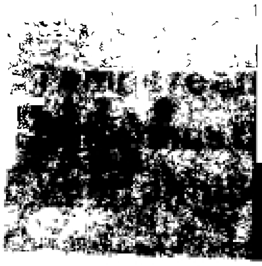

DEVELOPMENT OF SHALLOW WELLS IN RURAL WATER SUPPLY IN TANZANIA

by

MTUNZI, MARCUS B.E.

A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Civil Engineering of the Tampere University of Technology, Finland.

March, 1984
Dar es Salaam, Tanzania

Dedicated to my late Son

THOMAS MUHABUKI

whom I never saw.

May God rest his soul

in peace.

AMEN

DEVELOPMENT OF SHALLOW WELLS IN RURAL WATER SUPPLY IN TANZANIA

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ABSTRACT

In an aid programme often the context and requirement of the recipient country is not fully understood or sometimes ignored. The aid programmes are often governed not by considerations of demand but those of supply in as much as the donors offer such technological aid as is available with them or has proved appropriate in their own context. However, Tanzania has been quite lucky in getting technical assistance from the Netherlands, Finland and other agencies so as to advance the water supply programme using the technology which is quite appropriate to the country, especially at this time of ever expensive fossil fuel energy.

The development of shallow wells in Tanzania started in Shinyanga Region by Dutch DHV Consulting Engineers in 1974. Following the success of the Shinyanga Shallow Well Programme, the Rural Water Supply Construction Project in Mtwara and Lindi Regions was launched this time by Finnwater Consulting Engineers of Finland in 1978. It is after these two programmes that construction of shallow wells has spread nearly throughout the country; mainly to Morogoro, Mwanza and Tabora Regions to mention but a few.

The primary aim of this study is to give technical information requirements with regard to the construction of shallow wells; with special emphasis to the Tanzanian conditions.

It covers the geological and hydrogeological formations of the Republic including aerial distribution of ground water quality. Good attention has been paid to the use of less or non-sophisticated methods for exploration of shallow ground water and siting of shallow wells.

The study gives the procedure for both dug-well and tube-well construction, pumping equipment and their installation, disinfection of wells and protective measures against pollution. Furthermore, the tapping of spring water and preservation of springs.

Shallow groundwater resources in four selected regions of Mtwara, Lindi, Mwanza and Morogoro are reviewed. The shallow wells construction systems in these regions are also discussed including cost comparisons and finally recommendations for improvement of shallow well programmes in the country are given.

1. INTRODUCTION

Since time immemorial out ancestors were collecting water from various sources such as perennial rivers, lakes, ponds, dug wells etc. The dug wells as they are very well known by most of us were made manually in very soft formations like the sandy river beds. Sometimes crude tools were used to make wells in open plains - "Mbugas" - where it was thought the phreatic surface was not very deep. In some cases where the water table was as deep as 8 - 10 metres the people could still skillfully dig the water holes so as to be able to get out the water for themselves and their livestock. Such carefully dug wells have been found in different places in Tanzania e.g. in Misenyi in Kagera Region, Nachingwea plainlets in Lindi Region and Kitwai plains in Tanga Region to mention but a few.

The question, however, that has remained persistant with those concerned with the provision of water to people has been on how to improve the dug wells (some of which are still in use) as to obtain good water both qualitatively and quantitatively, ensure safety of the wells and above all make it fairly easy to abstract the water from the wells. Incidentally not only the wells do need to be improved but also other sources like springs, brooks etc.

Way back to 1971, the Tanzania embarked on an ambitious programme to provide potable wholesome water for everyone by 1991. This 20 years water development objective as spelled by the government, was supported by the United Nations Habitat Conference held in Vancouver in 1975 and furthermore, the Mar del Plata Water Conference held in Argentina in 1977 resolved more or less on the same lines as the Tanzanian Policy.

Whereas the original target was to provide a source of clean wholesome and dependable water within a reasonable distance of each village by 1981, and to provide a piped water supply to the rural areas by 1991, so that all people would have easy of access of less than 400 metres distance to a public water point, the sheer magnitude of this task in combination with financial limitation forced the government to re-assess the programme and focus attention on attaining the 1991 goal. This resulted in shifting the emphasis from piped supplies to shallow wells with hand pumps starting with a few selected regions.

The difficult situation of implementing the programme can be easily explained by table 1-1 which shows the percentage of the rural population that is supplied with water from improved sources by January, 1980. It clearly indicates that nearly 63 % of the rural population still have to rely on the traditional water sources, while improved sources are mainly surface water supplies. DHV Consulting Engineers believe that this picture will have changed drastically in the future as is indicated in table 1-2.

In order to achieve what is indicated in table 1-2, the exploitation of ground water offers the most appropriate solution. This is because surface water contains heavy sediment loads and is usually bacteriologically unsafe. Before surface water can be used for human consumption water treatment facilities have to be constructed hence, high investment, high operational and maintenance costs, and a high demand of skilled manpower.

Table 1-1. Number of rural population and water supply situation, per region. /11/

Region	Rural population (1978 - census)	Rural population served with water: Number	%
1. Arusha	934,397	345,919	37
2. Coast	516,849	191,684	37
3. Dar-es-Salaam	94,176	66,000	70
4. Dodoma	813,344	504,267	62
5. Iringa	865,619	242,500	28
6. Kigoma	590,162	141,530	24
7. Kilimanjaro	832,930	453,510	54
8. Lindi	500,594	204,048	41
9. Mara	679,315	135,863	20
10. Mbeya	790,230	361,889	46
11. Morogoro	939,190	292,000	31
12. Mtwara	723,216	256,730	35
13. Mwanza	1,435,418	433,608	30
14. Rukwa	394,095	120,785	31
15. Ruvuma	514,810	170,732	33
16. Shinyanga	1,254,736	900,900	71
17. Singida	558,138	288,445	52
18. Tabora	750,657	92,982	13
19. Tanga	892,043	247,650	31
20. West Lake	932,357	113,445	12
Total	15,012,276	5,591,487	37

Table 1-2. Technology mix on a national level at present and in the future (1991). /11/

Mode of supply	Percentage of population served: at present	in 1991	Average investment costs per capita (TShs) 1977	1983
1. Surface water supply, gravity	10%	15%	230	920
2. Surface water supply, pumped	14%	23%	250	1000
3. Boreholes	8%	12%	300	1200
4. Shallow wells	3%	50%	80	320
5. Unimproved water sources	65%	0%	- PM	-
	100%	100%		-

2. SOME BASIC FACTS ABOUT TANZANIA

2.1 Land

Tanzania with a population of about 20 000 000 people (1982 estimates) covers an area of roughly 940 000 km^2 and lies between the latitudes 1° and 11° - 30' south and the longitudes 30° and 40° east. The country is bounded by Kenya and Uganda in the north and northwest, while Mozambique is to the southern side, Zaire, Burundi, Rwanda and Zambia to the west and southwest respectively. The sea border on the East Coast is 800 km long facing the Indian Ocean. Lakes Victoria, Tanganyika, Nyasa, Rukwa, Manyara, Natron and Eyasi do occupy about 54 000 km^2 of the total surface area of the country.

2.2 Topography

The topography relief of the country is very extreme and of very unique reature. Mt. Kilimanjaro rises to 5 963 m above mean sea level, Mt. Meru to 4 566 m and through like depressions covered by lakes are found in the western margin.

However there are vast plains and plateaux in the interior of the country with Tabora at its centre and another plateau is known as the Maasai-steppe. Behind the coastal plains, varying in width from 15 km to 70 km the country rises gradually to these plateaux. The great central plateau is gently undulating and monotonous at an altitude of about 900 to 1 500 metres above sea level though sharply defined along greater part of its eastern and western margins by a series of step sided and deeply eroded escarpments. Isolated hills and minor mountains ranges such as Usambara, Uluguru, Rubeho, Udzungwa, Nguu and some imposing massifs including the volcanic highlands of the north and northeastern areas and those of South Mbeya do exist in high scattered parts of the country. Broadly speaking, the characteristic topography is that of flat and as earlier said, gently undulating plains and plateaux /21/.

2.3 Lakes

The Lake Victoria occupies a shallow basin in North-West Tanzania between Western Gregory Rifts (67 598 km^2 in area, 90 m deep and second largest lake in the world). Lakes Tanganyika and Nyasa cover the Western Rift which is divided into northern and southern basins, the Lake Tanganyika being the second deepest in the world. Lake Rukwa fills a small depression, diminishing in size, because of evaporation. Besides these, there are other dischargeless lakes in the Gregory Rift such as Manyara, Natron, Eyasi and others, decreasing on account of evaporation and with increasing concentration of salts.

2.4 Drainage

In the orthwest, the Kagera, Mara and Simiyu rivers flow into Lake Victoria forming the Nile drainage into the Mediterranean Sea. The Malagarasi debouches into the Lake Tanganyika, ultimately going to the Atlantic Ocean. The rest of the country either drains into inland basins and lakes such as Rukwa, Eyasi, Natron, Nyasa etc. or into the Indian Ocean. Among the latter notably are the Pangani, Wami, Ruvu, Rufiji and Ruvuma rivers. All except Pangani, have a wide seasonal swampy flood plains and empty into extensive deltas.

2.5 Climate

The climate is of equatorial type, although there are considerable modifications caused by varied topography and latitudinal position for instance, warm and humid climate on the coast and temperate climate in the mountainous areas. Over the country the temperatures are high or moderately high (25°C to 30°C). During the winter season, which lasts from June to September, the temperature goes slightly below 20°C. But the seasons are not very distinctly marked for the obvious reason, that the country is situated immediately south of the Equator /6/.

2.6 Rainfall

The average rainfall is fairly low in most parts of Tanzania. Areas with high precipitations (between 1 000 and 2 600 mm) are the coast (except in the south), the mountainous areas and the west of Lake Victoria. In most of the country, rainfall is seasonal with one or two peaks (Dec-May or Nov-Dec and March-May). In many areas the dry season is almost rainless. The interior plateaux are driest and large areas get less than 500 mm a year. Figure 2-1 shows the average annual rainfall in the country.

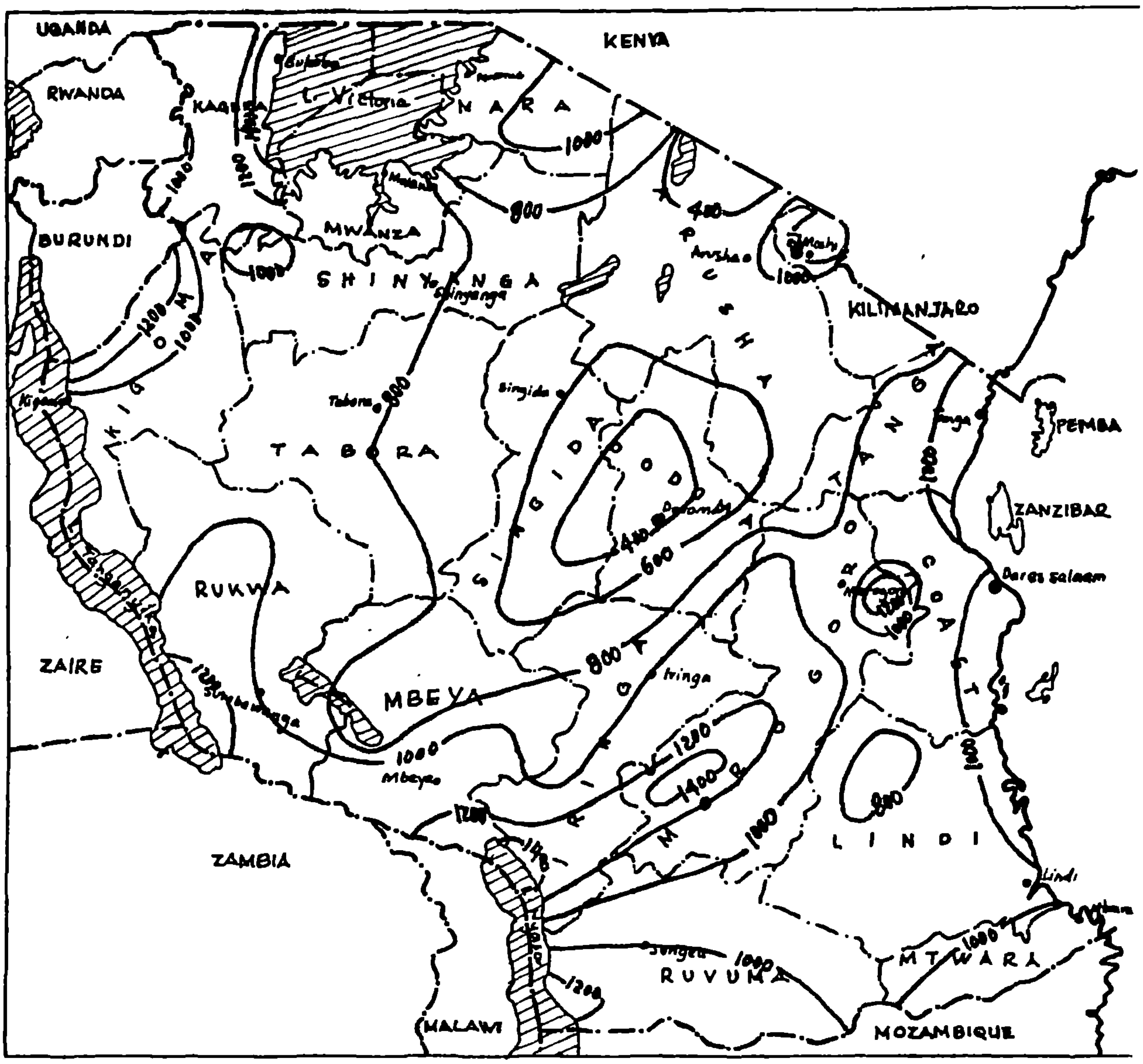


Figure 2-1. Average annual rainfall in Tanzania.

