and in so many diverse ways. Accordingly, the investigation and research are also spread over a very wide range. Organised research however caters to only major problems of development, control and utilisation.

Any meaningful researcher investigation connected with water be it basic, applied or routine, can prove extremely beneficial to us since our largely agrarian economy depends critically on water.

Basic research can enable us to understand the crop-water-soil-climate system better. This can lead to new thinking and new avenues of action which can yield larger stable production within the existing constraints. The effort spent in basic research usually pays for itself many times over, though not necessarily immediately.

Basic research in hydraulics and soil mechanics, i.e. understanding the behaviour of flow of water and its interaction with the medium through which or over which it is flowing is becoming increasingly more important, as are the allied fields of hydel power and water transport. So far we have developed only less than 20 per cent of the available hydel potential (about 40,000 Megawatts). We have a long way to go. Better basic understanding of the system and engineering can enable us to cut cost and avoid pitfalls.

In the applied area, our concern is mainly about practical problems which are well denned. The problems may pertain to only small regions; their solution can still make a great economic impact. For example, any improvement and cost reduction in the irrigation technology when applied even over a small region adds up to a big saving. Substitution of cheaper materials, saving labour, introduction of better implements make tremendous impact on regional economy. Development of methods of control of land erosion and sedimentation, suited to our social and physical environment, is a crying need.

All developmental projects require collection of routine data. Though not exciting, the acquisition of these data is extremely important. If these data are not available, the planning and execution of the project can go completely haywire, resulting either in underutilisation or in building excess capacity. The hydrological data needed for undertaking various projects like dam-reservoirs, ground water development, flood control, flood forecasting, river-training, and intensive cropping must be collected. These data pertain to rainfall, stream discharge, water-table depth, recharge condition of the aquifer etc. It is possible to improve and simplify the methods of procuring these data. The data need to be collected over an adequate length of time. A part of our effort is directed towards this end.

The data need to be analysed and processed to suit the requirements of the particular project we wish to execute. This requires some specialised knowledge of data handling. As an example, let us say that we need 'to decide on the height of a dam which we propose to build. As the height is increased, the dam becomes longer and longer at the top. Further, a taller dam has also got to be made thicker all through. Therefore, the resource requirement increases rather rapidly with small increments in height. It is therefore no good building a very tall dam and a big reservoir which fills to the brim only once in a blue moon. On the other hand, we should not build a pigmy dam and let a lot of water overflow every year. We should therefore develop some criteria which will enable us to impound a large quantity of water (on the average) without increasing the re-source requirement unduly; it does not matter if we allow a small quantity of water to overflow once in a while. This requires specialised analysis of rainfall and discharge data and economic trade-offs.

In order to allow the overflow to occur without causing any damage to the dam, it is necessary to make special arrangements, such as spillway or siphon, in the dam construction. These are expensive propositions, and should not therefore be grossly over-designed. In order to be able to do that we must be in a position to assess the intensity of flood waters that are likely to come into the reservoir at different times. This again requires special analysis of rainfall and discharge data.

After the reservoir and the associated works are ready, we have to chalk out a sensible policy for operating the reservoir for deriving maximum benefits. The three main objectives, i.e. irrigation, power generation and flood control, pose somewhat conflicting require-ments for the operation of the reservoir.

(1) For irrigation, it is best to conserve as much water as possible in the reservoir during the rainy season so that it could be used later. During the rainy season, only a small quantity of water need be released into the canals for meeting the irrigation demand

of the Kharif crop. Subsequently, the release of water needs to be stepped up or down as per irrigation demand of the crops.

(2) For generating electric power, it is best to keep the reservoir as full as possible all the time and release the water as per power demand. The power and irrigation demands do not necessarily keep in step with each other.

(3) For the sake of flood control, we should always keep some spare (empty) capacity in the reservoir during the rainy season in order to contain the flood. Therefore, it is necessary to keep releasing the water in between the rains so that the reservoir is never completely full.

Keeping in view these conflicting requirements and also some estimates of probable in-rush of flood water at different times, the engineer-in-charge works out a policy for release of water. Since the three demands are only partially conflicting, it is possible to reconcile all three to optimise the net benefit. But it requires special expertise in data handling.

Apart from purely hydrological data, certain projects require an intensive survey of the geology and physiography of the region. Then, an appropriate design for actual engineering details needs to be worked out. For this purpose, scaled-down models of the project are often used. This is a very necessary step, not only from the point of view of ensuring safety and reliability but also for avoiding over-designing and thus avoiding needless waste and effort.

The same considerations apply for digging canals and water courses and for their lining. Often a small appropriate change in any step can result in a substantial net saving of effort and materials. Research in irrigation has got to be a continuing activity since a lot is at stake.

Some effort is necessary in identifying, evaluating and controlling pollution. Developmental effort for treating waste water for reuse at least for some restricted purposes is another active fertile field of research. Other fashionable areas of research include studies of behaviour of hydrological systems with the help of electrical and computer simulation models, investigations on potential usefulness of satellites in hydrology, computations of the future water needs and the methods of meeting them, and the projections of environmental changes.

Research in non-glamorous, down to earth, problems can prove more useful in the short run and must have top priority. But we can not afford to ignore the basic research involving specialised expertise and high intellectual content despite the fact that its benefit may not be immediately available or even visible. It is necessary to prepare and plan for the distant future too.

