Ground-Water Dams for Rural-Water Supplies in Developing Countries

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ABSTRACT

The use of ground-water dams to store water in regions with arid or tropical climates is a method that has received considerable attention in the last few years. By storing water behind subsurface dams in natural aquifers or in the sand accumulated in sand storage dams, the disadvantages of conventional surface storage, such as high evaporation rates, pollution, siltation, and health hazards, may be avoided. The techniques are very old, but only recently have there been some attempts to make systematic studies and to develop proper siting, design, and construction methods. This paper presents the experience gained from existing structures all over the world and describes the physical setting in which the techniques may be applied. Design and construction alternatives are shown, and case studies from India and Ethiopia are presented. The construction of ground-water dams may be a feasible solution to water-supply problems in many parts of the world if preceded by proper planning and site surveys.

BACKGROUND

The use of surface reservoirs to store water in areas with dry climates has several serious disadvantages, such as pollution risks, reservoir siltation, and evaporation losses. Using ground water is one way of overcoming these problems, but in some areas good aquifers are not available or they may only yield sufficient quantities of water seasonally. Experience also has shown that conventional development of ground water in developing countries involves serious problems related to operation and maintenance of drilling equipment, wells, and pumps.

During the last few years, considerable attention has been given to the use of ground-water dams as a method of overcoming water shortage in regions with arid and tropical climates. Damming ground water for conservation purposes is certainly not a new concept. Ground-water dams were constructed on Sardinia in Roman times and damming of ground water was practiced by ancient civilizations in North Africa. More recently, various small-scale ground-water damming techniques have been developed and applied in many parts of the world, notably in southern and East Africa, and in India. This paper summarizes the results of a state-of-the-art study during which literature and data from most parts of the world have been collected (Nilsson, 1984). It also presents examples of practical applications in two areas in Ethiopia and India (Hanson, 1984; and Nilsson, 1984).

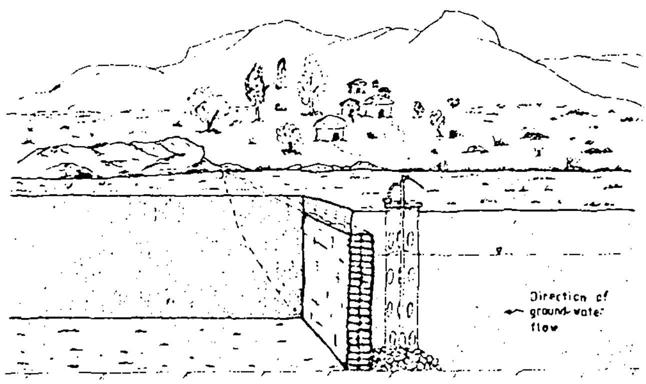

Fig. 1. General principle of a subsurface dam.

There are basically two different types of ground-water dams, namely subsurface dams and sand storage dams. A *subsurface dam* is constructed below ground level and arrests the flow of a natural aquifer, whereas a *sand storage dam* impounds water in sediments caused to accumulate by the dam itself.

The general principle of a *subsurface dam* is shown in Figure 1. An aquifer consisting of fairly permeable alluvial sediments in a small valley supplies water to a village by means of a shallow well. Due to consumption and the natural ground-water flow, the aquifer is drained during the dry season, and consequently the well runs dry. To prevent this, a trench is dug across the valley, reaching down to bedrock or some other solid, impervious layer. An impervious wall is constructed in the trench, and when the dam is completed the trench is refilled with the excavated material. A reservoir built in this way will not be drained and may be used throughout the dry season, provided of course that the storage volume is sufficient to meet the water demand.

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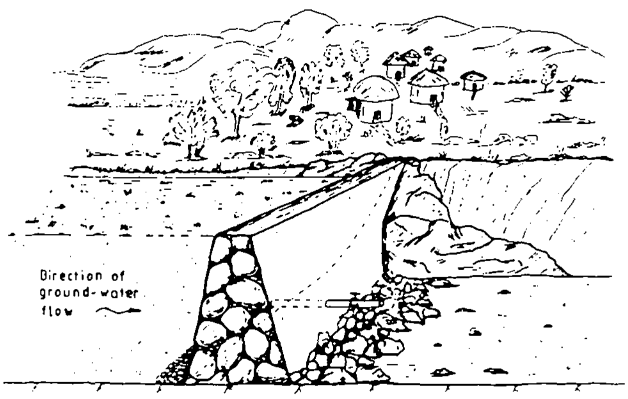

Fig. 2. General principle of a sand storage dam.

The general principle of a *sand storage dam* is shown by the example in Figure 2. The villagers collect their water from the small nonperennial stream at times when it carries water, or from holes dug in the shallow riverbed for a short period after the rains. The quantity of water stored is not sufficient, however, to supply water to the village during the entire dry period. By constructing a weir of suitable height across the streambed, coarse particles carried by heavy flows during the rains are caused to settle, and eventually the reservoir will be filled with sand. This artificial aquifer will be replenished each year during the rains and if the dam is properly sited and constructed, water will be kept in the reservoir for use during the dry season.