2.7 Water Resources

Large parts of Tanzania have scarce water resources. This is especially the case in the large interior basins, where surface water is only seasonal in many areas and ground water is difficult to obtain. Sometimes the ground water is saltish and may be regarded as sedimentary. The low and seasonal precipitation in combination with high evaporation (and evapotranspiration) gives a small add to the ground water. Where precipitation is relatively high, the water problems are usually less. Even in these areas it can, however, be difficult to find ground water.

3. GEOLOGY AND HYDROGEOLOGY OF TANZANIA

3.1 Geology

The geology of the country is comprised of:

- nearly 45 % of the country is of the oldest formation, the Archean
- 25 % the granitoid shield
- about 6 % the Nyanzian; Kavirondian and Muve Ankolean
- about 6 % Bukoban
- about 8 % Karroo
- 7 % Post Karroo sediments and
- 3 % Rift Valley Volcanics.

Much of the country is overlain by deposits residual in origin, laterite and superficial terrestrial sandstones and chartified deposits and lacustrine muds and sands of small dischargeless basins. Exposures on the whole are numerous, though best exposed on the main scarps, stream courses and drainage valleys.

Table 3-1. The geological succession of Tanzania has been classified as below /21/:

Age	System & Formations	Rock type	Intrusions	Locality
Recent to Late Tertiary	Neogene Deposits	Mbuga clays, limestone, sandstone, Kankar, salt	Associated with decomposed granitic rock.	
	Tertiary	Limestone, clays, sandstone (Marine)		
	Rift Valley Volcanics	Basic, Ultrabasics. Acid and Alkaline mostly the Phyolites, Trachytes, Phonolites, Kenytes, Basalts etc.	Tertiary dykes	Rungwe Rukwa Kilimanjaro Hanang
Cretaceous	Cretaceous	Unconformity Limestone clays and sandstone	Late cretaceous Kimberlites	
Jurassics	Jurassics	Sandstone, Limestone, clays		Coastal areas overlain by Neogene deposits
Lower Jurassic to Upper Carboniferous	Karroo	Terrestrial sediments sandstones, Conglomerates Shales, Coal Oil fields with thin marine intercallations.	Dolerites	Tanga Ruvuma Songea and South Morogoro
Pre-Cambrians	Bukoban	Unconformity thick bedded sandstone and shale, siliceous limestone and shale and sandstone.	Gabbro, Norite serpentine suite	W. Lake Kigoma
	Karagwe	Major Unconformity Phyllites, Quartzites with intrusive granites sediments regionally metarphosed.	Granite	E. and W. Tanzania respectively
	Usagaran and Ubendian	Gneiss, Schist, Granulites, Quartz, Limestone Graphitic rock (Sedimentary and Volcanic origin)	Granite	E. and W. Tanzania respectively
	Kavirondian	Conglomerates, Volcanics Quartz and Grits	Granite	Musoma Nzega
	Nyanzian	Volcanics. Quartz Bonded Ironstones. Low grade Metamorphic rocks with permeations		N.W. Tanzania
	Dodoman	Coarsely Crystalline metamorphic rocks of sedimentary and Volcanic origin	Granite and Ultrabasic	West and Central Tanzania

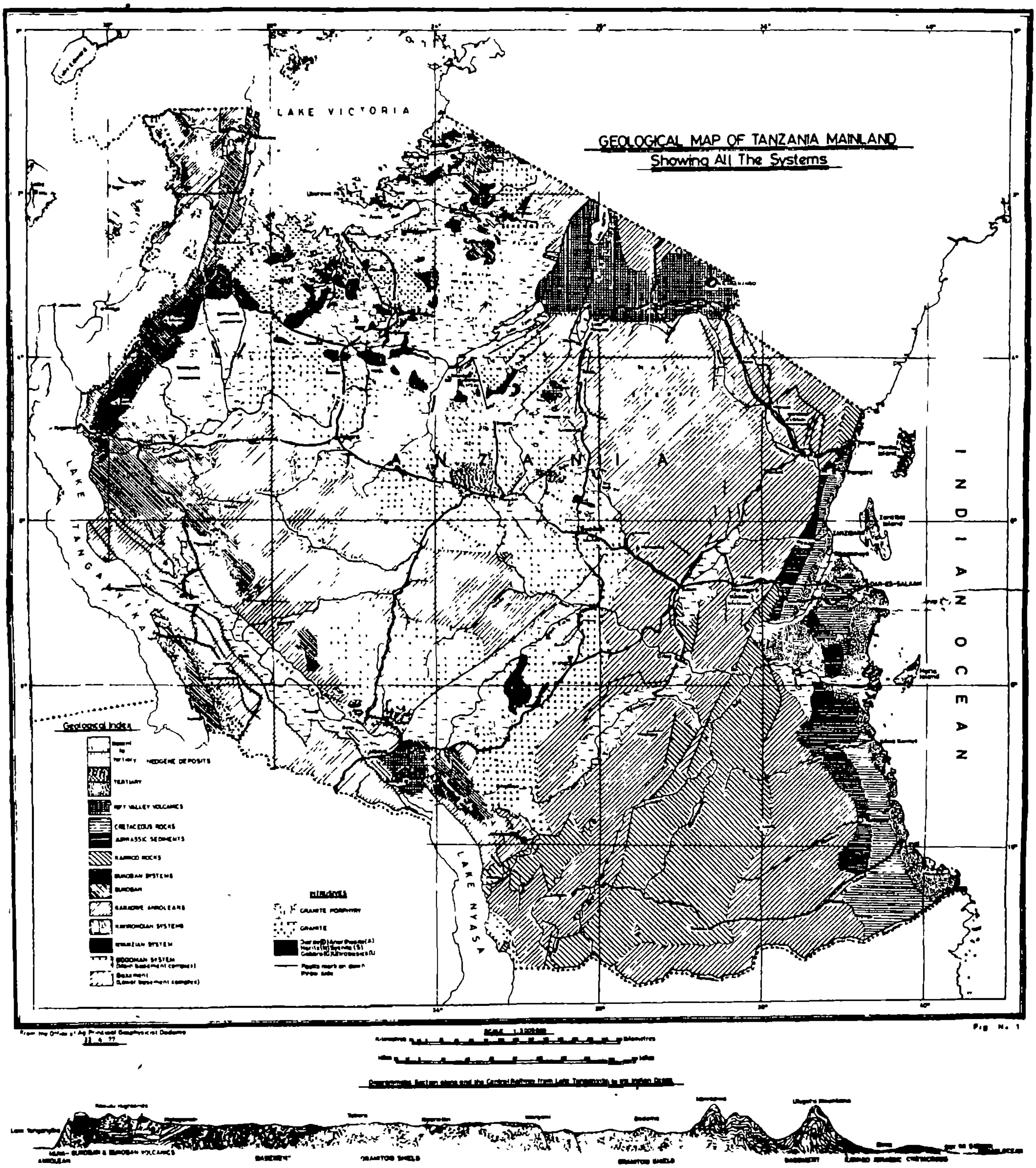


Figure 3-1. Geological map of Tanzania./21/

3.2 Structure

The older pre-cambrian rock formations belong to the main orogenic belts, which have been originally laid down as geosyncline, shelf, epicontinental or continental deposits. Of these structural units, the Dodoman is the oldest, with a regional east-south-east trend. On the west are the Nyanzian, Kavirondian belts, their present altitudes being a result of intrusion of granite batholitis. In the east is the Mozambique belt, subject to multiple orogenesis. There is a cover of Neogene volcanics, in the north and marine sediments in the east. The Karagwe Ankolean rocks have been folded into geosyncline with granite intrusion. The Bukobans are mainly terrestrial deposited in shallow basins resulting from the erosion of the Pre-Bukobans surface. There were much oscillations erosion and sedimentation with contemporaneous block faulting and folding in past Karroo times.

3.3 Hydrogeology

For more than fourty years now, more than 3 000 boreholes have been drilled in many parts of the country. From the geological systems penetrated, some facts can be said on the hydrogeological formations.

3.3.1 Neogene Deposits

These deposits are classified into marine lacustrine, riverine and terrestrial deposits, depending on the mode of origin of the material. Of these the marine deposits fringe the eastern seaboard, while the lacustrine formations are confined to Wembere plains, Bahi basin and the shores of Lakes. Riverine formations are seen along the valleys of rivers and streams. The terrestrial deposits consisting of silcrete, claycrete, conglomerates, cemented gravies etc. cover large areas of the Central Plateau, overlying the Pre-Cambrian formations. The marine lacustrine and riverine deposits comprise generally sands, silts, clays, unconsolidated sandstone. The marine sediments run parallel to the coast outline, ranging in width of less than 10 km, very often exposing old buried river channels and marging with the deltaic deposits of the present day.

3.3.2 Tertiary Formation

The recent deposits mentioned above are often not distinguished from these formations. The older marine deposits and the terrestrial formations are found in Manyoni District of Singida Region and are known as the Kilimatinde Cements; in these formations water is available in the order of 1.7 l/s in the top 60 m, under confined conditions, though some of the craters may be from fractures and joints of the underlying granite and gneisses.

3.3.3 Rift Valley Volcanics

These spread over the northern parts and southwest consisting of alkaline volcanics, basalts with a good deal of pumice ash, vesicular material and pyroclastics. The depth of sealthering is generally large and also intense jointing in the volcanic rocks. Hence, large quantum of water is available in boreholes located on the southern slopes of Meru and Kilimanjaro mountains and very often under sub-artesian conditions. In Arusha area a number of springs at the contact of the different flows and rock type issue out of favourable locations on slopes /21/.

3.3.4 Cretaceous Rocks

These are largely found in the Rukwa depression and Makonde Escarpment as sandstone with low to moderate porosity with subordinate shale and limestone. In the Makonde area, springs with yields of 10 l/s issue out of the escarpment slopes, at the contact zone with the basement metamorphic notable of which are the Mkunya, Newala and Mahuta springs. The case is somewhat similar in Rondo Plateau of Lindi Region with maximum spring yields of the order of 22 l/s shallow wells have shown a yield of 1,1 l/s in the Makonde sandstone, along some favourable valleys, with accumulation of valley fills /6/.

3.3.5 Jurassic Sediments

These are mainly sandstone and siltstones of low to medium porosity in permeable shales and limestone forming bigger parts of Morogoro and Tanga areas. Low to medium yields (1 to 5 l/s) are common in the formations under confined conditions, encountered in the fractures and joints. Because of rapid movements and vertical flow, the cavernous limestones are dry as a rule, and very low yields are reported in the shale sequences as at near Kidugalo in Morogoro /10/.

3.3.6 Karroo Rocks

Again these are typical in Morogoro and Tanga areas, they comprise of sandstone and siltstone of low porosity with shales and claystone. The shale and claystone have higher porosities and indicate better yields, possibly due to the migration of water from underlying sandstones towards the upper confining layer. Because of the gentle seaward dip of these formations and faulted contact with the granites exposed in the hill ranges towards the west of them, very high yields (15 to 20 l/s) with artesian conditions in the eastern margin of Genda Hill and Moa areas in Tanga have been observed. However, this has been caused by favourable topography, gentle dips, vicinity of the fault and high rainfall in the area /6/.

3.3.7 Bukoban System

These comprises mainly sandstones, shales, quartzites, limestones basic volcanics etc. extend as large linear strips in Western Tanzania. Intense folding and faulting with resulting antiforms and synforms, combine with alteration of impermeable shale beds with pervious bands of jointed sandstone have caused development of springs on hill slopes of the western part of Lake Victoria with water yields of 3 l/s. In Malagarasi basin, these rocks are flat bedded and gently folded with yields up to 4 l/s largely due to the recharge of the beds from the stream /21/.

3.3.8 Karagwe/Ankoleans

Phyllites, schists, quartzites with intrusive granite typify these in Northwest Tanzania, bordering Rwanda and Uganda. Regional folding have resulted in the formation of antiforms and synforms with faulting. Since impermeable and permeable beds alternate here also, the hydrogeological conditions are similar to the Bukoban, with a number of springs in the valley slopes /6/.

3.3.9 Usagaran, Ubedian System

Crystalline limestones occupy part of the Eastern and Western Tanzania ranging from schist to gneiss and consisting of metamorphic rocks.

Not much detailed information is available about boreholes in these formations, since they are far too much scattered, with yields ranging to 2 l/s. But a number of boreholes with depth of 90 m have yielded water in the Masasi area with static water level at 3 - 10 m below ground level and a supply of 0.5 to 3 l/s /10/.

3.3.10 Kavirondian and Nyanzian System

These do occur along the western and southern borders of Lake Victoria and do consist of conglomerates, grits, volcanics, bonded ironstones and low grade metamorphic rocks. In the Nyanzian rock, the rocks have very low yields not exceeding 1.3 l/s /6/.

3.3.11 Dodoman System

Schists, gneiss, quartzites, amphibolete homblende gneiss, acid gneiss, granite and migmatites with granodiorite are rock types in these, covering extensive area of Central Tanzania. Quite a good number of wells drilled in these areas have yielded water to the extent of 0.9 to 1.1 l/s from fractured zones of depth up to 28 to 35 m /21/.