Some economists and social scientists conduct an analysis of the actual working of, and benefits realised from, the projects already undertaken. They analyse the data in terms of not only the economic factors but also social and political objectives. Such analysis is very useful since it enables us to identify the lacunae, locate the inequities and take remedial steps. Overhauling the water distribution system, pricing policy, and removing the causes of mismatch between demand and supply of irrigation water can go a long way in making more effective use of already created irrigation facilities.

There are several new problems which have crept up recently and require new concerted research effort. For example the problem of deforestation, is drawing a lot of attention. And rightly so, since deforestation leads to quick flow of rainwater, causing soil erosion, and thus siltation of reservoirs, stream beds and harbours. It is also surmised that the deforestation leads to decrease of rainfall, possibly due to consequent lack of evapotranspiration and the organic aerosols which the forests normally introduce into the atmosphere. Obvious cure for deforesation is afforestation. But is this the only remedy? Is there no possibility of introducing some specialised cultivation with the same effect? If afforestation is a must, what kind of afforestation is the best?

Does Pipal for which we still seem to have some regard have some place in afforestation? Whatever actual line of action we take; large scale man made forestry will become inescapable. Research effort similar in scales to what exists now for farming, will be required for, forestry too.

There is a rumour that floods and droughts are be-coming more severe and more frequent than before. Is this merely a scare or is it true? If true what can be done to reverse the trend.

One can enumerate many such problems which need to be looked into scientifically. A number of organisa-tions and research institutes have already been set up in the country; they can legitimately undertake such investigations.

The need for development work is obvious. What is even more important is the search for new ideas, new leads and new breakthroughs. No situation is ever completely hopeless.

XII

Who's Who in Water

Every one of us has to deal with our individual water problems in one way or the other. But the Government has created several organisations to deal with larger problems professionally.

The Irrigation Department of each State Govern-ment generates schemes for development, control and utilisation of water. The same Department also conducts necessary investigations and takes up the execution of these schemes after obtaining approval and financial sanction from the Central Government. Most Irrigation Department in the States have some sort of research wing associated with them.

At the Centre, the Ministry of Irrigation looks after the overall developmental aspects for the entire country. They have a technical wing, the Central Water Commission, to look into the technical aspects of various proposals. They also have a field station, the Central Water and Power Research Station, at Khadakvasla, Poona which investigates the actual engineering and other details of the schemes. The Central Ground Water Board (Ministry of Food & Irrigation) advises and assists the States in matters of groundwater assessment and development. The Irrigation Commission takes stock of, and projects the needs for, irrigation supplies. There are several organisations specially created for purposes like river valley development, discharge measurement, flood forecasting, flood warning, flood control etc.

There are many other organisations which have to deal with the civil engineering aspects of water. Civil Engineering Departments of Municipal Corporations, Shipping and Transport, Railways, Forests, Technical Institutions, Agricultural Universities, Research Institutes etc. also deal with water professionally.

Some organisations have recently been created both at the Centre and at State level to evaluate and advise on matters of pollution and its control. The National Environmental and Engineering Research Institute, Nagpur has its hands full with numerous genuine, immediate and difficult environmental problems connected with our water supply.

An extremely important, though now relatively routine, function of measuring the rainfall and snowfall over the entire country, collecting and storing these data, is carried out by the India Meteorological Department. The Department also issues cyclone warnings and weather reports, and attempts to make weather forecasts also.

XIII

Conferences

We hold about half a dozen conferences (symposia, seminars, workshops etc.) every year on various topics connected with 'Water'. These conferences certainly have and educational value. In addition, they provide the participants a welcome change from their routine. The only objectionable part perhaps is that generally the same people tend to come to each one of these gatherings. One wonders whether that much change is essential or even beneficial.

The real aim of these conferences and symposia is, of course, to discuss new ideas, new developments and new experiences; compare notes on these, exchange ideas and possibly move towards new avenues. This does happen, to an extent. Some participants present new technical data and new approaches. But it is too much to expect new thinking, new results or new developments every couple of months. Therefore, we hear a good bit of rhetoric too. Generalities and platitudes, clothed in standard apt sounding language, are a hit with the popular press. Sometimes an impression is created that instant solutions are at hand, and that mutually conflicting demands can be met; all this by vague and high sounding language. Another highlight of these conferences is to predict doom of various kinds, perhaps intended to focus attention on some particular aspects. This is all in the game.

On the other hand, certain well organised business like symposia on special narrow topics meet commend-able success. Since most conferences do achieve their main objective partially, and they do have some education value also, there is not much harm if they proliferate. We seem to be able to afford them alright.

XIV

The Challenge

As discussed earlier, the utilisation of water can be doubled from 40 mhm to 80 mhm using the known technology we have at hand. We are going to need this development over the next two decades. To make it happen promptly and appropriately, the water law may require some amendment. Some changes in organisa-tional structures may also be needed. But this magnitude of development, i.e. 80 mhm, can certainly be achieved. The real challenge is what after 80 mhm? In fact, challenges will start appearing even before the development reaches 80 mhm mark i.e. even before the year 2000, a date very fashionable to mention these days. There are five different leads, each one very challenging, which we can still take. They have been mentioned earlier, and are restated below:

Long range forecasting of rainfall (a week or so ahead). This can improve the effective utilisation of the existing irrigation facilities.

End