Quite often a ground-water dam actually is a combination of the two types. When constructing a subsurface dam in a riverbed, the storage volume may be increased by letting the dam wall rise above ground level, thus creating an accumulation of sediments. Similarly, when a sand storage dam is constructed, it is necessary to excavate a trench in the sand bed in order to reach bedrock or a stable, impervious layer.

Figure 3 shows a map on which all known ground-water dam sites are marked, and also where it has been proposed, after preliminary investigations, to implement the technique. The schemes in Europe and northwestern Africa are mostly large-scale projects, whereas in certain parts of Ethiopia, East Africa, and Namibia, ground-water dams are used quite extensively as storage reservoirs for small-scale rural-water supply. There is a long tradition of building ground-water dams in the arid southwestern part of the United States and northern Mexico, and there are isolated examples of subsurface dams in Afghanistan, India, and Japan.

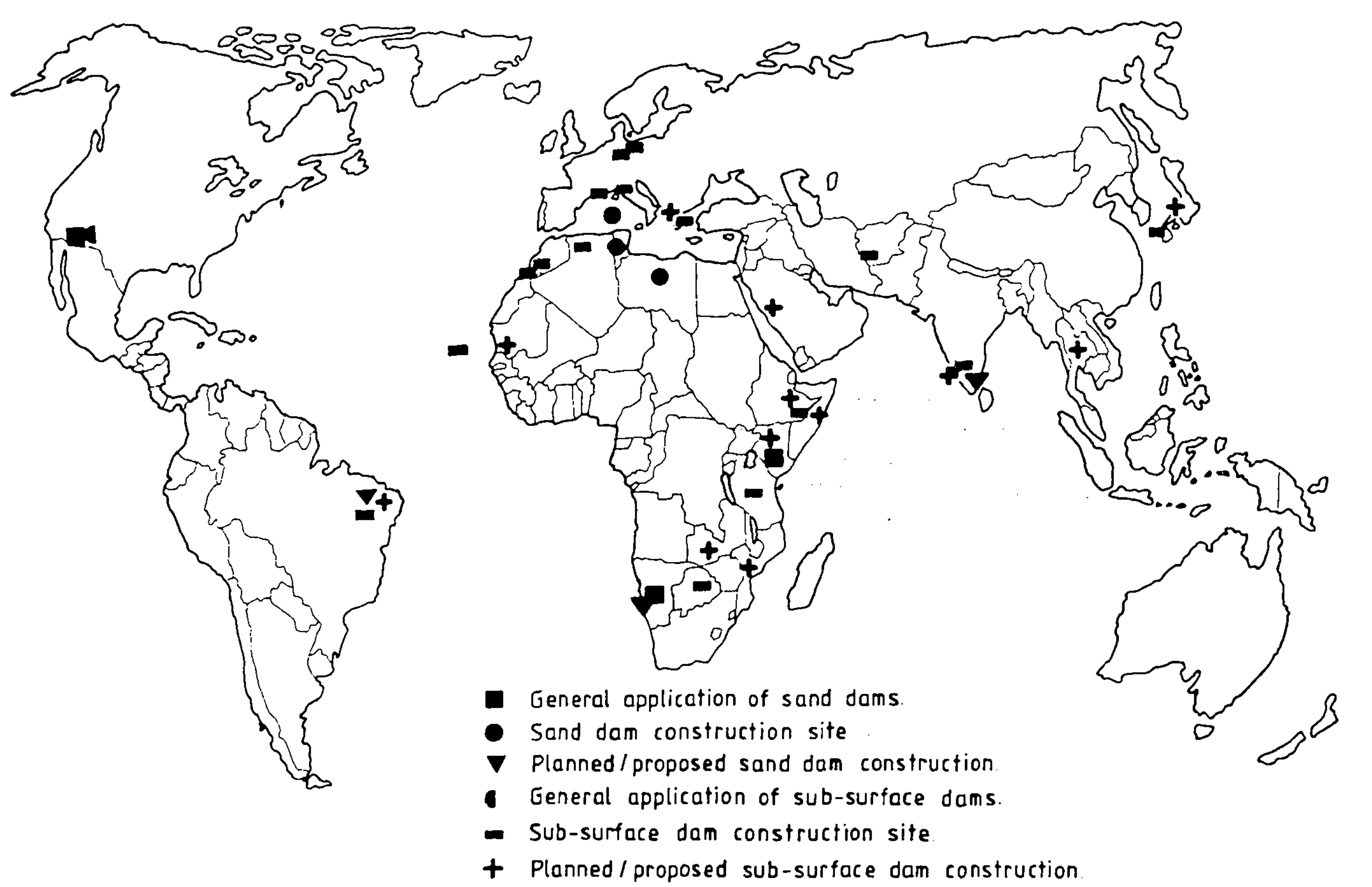

Fig. 3. Ground-water dam sites and proposed construction areas.