4. GROUND WATER RESOURCES

In terms of water resources, the country is divided into two distinct regions on either side of an imaginary line running from Mbeya (North of Lake Nyasa) to Tanga (a post on the Indian Ocean near the Kenyan border). To the South East of that line, i.e. over one third of the country, surface water is plentiful and can be used in large hydroelectric and agricultural schemes. To the north east, on the other hand two thirds of the country (the central regions of Dodoma and Singida, West and part of North, particularly the Masai Steppe) the bioclimatic conditions are of the semi-arid type, with the exception of Kigoma and Kagera Regions where there are plenty of perennial rivers and streams /27/.

4.1 Origin and Occurrence of Ground Water

The occurrence and distribution of underground water cannot be readily understood unless the fundamental processes by which water reaches the soils, rocks and other deposits in which it is generally found are briefly explained.

Ground water may be classified as being of either internal or external origin /28/. Internal water (juvenile water) is derived from the interior of the earth as a new resource.

External water is derived from atmospheric or surface water and may be trapped in rocks at the time the constituent material was deposited (connate water), or it may be absorbed into interstices some time after deposition (absorbed water). The second type of ground water is that one based on the tentative assumption that existing ground water resource was intitially absorbed from atmosphere or surface water supplies (meteoric water) and that their resource is currently being wholly from these sources. All other terrestrial and extra terrestrial resources of water can be safely ignored /28/.

4.1.1 Hydrological Cycle

The general process of water circulation, including ground water renewal or recharge is often referred to as the hydrological cycle. This cycle is divided into a number of stages, one of which is the ground water stage.

The hydrological cycle (fig. 4-1) encompasses the whole process of water circulation from the evaporation of water in the form or snow, rain, hail or mist may be precipitated, until its return to the sea by both overland and underground through devious paths - some short and some long, in terms of both time and space.

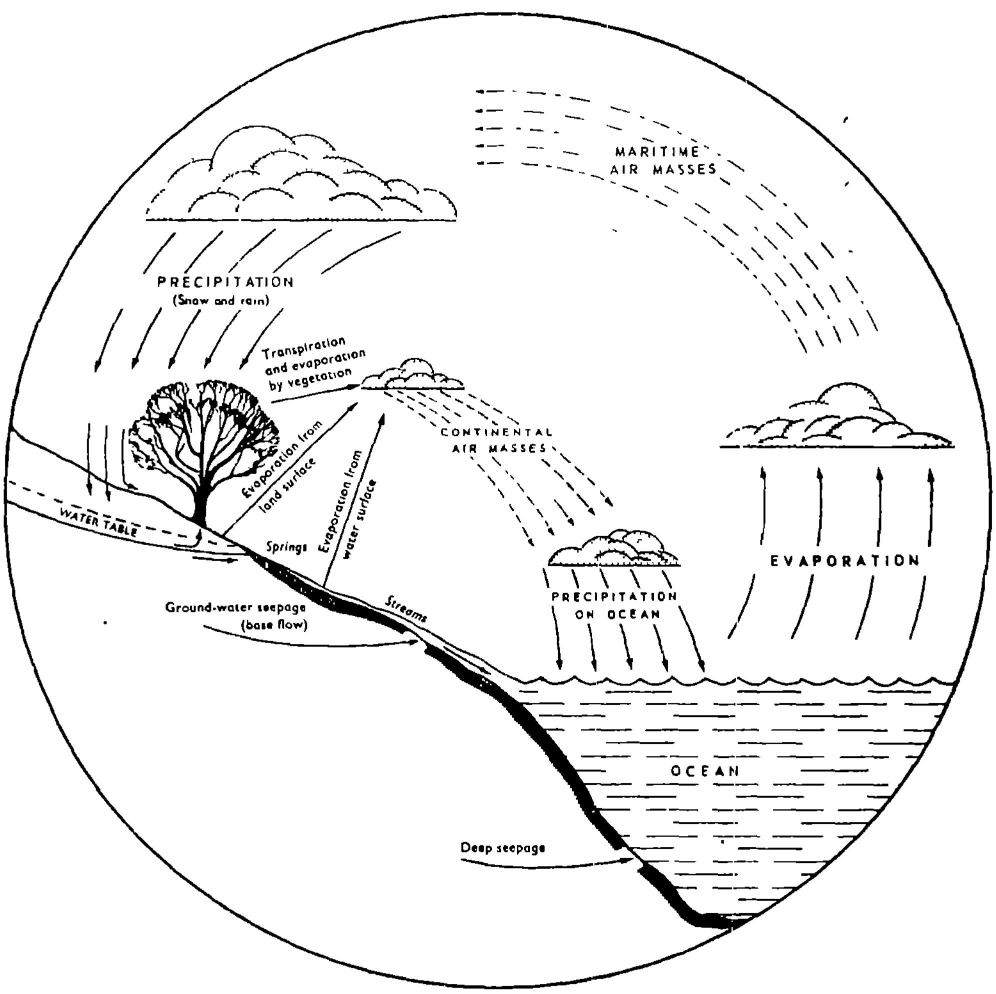


Figure 4-1. Schematic representation of the hydrological cycle./6/

The ground water phase is only the integral part of this large cycle and can be regarded as starting at the state when precipitation reaches vegetation on the ground and continues until the water again issues on the ground surface or finally reaches the sea. The ground water phase is of main importance for this particular case study. In this phase the water which has entered the ground have been stored in the subsurface storages, technically known as aquifers. It is from these aquifers one gets water by drilling a deep or shallow well, depending upon the depth of their location.

The process of renewal or recharge which takes place during the water cycle can be expressed by the simple equation:

precipitation = runoff + evapotranspiration + recharge.

Evapotranspiration and recharge both depend on percolation of precipitation into the ground and its delivery to the ground water area. Finnwater Consulting Engineers have studied this behaviour in Mtwara-Lindi Water Master Plan as shown in figure 4-2. It can be seen that the ground water table rises and vice versa /12/, in relation to the magnitude of rainfall.

4.1.2 Concept of the Ground Water Regime

The concept of the ground water regime is based on the fact that the local occurrence is the consequence of a finite combination of climatic hydrologic, geologic, topographic, ecologic and soil forming factors that together form an intergrated dynamic system /4/.

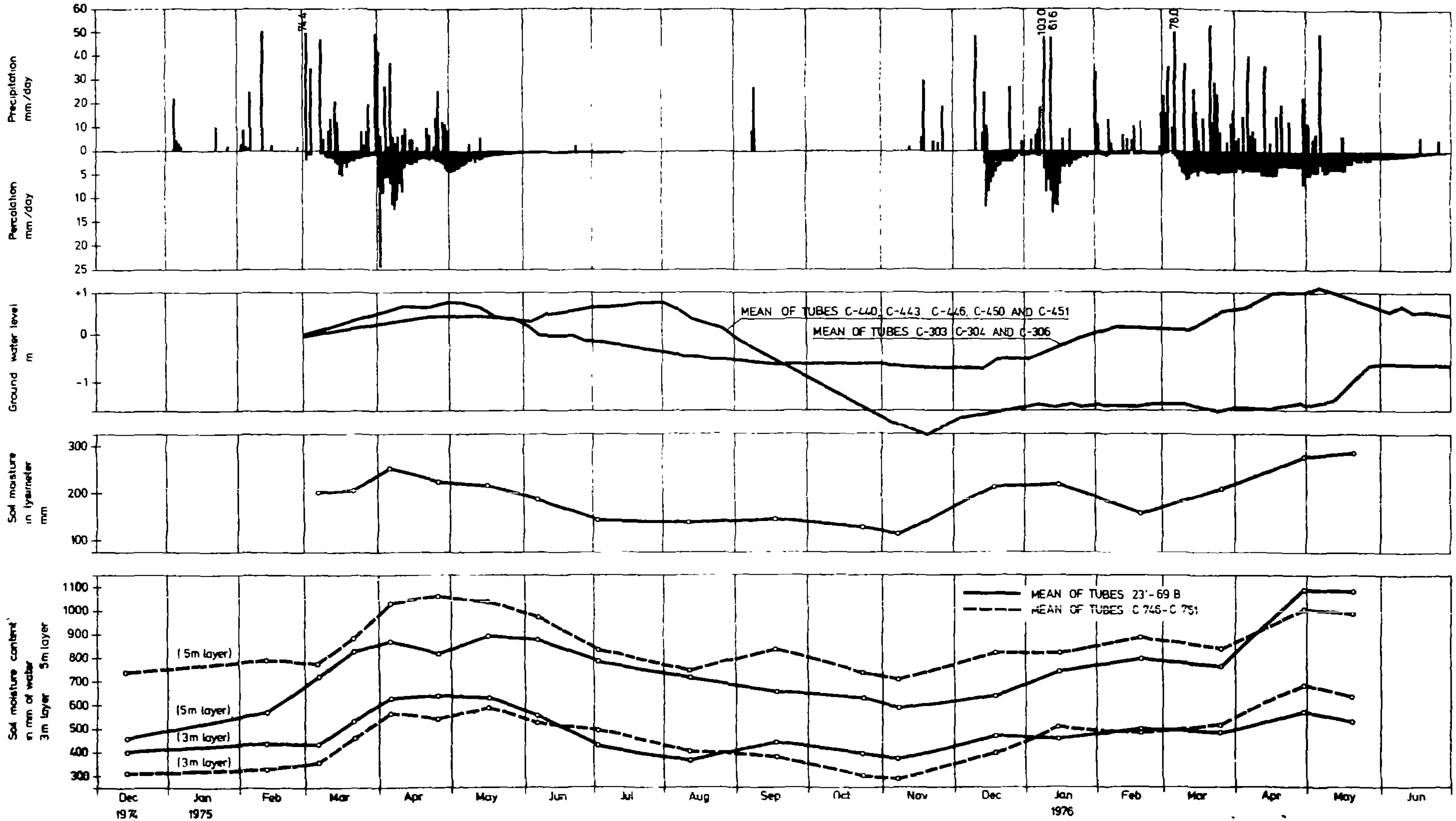


Figure 4-2. Masası Index Basin
Precipitation, percolation, ground water level and soil moisture fluctuation./12/

There are three main divisions of the process of ground water recharge by the precipitation percolating into the ground. The three main divisions are from the surface downwards (see fig. 4-3.):

- belt of soilwater
- intermediate vadose water
- zone of saturation on ground water zone.

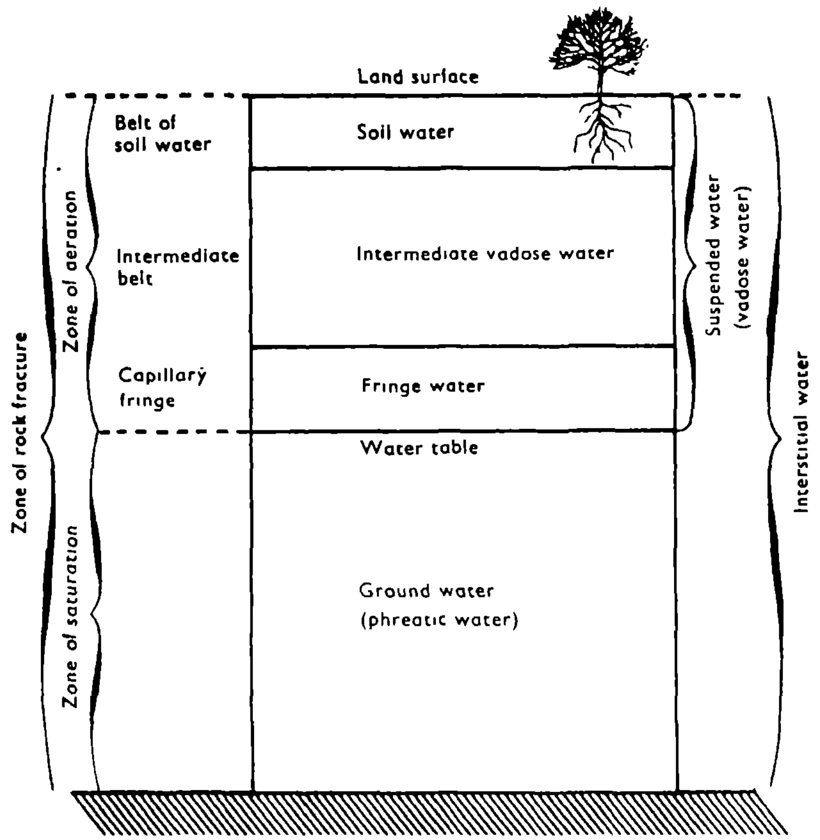


Figure 4-3. Diagram showing divisions of subsurface water /6/ (after Meinzer, 1923).

In between the last two there is also a sub-belt known as the capillary fringe. Again the combined first two and the capillary fringe are called zone of aeration. Briefly, the downward movement of water is as follows:

- within the soilwater belt infiltration and evapotranspiration occur

- water moves under the force of gravity in the intermediate belt and
- the movement of water in the capillary fringe is mainly towards the surface under the influence of capillary forces and due to surface tension which is opposed to the force of gravity
- hydrostatic pressure governs the movement of water in the saturation zone.

Generally speaking, ground water occurs in a subsurface reservoir, the boundaries of which are formed by neighbouring permeable or impermeable rocks.