PHYSICAL SETTING

The rationale of damming ground water is the irregular availability of surface and ground water. Ground-water damming techniques may thus be applied in arid and semiarid areas where there is a need to conserve the scanty quantities of rainfall. They are also highly suitable in areas with a monsoon climate where there is a need to store surplus water from rainy seasons for use during dry periods.

The topographical conditions govern to a large extent the technical possibility of constructing the dams as well as achieving sufficiently large storage reservoirs with suitable recharge conditions and low seepage losses. The basin in which water is to be stored may be underlain by bedrock or unconsolidated formations with low permeability. It is generally preferable to site ground-water dams in well-defined and narrow valleys or river courses. This reduces construction costs and makes it possible to assess storage volumes and to control possible seepage losses. This is obviously difficult in areas with flat topography. On the other hand, efforts must be made to maximize storage volumes without the construction of unnecessarily high dams. In mountainous areas with very high gradients, it may be difficult to find an acceptable relation between storage volume and dam height. An optimum composition of riverbed material is generally found in the transition zones between mountains and plains.

One of the basic conditions justifying the construction of a subsurface dam is the depletion of ground-water storage through natural ground-water flow. The gradient of the ground-water table and thus the extent of ground-water flow is generally a function of the topographic gradient. This fact indicates that the construction of subsurface dams is feasible only at a certain minimum topographical gradient, which naturally varies according to local hydrogeological conditions. Most ground-water dams in existence today have been constructed in areas with a 1-5% slope, but there are examples of dams constructed where gradients are 10-15%.

The storage capacity of sand storage dams and subsurface dams constructed in riverbeds is a function of the specific yield of river sediments. Dams are therefore preferably constructed in geological environments where the weathering products contain a substantial amount of sand and gravel. As a consequence, cases where dam construction has met with success are mostly found where the bedrock consists of granite, gneiss, and quartzite, whereas areas underlain by rocks such as basalt and rhyolite tend to be less favorable.

Climate has a great influence on sediment characteristics in that it governs the relationship between mechanical and chemical weathering. A lower rate of chemical weathering in arid climates may result in more coarse-grained sediments (Sundborg, 1982).

The stage following weathering in the sediment cycle is the erosion of the particles. Topography and land use govern the extent of erosion, and an engineer interested in constructing sand storage dams would be happy to find steep slopes and low vegetation cover in the catchment area, generally very contrary to the preferences of agricultural and hydraulic engineers.

The coarse sediments one wishes to trap by a sand storage dam are generally transported as bed load. It is therefore necessary for the rainstorms producing the initial floods at the outbreak of the rainy season to be sufficiently heavy. On the other hand, the flood intensity must not be so high that the dam stability is jeopardized. Extremely high flood intensity will also mean that the existence of natural riverbeds is limited (Jacob, 1983).

Subsurface dams are mostly commonly constructed in riverbed aquifers consisting of sand or gravel. Other types of aquifers that may be dammed are weathered zones, alluvial or colluvial layers, or any type of overburden with sufficiently good aquifer characteristics. Infiltration conditions must be such that the reservoir is properly recharged during the rainy period.

The storage reservoir must be contained by impervious or low-permeability layers that prevent vertical and lateral seepage losses. In most cases bedrock will serve as the natural container, but there are also examples of low-permeability overburden layers serving this purpose, such as buried clay layers of alluvial origin, the upper clayey portion of the weathered profile, or the lithomarg in laterite profiles.

The containing layer must be at such a depth that it is technically possible to carry out the excavation at reasonable cost. In general, the limit seems to be at around 4-5 m, but, depending on the scale of the scheme, it may be possible to extend this considerably. If injected cutoffs are used instead of the conventional construction of dams in trenches, there is no practical limit to the depths possible.

The basic idea behind constructing a subsurface dam for storage purposes is to arrest the natural flow of water; it is necessary to quantify this flow so that the benefits of the scheme may be properly assessed before construction starts. If it is not economically feasible to use standard hydrogeological procedures for this purpose, a fairly simple monitoring program indicating seasonal ground-water level fluctuations will give a good estimate.

One prerequisite for using ground-water dams for rural-water supply in developing countries is that it must be possible to do so at low cost. A large part of the total project cost is generally the construction material; it is therefore imperative that suitable material is available locally and at reasonable cost. The various alternative materials that have been or may be used are described below. The identification of such materials should be done in the initial stages of planning the construction of a ground-water dam.

DESIGN AND CONSTRUCTION

The principal designs of subsurface dams and sand storage dams were shown in Figures 1 and 2. Since the two types are basically different, the presentation of design and construction alternatives has been divided into two parts, followed by a part covering certain aspects common to both types.