In some cases this reservoir (or aquifer) may be open to the land surface and thus known as unconfined aquifers, or it may be capped in large part by impermeable or relatively impermeable rocks and thus known as confined aquifer. These ground water reservoirs may cover an extensive area or just a representation of only an elongate ribbon or strip of sand deposited in an old abandoned river channel. These aquifers may be composed of mainly unconsolidated sediments on or of bed-rock; and of varying permeability both vertically and horizontally. Figure 4-4 shows the schematic cross-section showing occurrence of ground water.

4.2 Shallow Ground Water Occurrence

During the study of various Water Master Plans in the country by various competent authorities, occurrence of shallow ground water accessible near the surface or in extreme cases to 30 m depth, have on the whole, been thoroughly explored.

A division of the main shallow ground water occurrences can probably best be made according to the geological formations in which this type of ground water is to be found. A schedule of these formations is given below and arranged in order of importance.

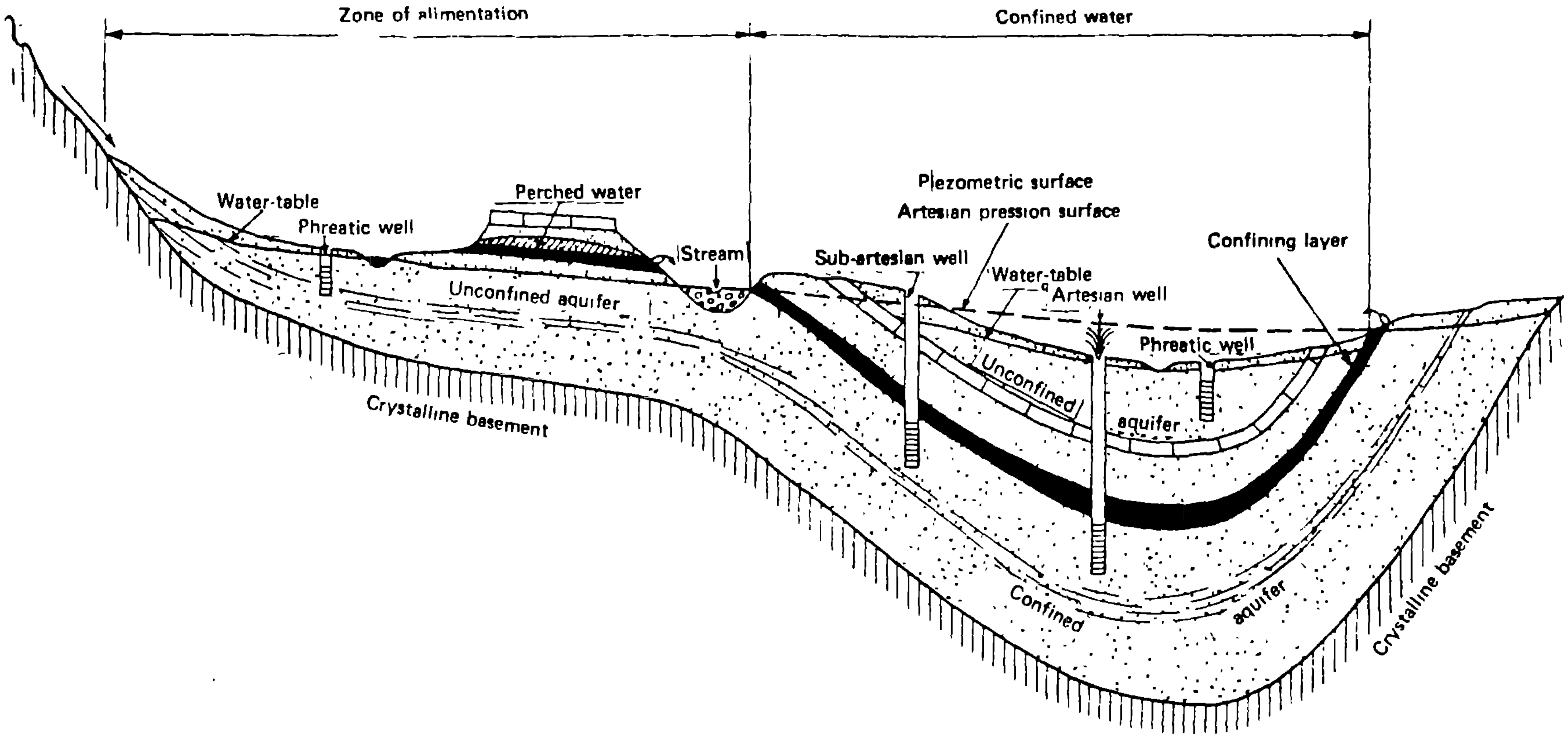


Figure 4-4. Concept of ground water occurrence./28/

4.2.1 Alluvium

These formations consist of two main types namely riverbeds of non-perennial rivers and fan deposits below mountains or scarps.

a) Riverbeds of non-perennial rivers:

It is possible that more water is extracted from this type of formation than from any other. In the arid and semi-arid parts of the country a great number of sandy and "dry" riverbeds occur where water can be found near the surface all through the dry season. At the end of the rainy season the riverbed sands are saturated with water which reaches the surface or stands only a few centimetres below it.

For a short period after the rains, water in the sand is still being replenished by effluent seepage. Later, when this seepage ceases, the upper layer of the riverbed becomes dry as the water slowly moves downstream.

Many old riverbeds are sometimes covered with 3 - 6 m thick clays and this may restrict the construction of well in these areas /6/.

b) Alluvial fans

Such deposits are of very minor importance as a source of shallow ground water. However, in mountaneous areas availability of ground water, on tops and steep slopes is generally not possible, and this is because erosion removes the weathering products which form potential aquifers.

These erosion products are usually deposited in the valleys found in hilly areas and thus at the transition from mountain slope to valley bottom coarse material are deposited while the finer materials are carried further away from the mountain slope. In such areas, best aquifers are found along the edges of the valleys. As shown in figure 4-5 drilling for water should lie executed along profiles at right angles to the mountain range /11/.

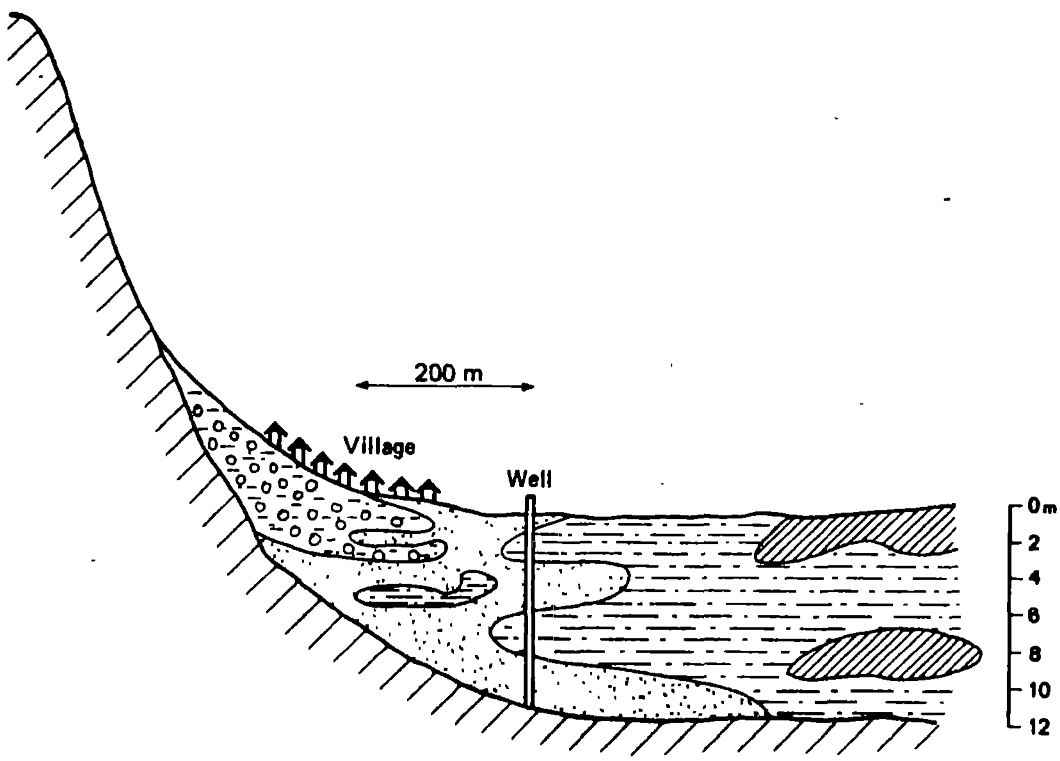


Figure 4-5. Alluvial fan. /29/

4.2.2 Limestone Formations

a) Mbuga limestones:

Though these formations are not so common with the area of study as they are in the central regions, they form a good potential for shallow ground water. Water wells dug in these formations in general consists of clays, marls, siliceous limestone, conretionary limestone and limestone rabble /2/.

Many of the mbugas are flooded during the rains and many sandy rivers or large sand traches and deposits are found on top of these mbugas and these sandy areas are good potential areas for shallow wells (see fig. 4-6).

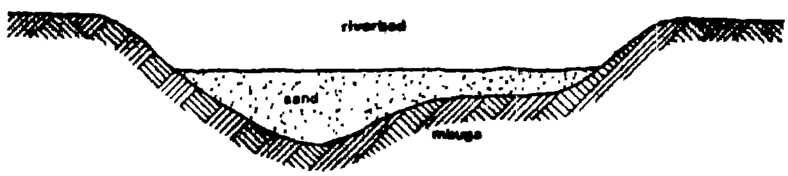


Figure 4-6. Mbuga limestone./7/

b) Coral limestone and marine limestone:

These are mainly found along the coast e.g. Mikindani and Magomeni areas in Mtwara Region. The water found in the coral limestone wells is frequently slightly saline.

4.2.3 Lateritic Hardpan

The hardpan consists of quartz, iron oxides and aluminated and many different types of soils may be encountered. The two main types are the vesicular and the more solid. In the latter visides seem to be filled with weathering material. In consequence all lateric hardpan do not carry water. The two main groups of laterites are:

a) Eluvium as used here, comprises a number of weathering products or rocks and other deposits which, lack sorting such as subsoils, rock rubber and non-lateritic bedrock cements. Many successful water wells have been dug in these formations.

b) Granites fors or kopjes. The water supply of wabiwells dug in the vicinity of bare granite fors or kopje depends entirely on the large run-off from bare granite which collects in the sandy eluvium at or near the foot of the kopje /6/.

4.2.4 Hard Rocks

a) Fissure wells. The yield from such wells, is as a rule small but in many places it is the only water available for kilometres.

b) Weathered cavities basins and pockets in hardrocks. In general only a relatively small number of wells have been sunk in these formations and have been successful, and mostly weathered zones of granitic and basement rocks do contain water /2/.

4.2.5 Beach Sands

a) Sea Shore

Along the coast of the Indian Ocean water wells are dug in beach sands at suitable places by the local people from Lindi in the South to Bagamoyo in the North. The fresh ground water often rests on the underlying sea-water and the water level changes with the tides.

b) Lake shores and old-shore line

These formations are not commonly utilized for obtaining surface water supplies, but examples can be found in the Bahi depression of Dodoma Region.

4.3 Springs

There are quite a good number of springs available scattered unevenly all over the country. The main spring areas are found in the neighbourhood of the rift valley and rift scarps and in the region interselected by major fracture and fault systems.

Springs are classified according to the nature of the force which brings about water to the surface. The two main types are /6/:

a) gravity springs
b) springs of deep-seated origin flowing as the result of agencies other than gravity.

4.3.1 Gravity Springs

These springs are commonly found in the areas of sedimentary rocks of the coastal belt, the Karagwe - Ankolean and Bukoban formations and the regions covered by volcanic rocks. These springs have in general potable and useful water.

Springs of this type are largely found in Lindi and Mtwara Regions. In these regions fairly large quantities of water issue from solution openings in limestones north of Lindi and north of the Mbwenkuru Valley, south of Lindi Bay, springs rise from sandstone formations. Other springs occur in the foot of the Makonde and Rondo plateaux and in Kilwa there are contract springs /13/.

4.3.2 Springs of Deep-Seated Origin

These springs are often with saline water or carry high amount of fluoride and in many cases, contaminate large areas of ground water with fluorine. Another problem with such springs is that the water issuing from them is often hot i.e. of a higher temperature than the surrounding ground temperature. Springs of this classification are many within certain restricted areas of the country /6/.

5. GROUND WATER RESOURCES POTENTIAL IN SELECTED REGIONS

The ground water resources can be divided into two main groups namely, deep ground water and shallow ground water. This has been adopted in nearly all the water resources inventory in the country during the preparations of various water master plans. In this paper only shallow ground water will be discussed.

5.1 Hydrogeological Formations and Ground Water Conditions in Mtwara and Lindi Regions

The areas of Mtwara and Lindi have hydrogeological zones as follows (see fig. 5-1.) /13/.

a) Mesozoic sedimentary zone (I)
b) Tertiary - Quaternary sedimentary zone (II)
c) Karroo sedimentary zone (III)
d) Basement zone (IV)

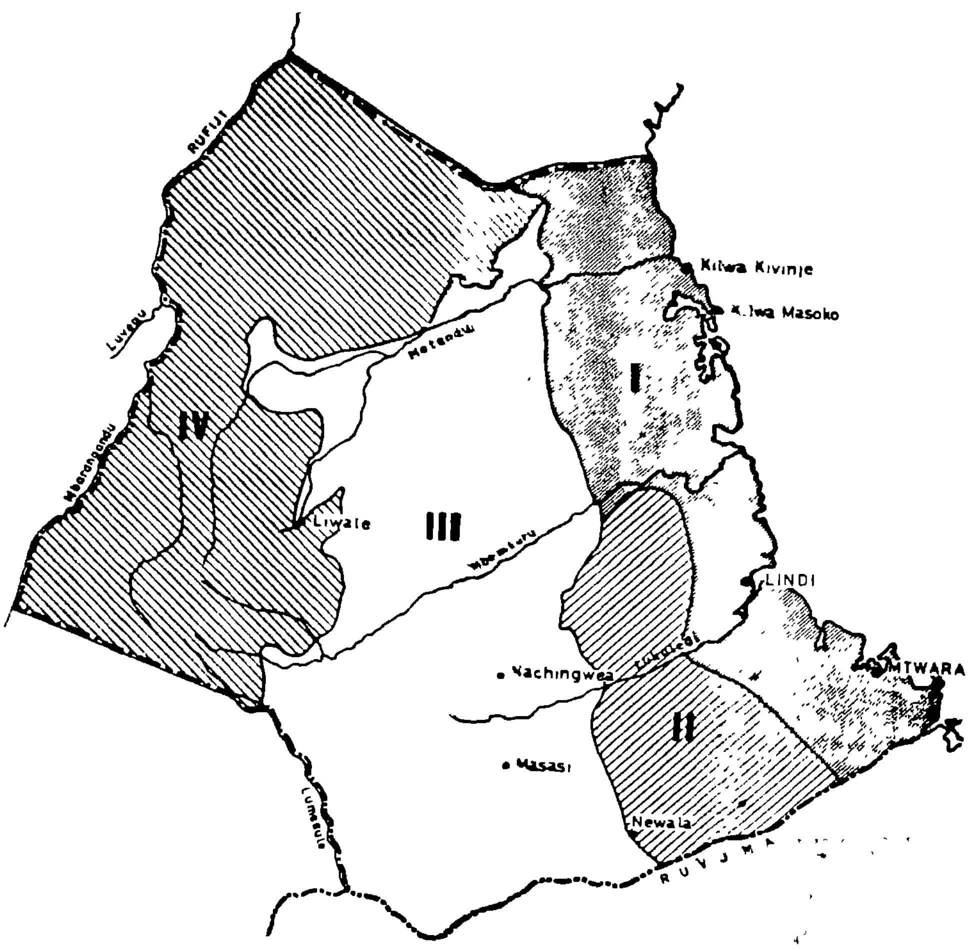


Figure 5-1. Hydrogeological zones of Mtwara-Lindi./13/

5.1.1 Zone I (Mesozoic sedimentary zone)

This zone covers all the coastal districts of Mtwara, Lindi and Kilwa including that of Newala.

The ground water level is very deep and can be found by drilling to depth of more than 200 m in the proper plateaux of Makonde in Newala and Mtwara districts, and Rondo in Lindi district. The strata are composed of sediments, the vertical permeability of which is at least in some places so good that a deep-going percolation is possible.

In the Rondo plateau it is possible that there are some areas with permanent ground water reservoirs, but the water level is generally too deep for economical extraction.

Ground water occurs in deposits close to the surface in river valleys, the brook areas at the base of the plateau as well as in some smaller valleys. Again in Mambi valley, there is deep ground water coming to the ground level as artesian water and can thus be classified as shallow ground water. Also smaller shallow ground water occurrences are found in isolated places such as Kitama valley on the southern slope of Makonde plateau. However, generally speaking the soils are quite poorly permeable to allow for shallow ground water, several alluvial river formations being of exception /13/.

5.1.2 Zone II (Tertiary-Quarternary sedimentary zone)

This zone covers again Mtwara, Lindi and Kilwa districts. The area is gently sloping towards the coast. Occurrence of ground water in this zone can be assumed to resemble that of zone I.

However, most of ground water is found in the valleys like Mtawanya and Mbuo in Mtwara district and along Lukuledi and Mbwemkuru rivers and this can be classified as shallow ground water. In addition to these valleys, ample shallow ground water is met in low-lying coastal plateaux /13/.

5.1.3 Zone III (Karroo sedimentary zone)

This zone is found only in Liwale district of Lindi Region. Little has been studied about this zone, however observations done indicate that there are Karroo sedimentary areas, and at least in many places have large perennial ground water storage /14/. The ground water discharge in the eastern part of the sedimentary area is very abundant, and the ground water is partially artesian and thus of the shallow ground water nature.

5.1.4 Zone IV (Basement zone)

Basement zone covers the whole of Masasi district and the western slope of the Makonde plateau in Mtwara Region.. In Lindi Region it covers the whole of Nachingwea district and the southern part of Kilwa district.

The most of basement area is generally covered by a thin layer of overburden, thus the available ground water is classified as deep ground water.

Two main sources of shallow ground water do occur. They are frequently of sandy formations containing perennial ground water bodies in the river beds. The depth of ground water level is generally below 2 metres /13/.

5.1.5 Ground Water Potential Classification

Shallow ground water occurrences are composed of individual units of different quality and they are usually classified as follows /14/:

Class I: Shallow water of small supplies

Mostly all the occurences located far away from river valleys and brooks are quite small. It is from these sources that the people get their daily water requirements in absence of rainfall and perennial rivers. Such occurrences do represent discharging deep ground water especially those of artesian nature; and sometimes do indicate the presence of perched shallow aquifer and thus do cover small areas of about one square kilometre. With yields varying between 2 and 25 m^3/day /14/.

Class II: Sandy river beds:

According to Finnwater the river potential was calculated by dividing the river beds into sections of appropriate length by using the equation

$$Q = \frac{0.6 \cdot L \cdot A \cdot P}{t_{dry}}$$

where

Q = average yield during the dry season in m^3/day

L = length of the river bed in metres

A = average cross-section of the saturated sand formation in square metres

P = effective porosity (20 % was used)

t_{dry} = time, when there is no or only some surface run-off in the riverbed = the number of days in the dry season, $t_{dry} \neq 0$.

The coefficient 0.6 was used because the estimated figure of discharge could not be estimated as ground water is percolating into the riverbed during dry season.

The effective porosity of 20 % is based on the experience especially in the edges of the plateau, the abundant share of silt fraction reduces the effective porosity /13/.

Class III: Area occurrences

This covers the occurrences in small lakes and ponds, the discharge of which could not be easily defined the most important categories being:

- damp areas in the valleys
- low-lying zones around perennial rivers, not belonging to the former group /14/.

5.1.6 Shallow Ground Water Potential

The shallow ground water potential in the twin regions of Mtwara and Lindi can be summarized as follows:

Table 5-1. Shallow ground water occurrence in Mtwara-Lindi /13/14/.

Class	Occurence description	districs covered
1	Springs & brooks are commonly found along the edge of the plateaux near the coast and in deep valleys cutting the plateaux.	Liwale, Lindi Kilwa, Masasi
2	Sandy rivers of Mbwemkuru Matandu Maruji, Nangare and Litopa the southern tributary of Mbwemkuru, Lukuledi, Miesi, Mbangala and Mb w inji	Lindi, Liwale Masasi
3	Small Lakes e.g. Chidya and other deep lying river beds of Matandu and its tributary Ngonga and many small areas in the two regions.	All the districts in the two regions.

5.2 Hydrogeological Formations and Shallow Ground Water Conditions in Mwanza Region

The Mwanza Water Master Plan detailed the hydrogeological studies at regional level only. Formations are as shown in table 5-2 and the hydrogeological conditions are as earlier explained in chapter 3.3.

Table 5-2. Geological formation of Mwanza Region /2/.

Group	System or Formation	Lithology	Group	System or Formation	
Kainosoic	Recent	Mbuga, alluvium and some young lake beds	Neogene	Recent and Tertiary	
	Tertiary	Terrestrial deposits incl. laterite and early lake beds			
Paleozoic	Pre-Karoo	Fresh dolerite			
	Pre-Bukoban	Granite suite including apophyses, tonalites and syenites		Nyanzian	
Archaean	Kavirondian	Conglomerates	Pre-cambrian	Late pre-cambrian or archaean	Dolerites, lamprophyres
	Nyanzian	Metasediments, banded ironstone acidic volcanics, basic volcanics		Early pre-cambrian late orogenic	Alaskitic granites
	Basement	Granitic and migmatic gneisses and hornblende shists		Synorogenic plutonic rock	Porphyritic granite hornblende granite granodiorite biotitic granodiorite migmatite

Half of Mwanza Region is covered by the precambrian bedrock and it is scattered in different parts of the region. This bedrock consists of mainly granite, conglomerates, gneiss and schists, faults, fissures and weathered upper parts of the bedrock form the best aquifers.

Rest of the region is of neogene deposits which include mbuga (open plain land) alluvium, young lake bed deposits, terrestrial deposits and early lake beds. All these formations are good for shallow well aquifers, unless they are deposited in deep valleys, which are very uncommon in Mwanza.

5.2.1 Shallow Ground Water Potential

Occurrences of shallow well have been classified into two major groups /3/:

Type I Shallow wells are those which are located in the alluvium characteristic of the stream or riverbeds.

Type II Shallow wells are those which are located near the boundary of the upper and lower sediment.

In estimation of shallow well potential of type I the following procedure was used:

a) The area required for a shallow well was estimated within an area of alluvium.

b) From aerial photographs the area of the aquifers was measured and the number of well determined by dividing by the area required per well previous determined.

c) The volume of water that can be extracted is the product of number of wells and yield per well

d) Because of the importance required for reliability of a well, three water levels potentials are determined.

The second type of shallow well location is as shown in figure 5-2. The theory behind such deposit is that during weathering process the hard granite a hard pan is deposited, and this intersects halfway between the transition zone between upper and lower pediments. The hard pan acts as an aquitard reducing the vertical water flow seeping downwards / 2/.

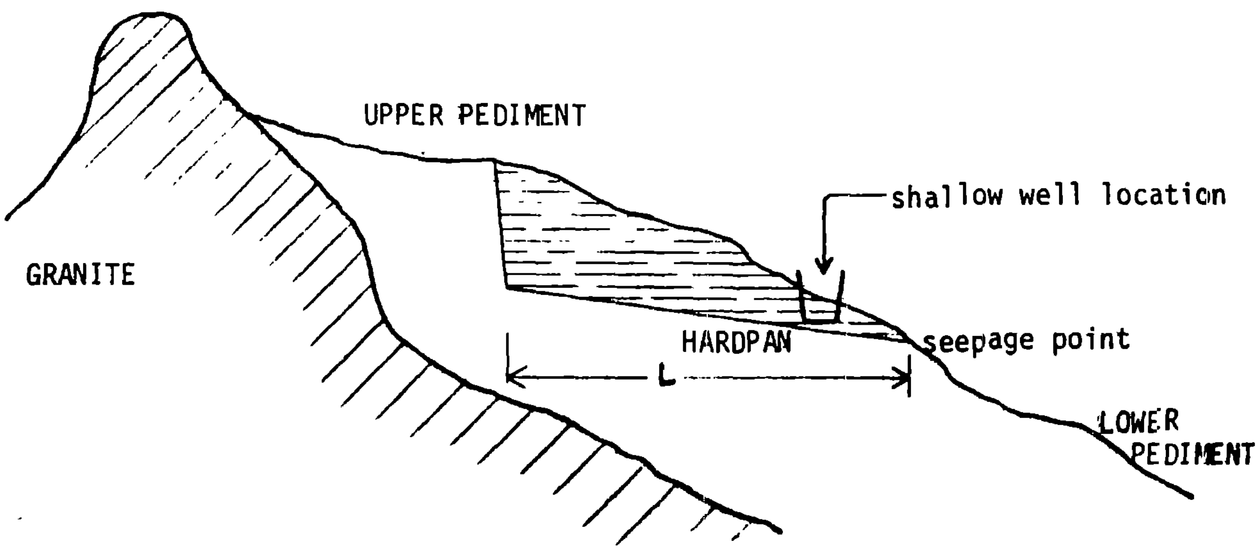


Figure 5-2. Typical upper pediment aquifer./2/

In analyzing the potential of such shallow wells two important aspects were carefully considered and are that:

a) the quantity of water in the aquifer is sufficient for the expected extraction rate

b) the number of wells located in the aquifer is correct in that particular location.

In the final analysis it was seen that the shallow well potential is good immediately west of Smith Sound and decreases as you move towards Geita in the west. Also potential is good in the north and north east and south west corner of Mwanza and the rest of the region has poor potential. Figure 5-3 shows the shallow well distribution of mean reliability /2/.