Subsurface Dams

The actual storage volumes of subsurface dams in existence today range from a few hundred to several million cubic meters and the designs are in consequence quite different. The following presentation concerns mainly small-scale schemes.

The most common way of constructing a subsurface dam is to build a dam in a trench excavated across a valley or riverbed. The earthwork involved may be carried out by manual labor since the excavation depths are generally not more than 3-6 meters. Subsurface dams are generally constructed at the end of the dry season, when there is little water in the aquifer. There is usually some flow, however, and this must be pumped out

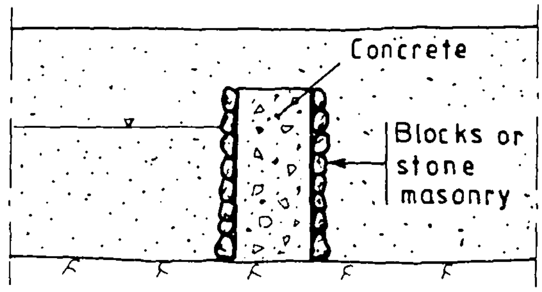

Fig. 5. Concrete dam.

during the construction. After the dam has been constructed and drains installed, the trench is refilled with the excavated material. It is important that the refill is properly compacted by mechanical means and watering.

The clay dike in Figure 4 is an alternative that is very suitable for small schemes in highly permeable aquifers of limited depth, such as sandy riverbeds. Clayey topsoils are generally available close to any construction site which means they can be excavated and transported to the site at low cost. The use of clay is a labor-intensive alternative but requires no skilled labor. Possible drawbacks are the large excavations generally required, the need for proper compaction and the risk of erosion damage to the clay surface due to the flow of ground water. The latter can be avoided by protecting the dike with plastic sheets.

A concrete dam covered on both sides with blocks or stonework, as shown in Figure 5, is an alternative involving slightly more advanced engineering for which skilled labor is needed. It necessitates the use of form work and the availability of cement and gravel. One advantage is that it is possible to raise it above the level of a riverbed and use it for further sand accumulation. This type of dam may also be constructed entirely of stonework.

Bricks are generally available or may be manufactured from local clay. Building a brick wall, as shown in Figure 6, and plastering it to

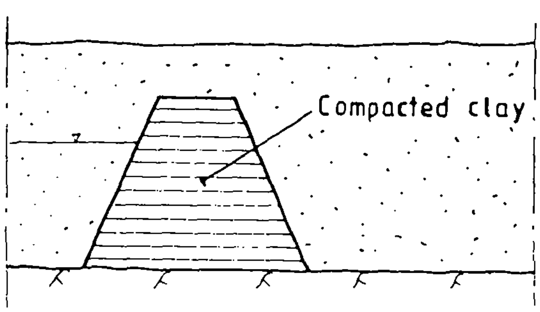

Fig. 4. Clay dike.

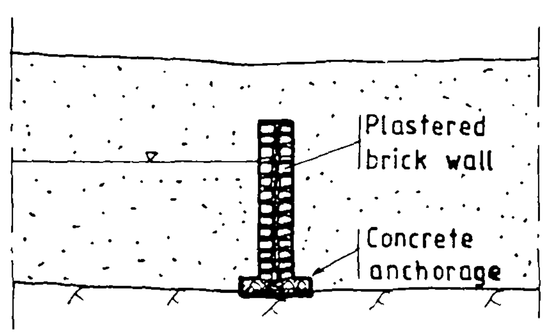

Fig. 6. Brick wall.

make it watertight is a fairly simple procedure (Ahnfors, 1980). The relatively high cost of bricks is a drawback, however, and there are also some doubts as to the stability.

Using ferroconcrete means that steel rods or wire mesh have to be used, but generally such material is available at reasonable cost. The method involves the use of form work, but its main advantage is that very little material is needed to achieve a very strong wall. The structure has to be anchored to the solid reservoir bottom.

Using thin sheets of impermeable materials such as tarred felt or polyethylene is an inexpensive alternative as far as the cost of materials is concerned. The mounting of the sheets on wooden frames and the erection process is rather complicated (Ahnfors, 1980). The material, especially the polyethylene, is highly sensitive to damage during erection as well as during refilling of the trench, and a minor rip will cause leakage losses. A small-scale scheme in south India where plastic sheets were used has functioned very well for three years, but it remains to be seen whether the material will withstand high ground-water temperatures, the activities of microorganisms in the soils, root penetration, and other activities over a period of time (Jayakumar, 1984).

Injected cutoffs have been used to arrest the flow in large or deep-seated aquifers in North Africa and Japan (BCEOM, 1978; Matsuo, 1977), and to protect fresh water from pollution in Europe and the USA. For large projects and when a deep aquifer is dammed, it is certainly a feasible alternative.