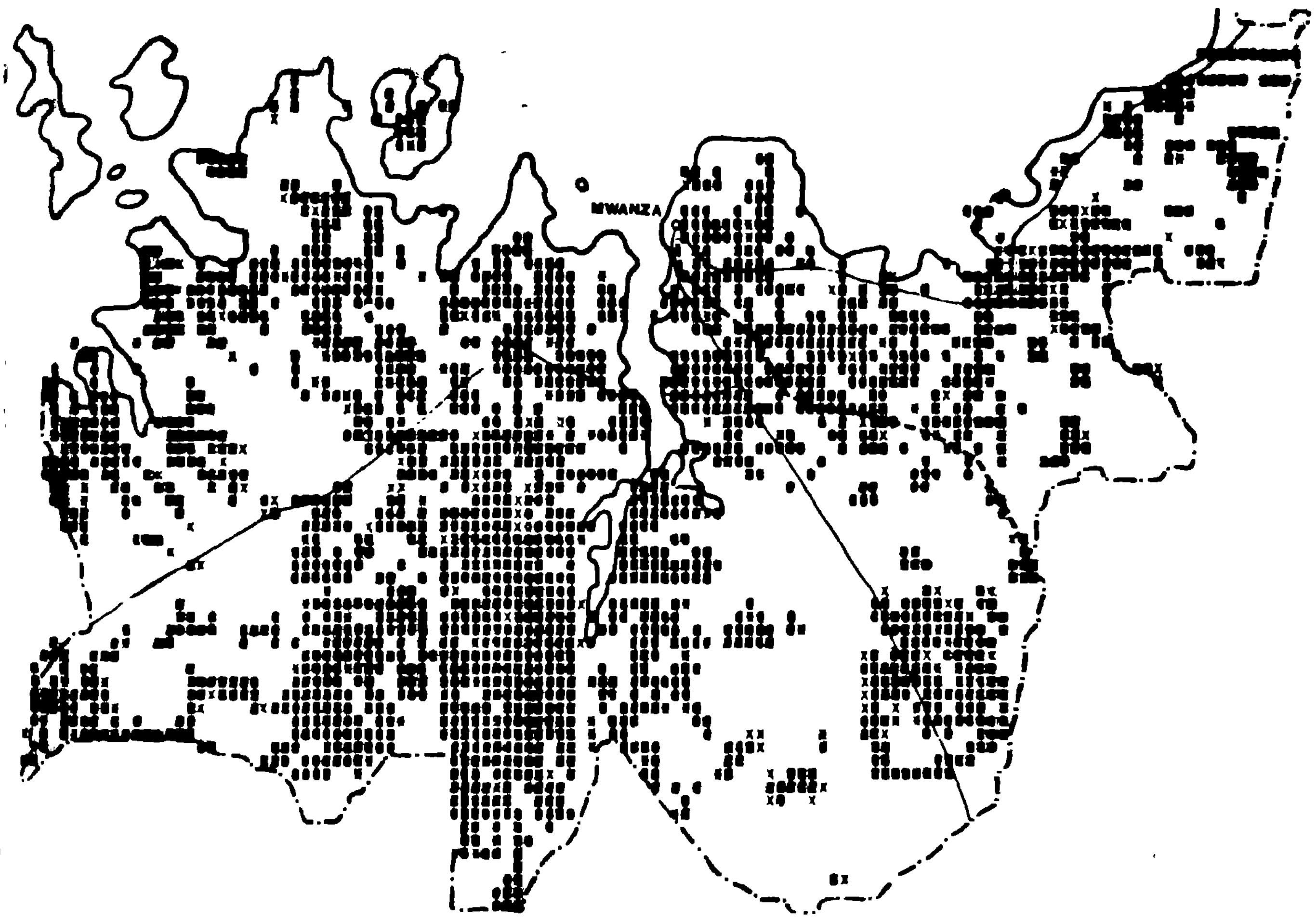


Figure 5-3. Shallow well distribution of mean probability /2/.

5.3 Hydrogeological Formations and Shallow Ground Water in Morogoro Region

There is no water master plan prepared for Morogoro Region, however the DHV-Engineers have produced a good detailed study of the hydrogeological formations of the region. A tentative division into hydrogeological sub-areas is shown in figure 5-4.

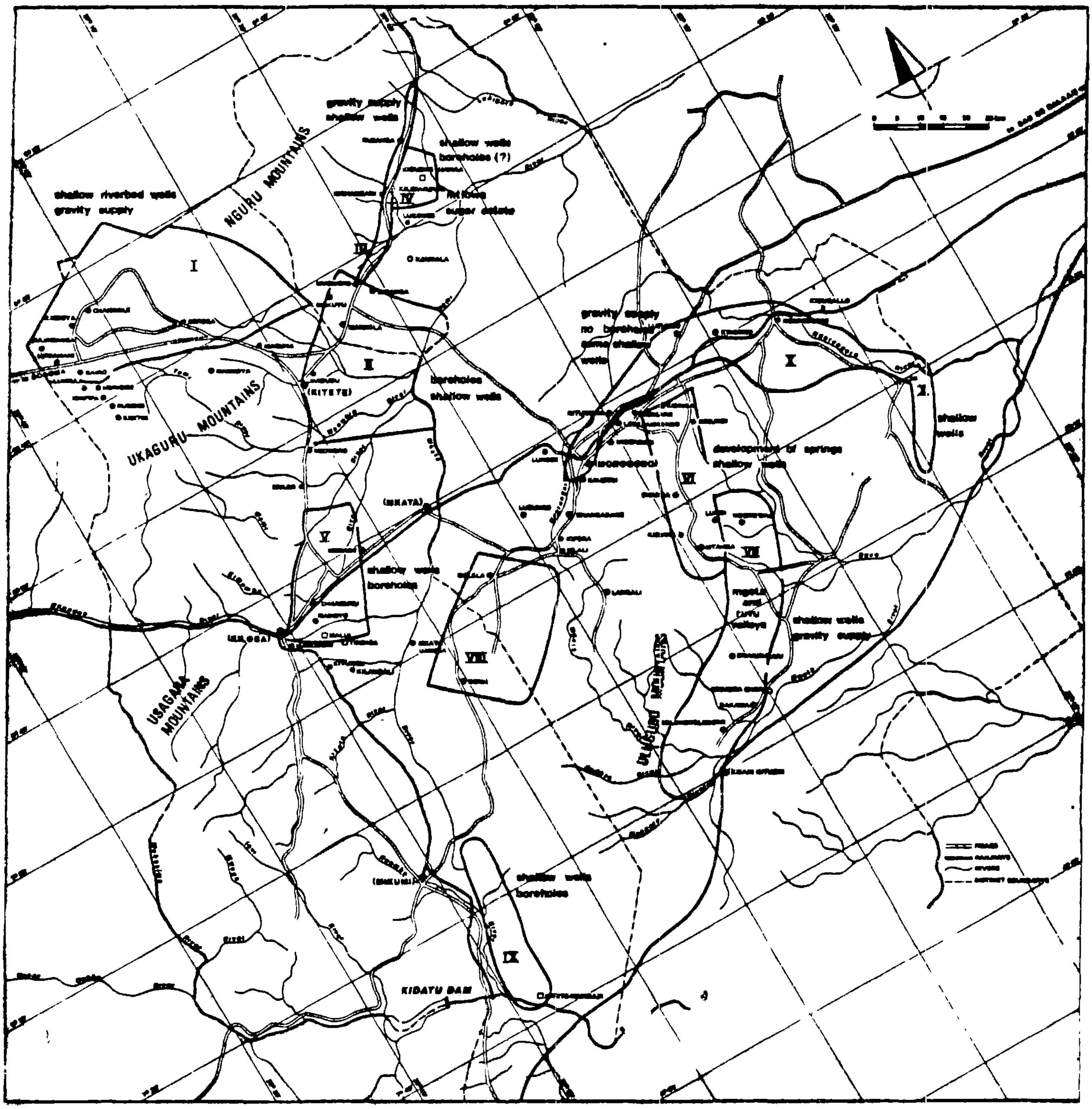


Figure 5-4. Water potential of hydrogeological sub-areas based on field work /10/.

The age and lithology, the rocks in Morogoro Region can be grouped into four major divisions /10/:

1. Pre-cambrian rocks which comprises gneiss, granulite and dolomite about 70 % of the region.

2. Karroo rocks of sandstone, siltstone and shale cover 6 % of the area.

3. Jurassic rocks which are made of sandstone, mudstone and limestone claim 4 % and

4. Quaternary-Tertiary rocks of clay, silt, sand and gravel take the remaining 20 %.

5.3.1 Ground Water Potential

The area with high potential for shallow wells is Wami (rift) valley which is mainly of quaternary-tertiary sediments., the pre-cambrian areas of Ukaguru Mountains, Uluguru foothills and Rubembe Valley which is composed of quaternary sediments.

There are also much areas of unconsolidated sediments of quarternary-tertiary age with main aquifers like the river terraces, buried river channels, alluvial fan deposits and colluvium. A good number of wells are located in weathered and decomposed basement rock mainly gneiss /10/.

6. GROUND WATER QUALITY AND ITS AREA CHARACTERISTICS

6.1 Chemical Water Quality of Ground Water

The rather slow movement of water percolating through the ground gives it much time to get into contact with the minerals that make up the earth's crust. These minerals get dissolved into water as it moves along. The dissolved minerals in ground water affects its usefulness for various purposes albeit they give the water a good taste if are not in excess. If one or more of the minerals are in excess of the amount that can be tolerated for a given use; some type of treatment may be applied to change or remove the undesirable minerals so that water will serve the intended purposes /19/.

However it is unfortunate that not all the dissolved minerals can be removed by simple treatment therefore sometimes some sources are abandoned despite of them having high and adequate quantity of water.

The ground water in Tanzania contains a small number of elements which combine to form salts in solution. The more common of these salts are listed below in table 6-1 /6/.

Table 6-1. Main salts in ground water./6 /

Salt	Formula
Sodium Chloride	$NaCl$
Sodium Sulphate	Na_2SO_4
Sodium Carbonate	Na_2CO_3
Sodium Bi-Or Hydrocarbonate	$NaHCO_3$
Sodium Fluoride	NaF
Calcium Chloride	$CaCl_2$
Calcium Bicarbonate	$Ca(HCO_3)2$
Calcium Carbonate	$CaCO_3$
Calcium Sulphate	$CaSO_4$
Magnesium Sulphate	$MgSO_4$
Magnesium Carbonate	$MgCO_3$
Magnesium Bicarbonate	$Mg(HCO_3)2$
Magnesium Chloride	$MgCl$

The geochemistry given in table 6-1 can on the other hand be generalized with reference to geological formations as follows /10/:

a) Ground water drawn from metamorphic basement rocks contains sodium, calcium, magnesium, chloride and bicarbonate in limited acceptable quantities. Fluoride content varies between 0.1 and 2.0 mg/l.

b) Ground water from Karroo rocks mainly contains calcium and magnesium-bicarbonates and fluoride varying between 0.2 and 2.0 mg/l.

c) Ground water from Jurassic sediments are rich in sodium and chlorides with fluoride below 1.4 mg/l.

d) Water from Quarternary-Tertiary sediments contains calcium and magnesium bicarbonates, sodium and chloride being the next important constituents.

e) Iron and manganese salts are quite common in ground water mined from Pre-Cambrian rocks.

6.1.1 Salinity (Conductivity)

Saline water is very objectionable to test. It is mainly found in upper Quarternary-Tertiary sediments, the Karroo, the Jurassic and the Pre-Cambrian geological formations.

Higher concentration of salts in water makes it unpalatable, in Tanzania it is measured as total filtrate residue. The relation between conductivity (as μS/m) and total filterable residue (mg/l) is approximately 0.13.

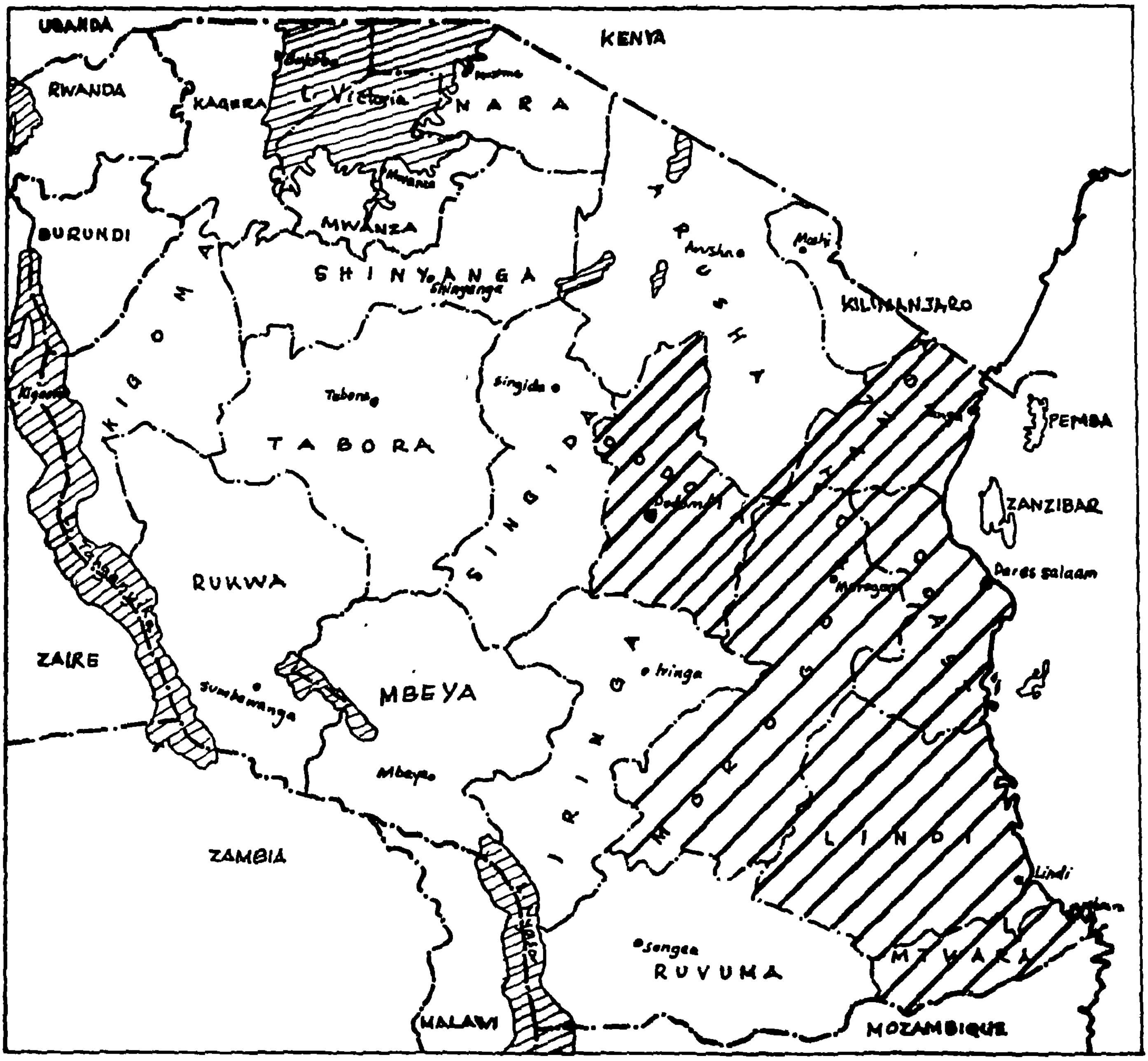


Figure 6-1. Areas with high frequency of conductivity ($> 200 \mu S/m$). /3/

Table 6-2. Frequency of samples with specified quality of conductivity.
Data from Ubungo Laboratory