The average heights of some of the dam types are shown in Table 1. In most cases the crest of a subsurface dam is kept at some depth from the surface. This is partly to avoid waterlogging in the upstream area, and partly to avoid erosion damage to the dam. A common distance from the dam crest to the surface is about one meter.

Sand Storage Dams

When a subsurface dam is built, it is always possible to obtain at least some idea of the hydraulic characteristics of the existing aquifer material. When planning the construction of a sand storage dam, however, the material in which the water is supposed to be stored is still in the catchment area waiting to be transported to the dam site by a flood of unknown intensity. The proper design of a sand storage dam is therefore a more complicated matter, involving more hydrological and hydraulic calculations. The subject has been treated by Wipplinger (1958 and 1984), Burger and Beaumont (date unknown), Beaumont and Kluger (1973), and Nissen-Petersen (1982).

Table 1. Heights of Some Subsurface Dam Types—Average Values from Schemes Studied

Dam type	*Average height in meters*
Injected cutoff	10
Brick wall	6
Concrete or stone masonry dam	6
Ferroconcrete dam	4
Clay dike	3

The upper limit of dam construction and thus also the upper limit of storage volumes are set by the condition that the dam has to withstand the maximum peak flow, and allow for a discharge of the peak flow below the bank level or through spillways.

A sand storage dam is generally constructed in stages, as shown schematically in Figure 7. The basic idea is to limit the height of each stage in order to keep a sufficiently high-water velocity, so that fine particles are washed out from the reservoir while the coarse particles settle. The height of each stage is determined by estimating the sedimentation process in the reservoir (founded on experience from sedimentation in previous stages), from the extent of natural sedimentation in the stream, or calculations of water velocities in the reservoir.

This method of constructing the dam by adding a new stage each season or even less frequently means that costs will be higher than they would be if the dam were constructed to full height directly. Two methods have been tried in order to solve this problem. One is to use a siphon, which discharges water over the dam and keeps the flow velocity in the reservoir sufficiently high. This method has not been found to be technically efficient and is very costly (Burger and Beaumont, date unknown).

Another method is to leave a notch in the dam which allows the accumulation of sediments

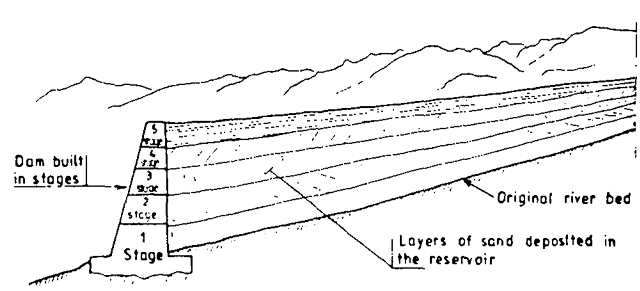

Fig. 7. Construction principle of sand storage dam (from Burger and Beaumont, date unknown).

only up to a certain height. The notch is then filled in before the next rainy season, and the reservoir is allowed to fill completely. This method has proved quite successful in Kenya (Werner and Haze, 1982).

Figure 8 shows a concrete dam which fulfills the basic requirements for a sand storage dam, i.e. it is sufficiently massive to take up the pressure from the sand and water stored in the reservoir, and it is watertight. The dam also may be built of stonework. For larger reservoirs, it may take the form of an arch dam.

The dam may also be made up by stone gabions or blocks sufficiently large to withstand the pressure. The gabion or block dam is covered on the upstream side by a thick layer of clay to make it impermeable. It is also possible to place the watertight clay layer as a core inside the dam.

The main dam body also can be a heap of stones covered by concrete walls for stability and tightness. A dam of this type serves at the same time as a bridge over a small stream in Kenya (Werner and Haze, 1982).

All sand storage dams must be very well protected against erosion along the banks, and even more so at the dam toe, where the energy of water during peak flows will be extremely high. The best way of avoiding erosion is to construct the dam at natural rock bars. If such are not available, it is important to extend the dam wall several meters into the river bank and to protect the dam toe with stone filling or concrete.

Common Aspects

Ground-water dams are generally combined with a drain along the upstream base of the dam. The function of this drain, which generally consists of gravel or a slotted pipe surrounded by a gravel filter, is to collect the water and transmit it to a well or through a gravity pipe to downstream areas. If the permeability of the aquifer material is very low, it also may be necessary to improve the flow along the reservoir bottom by using a system of collection, gravel or slotted pipe, drains perpendicular to the dam.

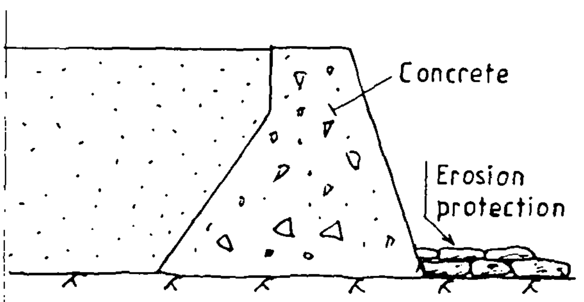

Fig. 8. Concrete sand storage dam.

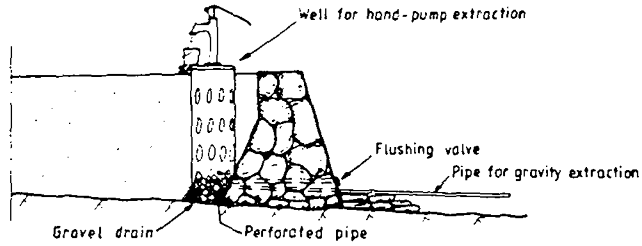

Fig. 9. Extraction alternatives from a sand storage dam.

The well through which water from subsurface dams is generally extracted may be placed in the reservoir or, for erosion protection purposes when dams are built in riverbeds, in the riverbank. When aquifers with low permeability are dammed, it may be necessary to construct a series of large-diameter wells or collection chambers to create sufficient storage volume.

If the community to be served by the scheme is located downstream of the dam site and the topographical conditions are favorable, it is possible to extract water from the reservoir by gravity. By using gravity extraction, problems with pump installation, operation, and maintenance are avoided. These are the problems which are today generally encountered in rural-water supply projects in developing countries, even in projects where shallow well and simple hand pump technology is applied. Figure 9 shows a typical sand storage dam where both extraction alternatives are illustrated.

Ground-water dams should, as far as possible, be anchored in solid rock. This generally provides the best stability, and fracturing of the dam can be avoided. Furthermore, it makes it possible in most cases to control seepage below the dam. Anchoring may be achieved using a concrete foundation on the rock surface. If the rock is weathered it is important that the weathered material is fully excavated before the dam foundation is made; otherwise, there will probably be a seepage below the dam. Controlling seepage losses through fracture zones is more difficult but may be achieved in some cases by pouring very thin mortar into the fracture system (Werner and Haze, 1982).

A ground-water dam may also function as a means of recharging an already existing aquifer by lateral or vertical flow. Figure 10 shows an example from Namibia of how this can work (Sauermann, date unknown). The dike was utilized as an aquifer by means of a well supplying water to an airport. The aquifer did not carry enough water to meet the demand, so it was decided to construct a sand storage dam which would increase the recharge. Sometimes a ground-water dam is considered a failure because it is drained out by a fracture system. It might, however, then be possible to drill a well in the zone and utilize the ground-water dam as an artificial recharge structure (Hanson, 1984).

If planned and executed properly, a scheme involving the damming of ground water will have no direct negative impact on the surrounding environment. It should be kept in mind, however, that the technique is implemented in a very fragile environment, where even a small change may have long-term physical as well as social consequences. This calls for caution. Aspects which must be considered are the possibility of upstream waterlogging, effects on downstream ground-water levels, salt accumulation, and pollution problems caused by the higher ground-water table.

In some areas it might be possible to construct a whole series of interconnected ground-water dams. Potential has been identified along sandy riverbeds in Kenya (Sörlie, 1978) and along narrow and very long valleys in South India (Jacob, 1983). The "jessours" (a type of silted-up surface dam) of Tunisia are examples of small-scale dams that may be placed at regular intervals along alluvial valleys (El Amani, 1979).

CASE STUDIES

South India

Two subsurface dams have been constructed in Kerala, South India. The sites are situated in the Palghat Gap, which is a graben dividing two hill ranges parallel to the west coast. The altitude is about 50 m and rainfall averages 2400 mm, the main part of which occurs in June-October.

Agriculture is intensive in the area. The water available during the rainy season is enough for one annual rice crop, and in part of the area two crops a year are possible. There is a need for additional water to expand the area covered by a second crop, and also to irrigate a third crop.

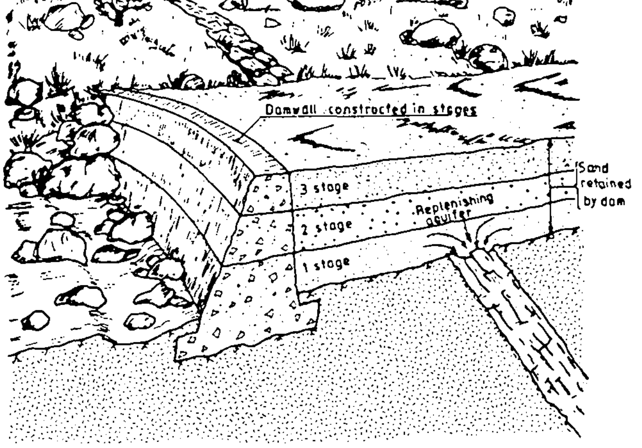

Fig. 10. Ground-water dam for recharging purposes (from Sauermann, date unknown).