REGION	Conductivity µS/m		
	201-400	401-	201-
ARUSHA	6	1	7
COAST	6	4	10
DODOMA	22	8	30
IRINGA	2	1	3
KIGOMA	3	3	6
KILIMANJARO	1	0	1
LINDI	25	10	35
MARA	4	1	5
MBEYA	2	1	3
MOROGORO	6	3	9
MTWARA	7	3	10
MWANZA	1	8	9
RUKWA	-	-	0
RUVUMA	-	-	0
SHINYANGA	4	-	4
SINGIDA	2	1	3
TABORA			
TANGA	9	4	13
KAGERA	-	-	0

The two main sources of salt contents are one seawater either fossil or from intrusion and two evaportranspiration. Seawater intrusion is common along the coast and for the latter Dodoma, Singida, Tabora and Shinyanga regions may be chosen as examples. Finnwater (when preparing the Mtwara-Lindi Water Master Plan) observed that there is a seasonal variation in the conductivity of ground water between dry and wet seasons.

6.1.2 Fluoride

Water with high fluoride concentrations is believed by many doctors of medicine to be the main cause of skeletal fluorosis and dental fluorosis in case of moderate concentrations.

Fluoride originates from the minerals, fluorite and fluoro-apatite which are mainly found in granite rocks. Fluoride dissolves in water from weathered rocks in case of surface water and since it is of rock and soil origin it is obvious that high concentrations are normally found in ground water.

The presence of areas with high fluoride concentration is a well known fact. Bardecki /3/ prepared a statistical evaluation of fluoride concentration. Table 6-3 shows the distribution in the country. It is seen that regions with high fluoride concentrations are Arusha, Kilimanjaro, Singida, Mara, East Mwanza and Shinyanga. Figure 6-2 shows the areas affected by high fluoride concentrations (4 mg/l).

Table 6-3. Frequency of samples with specified concentration of fluoride (values from Bardecki within brackets)

Data from Ubungo Laboratory

REGION	Fluoride concentration mg/l							
	0-1.0	1.1-2.0	2.1-4.0	4.1-8.0	8.1-16.0	16.1-	4.1-	8.1-
ARUSHA	25	24	18	10	9	14	33	23 (18)
COAST	94	4	1			1	1	1 (0)
DODOMA	70	15	8	7			0	0 (1)
IRINGA	88	8	3	1			1	0 (0)
KIGOMA				.				
KILIMANJARO	62	21	8	5	3	1	9	4 (5)
LINDI	86	8	5	1			1	0 -
MARA	32	35	20	9	2	2	4	2 (3)
MBEYA	83	10	3	2	1		1	0 (0)
MOROGORO	92	6	2				0	0 (0)
MTWARA	98	2					0	0 -
MWANZA	52	9	13	15	10	2	27	12 (10)
RUKWA	94	3	3				0	0 -
RUVUMA	93	7					0	0 -
SHINYANGA	57	12	11	17	1	2	20	3 (12)
SINGIDA	34	26	14	9	13	5	27	18 (24)
TABORA								
TANGA	75	19	3	3			0	0 (0)
KAGERA	96	3	1				0	0 (0)

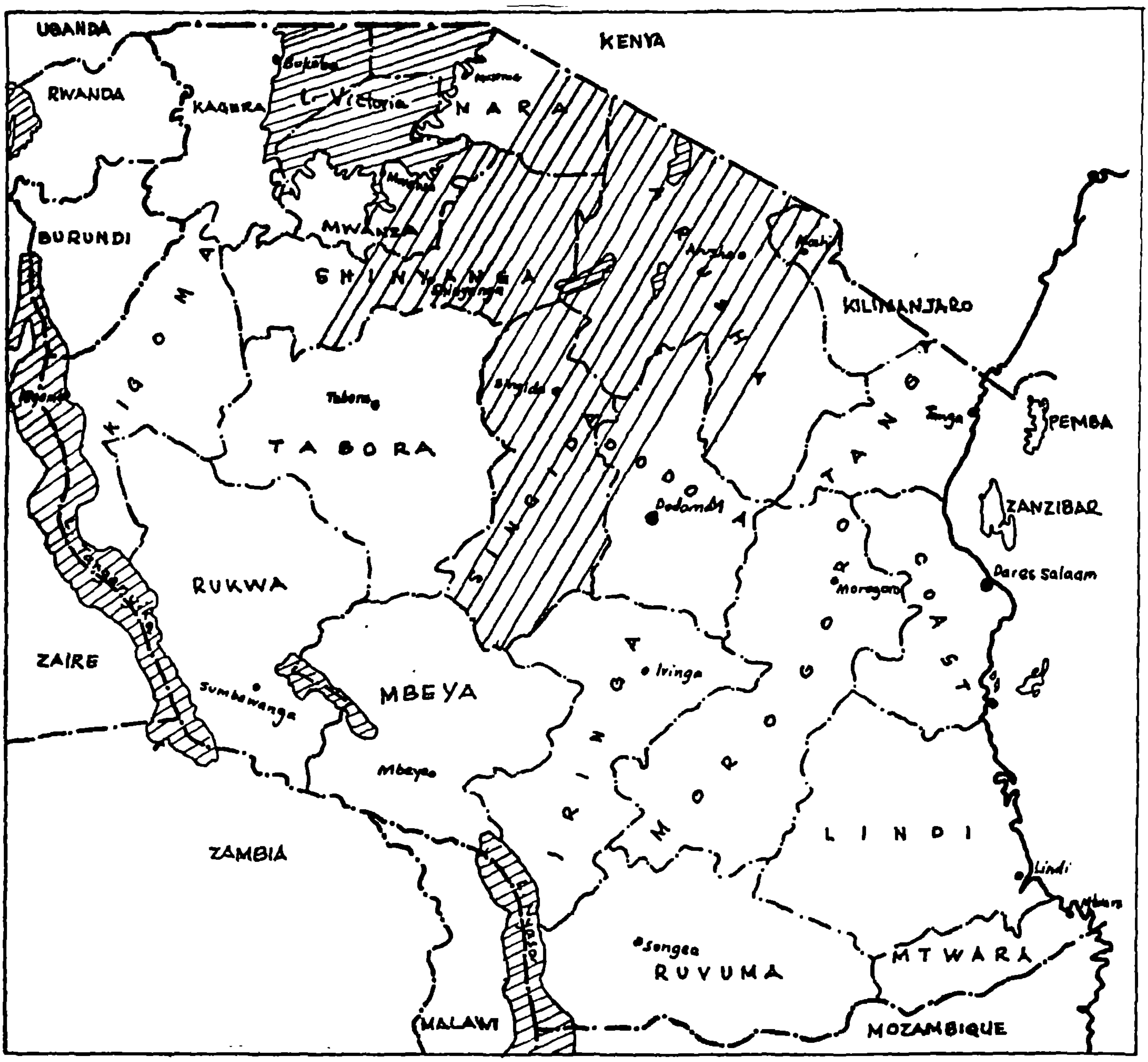


Figure 6-2. Areas with high fluoride concentration (> 4 mg/l)./3/

6.1.3 Nitrates

Nitrates are formed from excreta and vegetation when nitrifying bacteria oxidise its ammonia content. In reasonably wet areas with vegetation e.g. Kagera, Kilimanjaro and Mbeya regions the ammonia or produced nitrate are taken up into the plant. In dryer areas e.g. Dodoma, Singida and Shinyanga regions, however, with scarce vegetation the nitrates seep into ground. Nitrates in concentrations of more than 50 mg/l can cause blood charges and cyanosis when consumed by infants.

Evapotranspiration increases the nitrate concentrations before the water seeps down into the ground water formations, as such, high concentrations of nitrate are more frequent in ground water than in surface waters.

In Tanzania nitrate concentrations are reported as nitrate nitrogen and this must be multiplied by the factor 4.43 to obtain values of nitrate. The distribution of high nitrate concentrations in the regions are shown in figure 6-3. When doing the water quality programme Brokonsult Ab chose the level of 6.8 mg/l of nitrate nitrogen to avoid more erratic variation in the data. The data is also presented in table 6-4. The mostly affected areas are Singida and Dodoma where there are some places with concentrations above 22.7 mg/l nitrogen or 100 mg/l nitrate. Other regions with frequent, relatively high concentrations are: Mwanza, because of the use of fertilizers in cotton farms, Tanga. south of Kilimanjaro (also because of fertilizers in maize farms) and Mtwara region.

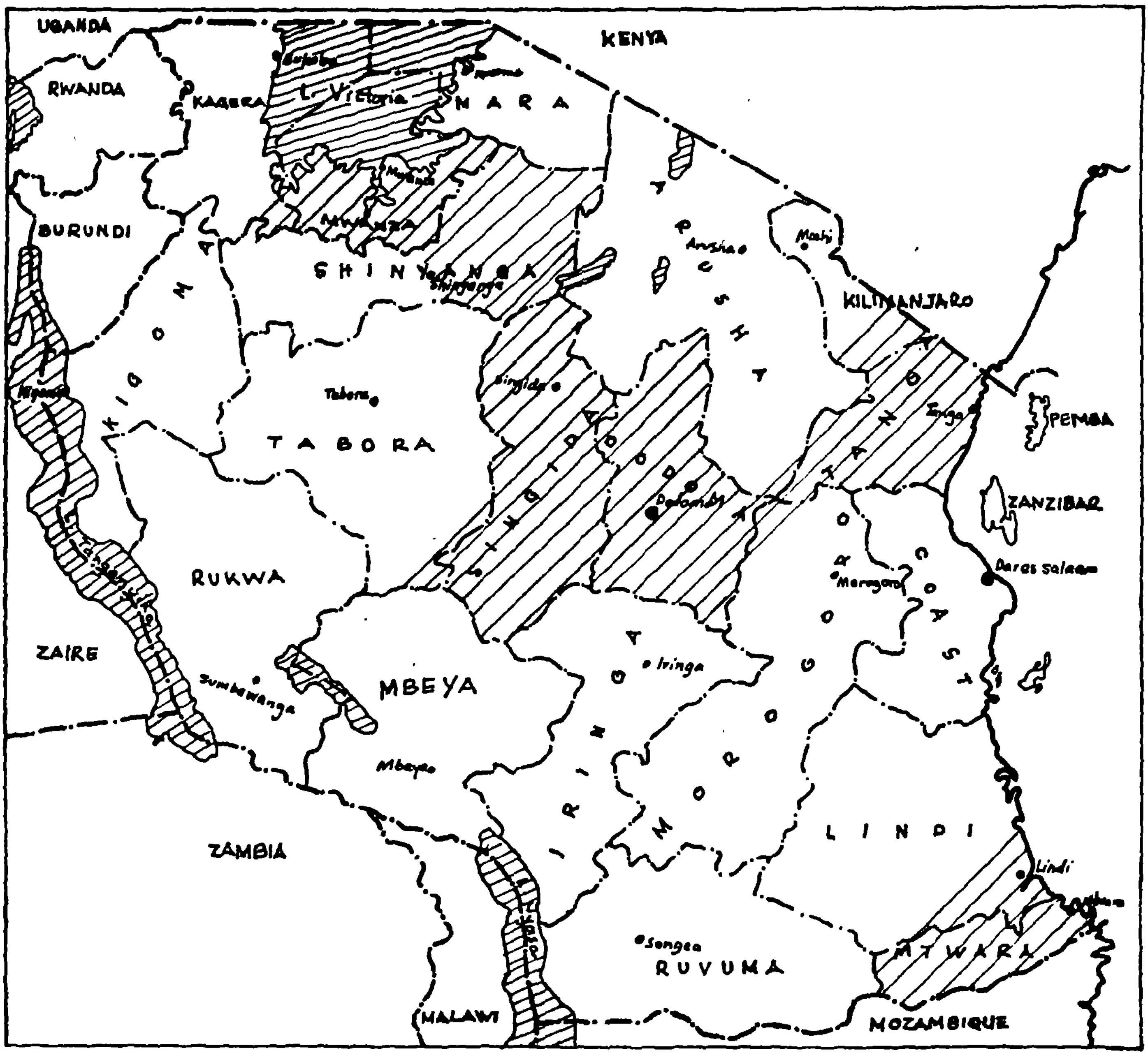


Figure 6-3. Areas with high frequency of nitrate-nitrogen concentration (> 6.8 mg/l)./3/

Table 6-4. Frequency of samples with specified concentration of nitrate nitrogen

Data from Ubungo Laboratory

Nitrate mg/1	30	50		100		30	50	100
Nitrate Nitrogen mg/1	0–6.7	6.8–11.3	11.4–22.6	22.7–45.2	45.3–	6.8–	11.4–	22.7–
Arusha	96	3	–	–	–	3	0	0
Coast	98	1	–	1	–	2	1	1
Dodoma	94	2	3	–	1	6	4	1
Iringa	97	–	1	1	–	2	2	1
Kigoma	1	–	–	–	–	1	1	0
Kilimanjaro	95	–	5	–	–	5	5	0
Lindi	93	4	1	–	1	6	2	1
Mara	97	1	–	–	1	2	1	1
Mbeya	98	2	–	–	–	2	0	0
Morogoro	97		3	–	–	3	3	0
Mtwara	96	7	5	2	–	14	7	2
Mwanza	91	5	4	1	–	10	5	1
Rukwa	100	–	–	–	–	0	0	0
Ruvuma	100	–	–	–	–	0	0	0
Shinyanga	98	1	–	–	1	2	1	1
Singida	75	3	8	7	8	26	23	15
Tanga	88	7	5	–	–	12	5	0
Kagera	100	–	–	–	–	0	0	0

6.1.4 Iron

In most cases all water supplies contain some iron. The iron content in small amounts is desirable but when it exceeds 1.0 mg/l it gives inktaste. Iron is not dangerous but causes staining of plumbing fixtures, staining of clothes during laundering, incrustation of well screens and plugging of pipes.