One factor restricting the possibility of constructing ground-water dams in this area is that land holdings are generally small, and it is difficult to organize the cooperative effort needed when several farmers are involved. Thus, the two existing dams are both situated on quite large farms. One was constructed by a private person and the other was built on a government seed farm by the Central Groundwater Board of India. The private dam was constructed in Ottapalam in 1962-64. A large-diameter well supplying water to the farm usually dried out during the dry season and there was a need to find an alternative solution. A 130 m long dike reaching down to bedrock was built across a narrow valley, surrounded by outcropping rock.

The depth to bedrock, which was established prior to excavation by steel-rod sounding, is on the average 5 m and reaches a maximum of 9 m at the center of the well. The aquifer consists of residual soils which, at least in the upper layers, are sandy. The transition between the weathered layer and the underlying fresh rock is distinct, and it was established during the excavation that the rock had no major fracture zones.

The dike consists of a 4-inch plastered brick wall (Figure 11). Water is extracted from the aquifer through a gravel drain along the dike to a series of storage wells connected to a pumping well. The catchment area of the dam is about 10 ha, and water is used mostly for complementary irrigation of 1.5 ha of paddy and, at the end of the dry season, 1 ha of coconut trees.

The dam built by the Central Groundwater Board was completed in 1979. In addition to supplying water for supplementary irrigation at the seed farm, it was also meant to serve as a pilot project for future dam construction. As a consequence, a scientific approach was used in the hydrogeological investigations and construction.

This dam was also constructed across a narrow valley and has a catchment area of about 20 ha. The bedrock consists of gneiss and granite which outcrops on the valley sides. The soils are sandy in the central parts of the valley and more fine-grained along the sides. The average specific yield, determined from tension-plate and neutron-probe measurements, is 7.5%. Other investigations carried out at the site were hammer sounding and resistivity measurements to establish the depth to bedrock, which at the deepest section is 4 m.

Fig. 11. Brick wall and storage wells in the background, Ottapalam, India.

The total length of the dam is about 150 m, and the crest was kept one meter below ground level in order to avoid waterlogging in the upstream area. The main part of the dam is made up by a plastered brick wall but there are also sections consisting of tarred felt and plastic sheets. Two wells, connected to each other by drill holes through an unexpected rock bar, were constructed along the dike.

The dam took three months to complete at a total cost of U.S. $7,500, including pumping equipment. One-third of this cost was for earthwork and the rest for equipment and construction materials. The storage volume of the reservoir was estimated at 15,000 m^3, which would be sufficient for supplementary irrigation of the second paddy crop and the raising of a third crop of black gram in a command area of 6 ha. The benefit/cost ratio at 8% interest rate was calculated to be 1.06.

Ethiopia

The concept of ground-water dams has been introduced recently into Ethiopia. The first proposals for ground-water dams in Ethiopia were presented in a master plan for rural-water development in Hararghe Region (VIAK, 1977), which have formed the basis for Swedish assistance to the Ethiopian Government in the water sector.

The first two ground-water dams in Ethiopia were constructed by the Ethiopian Water Works Construction Authority (EWWCA) in 1981. These two dams, located at Bombas and Gursum (Fugnambira), are described below. The positive experience gained from these pilot schemes has initiated a Research and Development Project with the aim of further developing the methodology and encouraging local application of ground-water dams in Ethiopia. The project is being carried out by EWWCA, with financial support from the Swedish International Development Authority (SIDA). The project is described in a Plan of Operation (VIAK, 1982).

Bombas

A sand storage dam was constructed in 1981 at Bombas, a village of about 500 inhabitants, on the road between Harar and Jijiga in Hararghe Region. The dam and reservoir can be seen in Figure 12. Excavation was carried down to the bedrock at 3 m depth. The bedrock is composed of crystalline basement rocks. The excavation work was interrupted by unexpected rains which once filled the trenches with sand. The dam is made of solid concrete blocks and raised 0.8 m above the original sand surface. Downstream of the wall, there is an erosion protection consisting of large boulders which can be seen in Figure 12. On the photograph, the original masonry protection is shown, partly collapsed. Water is piped by gravity to a steel tank 300 m downstream of the dam, where the villagers collect water from a stand post.

The dam is full several months after the end of the rainy seasons with a small discharge overtopping the dam wall. This indicates that the sand

Fig. 12. Sand storage dam at Bombas.

Fig. 13. Subsurface dam at Gursum.

dam is recharged by ground water. When the dam is full of water, there is a danger of pollution from animals entering the reservoir area. The dam has functioned well and without any breakdown since it was inaugurated. The cost of the project was U.S. $15,000.

Gursum

A subsurface dam was constructed at Gursum (Fugnambira), a town of 5,000 inhabitants, in 1981. The dam is shown in Figure 13. The structure is quite unique and is an example of a subsurface dam constructed in materials other than sand. The parent materials at the dam site are silt and clay, with only low permeability. To overcome this, a large excavation was made. A dam wall was made of stone masonry plastered with cement. Because of the low permeability of the parent materials, a reservoir of 200 m^3 was created and covered with concrete semicircular rings resting on pillars of concrete blocks.

The flow of ground water in the soil is blocked by the dam. Additional water is piped by gravity from a spring area upstream of the dam, using perforated PVC pipes laid in a trench with a graded filter. Water is pumped from a well in the reservoir to an elevated reservoir for distribution to communal water points in the town. The water supply has functioned well. The cost of the project was U.S. $150,000.

Research and Development Activities

The SIDA-sponsored research and development project which is now being implemented involves experimenting with various local construction materials in the dam walls and various means of extracting ground water.

The first dam was constructed at Gende Balina near Dire Dawa in 1983 but has not yet come into operation. The dam is shown in Figures

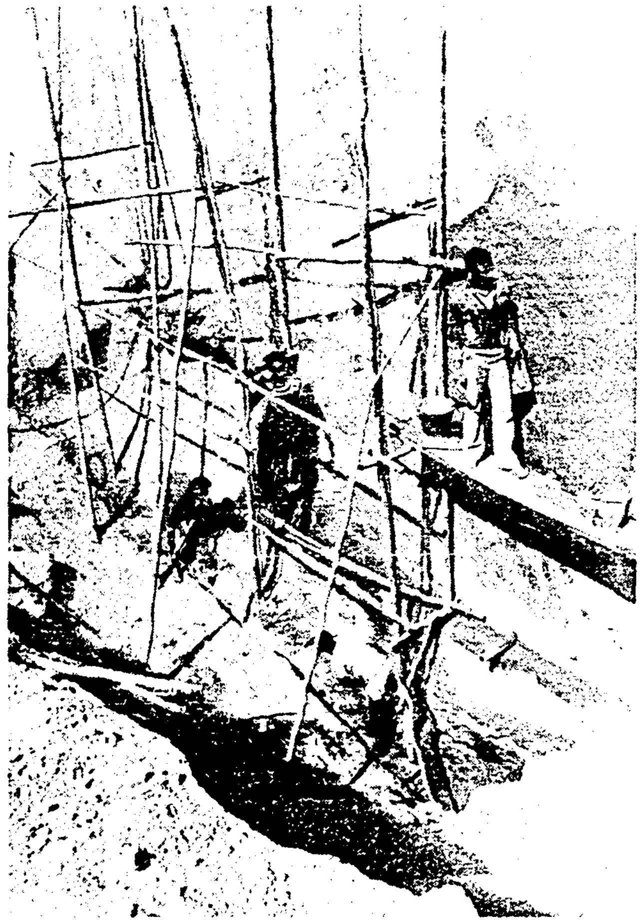

Fig. 14. Construction of a sand storage dam at Gende Balina.

14 and 15. The dam wall is made of stone masonry and should be raised in two stages. The first stage was raised 1 m above the original sand structure. This stage was completed in August 1983, and the reservoir filled with sand and water during a flood in September 1983. However, the decrease of the water level was very quick, and in December 1983 the reservoir was empty. It has not yet been possible to locate the leakage, whether under the dam or in

Fig. 15. Gende Balina sand storage dam near completion of Stage 1.

the reservoir. The foundation has now been improved by grouting. However, it could be possible that the leak is in the reservoir area, and the water is draining into faults and fractures in the bedrock. Should this be the case, ground water could probably be extracted through wells drilled into the basement rock. The dam would in this case provide artificial recharge of the ground water.

Seven additional ground-water dams will be constructed during the next few years by SIDA and the Swedish Red Cross. A subsurface dam is under construction at Eja Anani with a dam wall of solid blocks and ferroconcrete. The reinforcement is made of wire mesh. There are also plans to construct subsurface dams using clay in the dam wall.

CONCLUSIONS

Experience from the schemes discussed here, as well as from other parts of the world show that the construction of ground-water dams is a feasible solution for improving the supply of ground water in dry areas. It should not, however, be looked upon as a universal method but as an alternative in situations where water supply through conventional methods cannot be arranged or for some reason is not suitable.

The proper siting of ground-water dams necessitates a thorough knowledge of the hydrogeological conditions in the actual area. When a tentative site has been selected, it is mandatory to understand the ground-water flow system so that the dam can be correctly designed or, should the site be unsuitable, unnecessary construction costs can be avoided. For these reasons it is necessary to make general surveys as well as detailed studies on the selected sites. Due to socioeconomic conditions, however, these investigations have to be carried out at low cost. It is necessary to make generalizations and use simple geophysical methods.

Careful planning is also needed for the construction phase. This has to be scheduled according to the seasons in order to keep costs down and to avoid damage caused by heavy storm flows.

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