Iron is present in water either in dissolved form as ferrous iron or as ferric iron in a colloidal or solid form. Divalent iron is stable only in water without oxygen i.e. when ground water gets into contact with air, the ferrous iron changes to ferric state.

The frequency of high iron concentrations (above 2 mg/l) is shown in figure 6-4 and table 6-5. Brokonsult Ab found out that on the average as much as 23 % of the samples they analysed had a concentration above 4,1 mg/l.

6.2 Other Minerals in Water

These minerals are scattered in small pockets throughout the country.

6.2.1 Manganese

Manganese resembles iron in its chemical behaviour and occurrence in water. However, it is less abundant in rock materials than iron. Its effects are more serious than those of iron, the stains caused by manganese are more annoying and harder to remove than those caused by iron. Also slime forming bacteria similar to iron bacteria may also cause oxidation of manganese compounds to an insoluble form /18/. Allowable concentration is 0.5 mg/l.

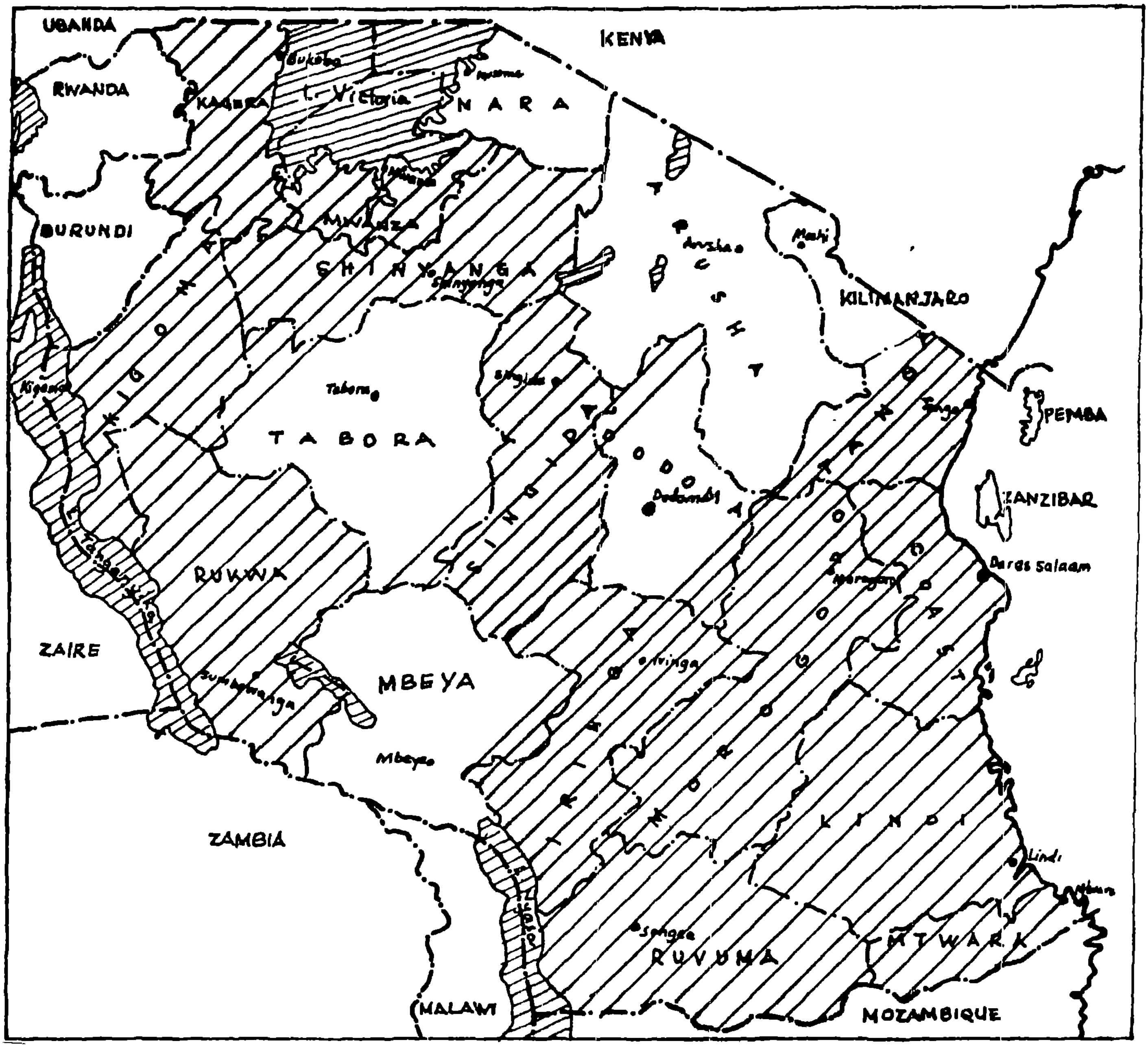


Figure 6-4. Areas with high frequency of iron concentration (> 2 mg/l)./3/

Table 6-5. Frequency of samples with specified quality of iron

Data from Ubungo Laboratory

REGION	Iron mg/1		
	2.1-4.0	4.1-	2.1-
ARUSHA	3	6	9
COAST	13	15	28
DODOMA	4	14	18
IRINGA	10	10	20
KIGOMA	10	20	30
KILIMANJARO	6	1	7
LINDI	11	15	26
MARA	10	10	20
MBEYA	5	12	17
MOROGORO	14	12	26
MTWARA	8	22	30
MWANZA	6	12	18
RUKWA	13	8	21
RUVUMA	22	11	33
SHINYANGA	15	15	30
SINGIDA	12	19	31
TABORA			
TANGA	5	12	17
KAGERA	11	16	27

Iron bearing waters also favour the growth of iron bacteria such as crenothrix. These growth form so abundantly in water mains, recirculating systems, and other places, that they exert a marked clogging action and cut down the flow rate.

6.2.2 Chloride

Chloride occurs in great abundance in seawater, thus boreholes and wells drilled along the coast sometimes contain amounts of chloride due to some seepage into the wells due to overpumping. The acceptable concentration of chloride is 200 mg/l and allowable is 400 mg/l, its main effect is causing permanent hardness in water when it combines and forms salts with calcium and magnesium.

6.2.3 Sulphate

As sulphate is mainly available within gypsum, water mined from gypsum bearing rocks in coastal regions do have dissolved sulphate, mainly as calcium sulphate. It also like chloride causes permanent hardness. Acceptable concentrations are 200 mg/l and allowable 400 mg/l.

6.2.4 Hardness

This is mainly due to calcium and magnesium. Hardness is not dangerous for the human health but reacts with soap, thus causing high consumption of soap. Also in industrial use, especially when heated, the salts form insulating layers on boiler walls. Salts of carbonates cause temporary hardness which incidentally is removed by boiling and as earlier said permanent hardness is caused when calcium and magnesium form chloride and sulphate salts. Both the hardnesses are found in various concentrations in many parts of the country especially in the central regions.

6.2.5 pH - Acidity and Alkalinity

pH is of great importance for the duration of metallic pipes. For this reason pH in larger schemes is kept close to 8.5 to avoid corrosion. Values of 6.5 to 9.2 are allowable though values of 7.0 to 8.5 are more acceptable. The distribution of pH in the country varies from place to place and is yet to be mapped. It has been established that deep ground water is more acidic than shallow ground water /13/.

6.2.6 Bacteriological Quality

As earlier mentioned ground water is in most cases free from organic matter except when polluted either accidentally or intentionally.

Generally speaking the problem of bacteriological quality has been overlooked just because ground water is bacterial free. However, in the recently completed Water Master Plan Study of Kigoma Region, Norconsult have identified some wells, streams and springs which have fecal streptococci of more than 10 Nos of F.S./100 ml to be 9 sources out of 43 identified sources /23/. The only explanation available is that these sources are lacking sanitary protection.

6.3 Water Quality Criteria: Standards of Drinking Water

At present, two different water quality standards are applied in Tanzania:

1. WHO-International Standards for Drinking Water, 1971 for Urban Centres

2. Tanzania Temporary Standards for drinking water for rural areas.

The WHO Standards are applicable to urban water supplies, large scale rural water supplies serving more than 5 000 people and all the water supplies having treatment systems more complex than simple sedimentation and/or rapid filtration.

The Temporary Standards will be in use until the circumstances allow the full application of the International Standards. Table 6-6 gives the Tanzania Temporary Standards for drinking water.

Both the standards are basically similar, but the Temporary Standards take the running of water supply systems in rural conditions into consideration.

Table 6-6. WHO/Tanzania Temporary
- Physical and Chemical Drinking Water
Quality Criteria

Group	Parameter		WHO Criterion	Tanzania Criterion
P	pH-value		6.5 - 9.2	6.5 - 9.2
P	Total hardness	(mg CaCO/l)	n.m	600
P	Sulphate	(mg SO_4/l)	200 - 400	600
P	Chloride	(mg CI/l)	200 - 600	800
P	Colour	(mg Pt/l)	5 - 50	50
P	Turbidity	(mg SiO_2/l)	5 - 25	30
P	Taste		n.o	n.o
P	Odour		n.o	n.o
P	Iron	(mg Fe/l)	0.3 - 1.0	1.0
P	Manganese	(mg Mn/l)	0.1 - 0.5	0.5
P	Copper	(mg Cu/l)	1.0 - 1.5	3.0
P	Zinc	(mg Zn/l)	5.0 - 15.0	15.0
H	Fluoride	(mg/F/l)	1.5	8.0
H	Nitrate	(mg NO_3/l)	3.0	(100)
T	Lead	(mg Pb/l)	0.05	0.10
T	Cadmium	(mg Cd/l)	0.01	0.05
T	Arsenic	(mg As/l)	0.05	0.05
T	Chromium-VI	(mg Cr/l)	0.05	0.05
T	Cyanide	(mg CN/l)	0.02	0.20
T	Silver	(mg Ag/l)	n.m	n.m

Notes:

n.m = not mentioned

n.o = unobjectionable

p = substances which may affect the palatability of drinking - water

H = substances which may affect human health

T = substances which may be toxic

As to the physical and chemical quality of water, both the standards categorize the standards into three distinct subsections:

1. substances which are toxic
2. substances which affect the human health, which could result in chronic states if ingested in large quantities over a long period
3. substances which affect the palatability of drinking water or affect the suitability of water for general domestic purposes.

As to the concentrations on non-toxic substances, the sub-section (3) above the Tanzania Standards are more tolerant than the International Standards. Thus, higher concentrations of different types of salinity such as chlorides, sulphates and nitrates are allowed in the Tanzania Standards. However, both the standards agree that water should not contain any organism of feacal origin /26/.

Of all the parameters in the temporary standards, that of fluoride brought out some criticisms from different people and agencies. The upper limit of 8 mg/l was reached after analysing different samples from different sources in areas affected by the mineral and it was found out to be the optimum upper limit if the people in these areas are to get water at all.

7. SURVEY FOR SHALLOW WELLS

Water can be found almost anywhere under the earth's surface. However, it is important to start a well sinking project or programme by being sure that:

- water must exist in sufficient quantities and is
- capable of having a good recharge over long periods, and
- of good quality both chemically and bacteriologically.

7.1 Preparatory Investigations

Before visiting the area to be investigated, the following studies are of primary importance:

- study of geological maps and their cross-sections
- study of topographical maps
- study of areal photographs
- both geographical and hydrogeological surveys and
- study of surface evidence.

The last two studies are quite important and for Tanzania they have been carried out in detail when preparing the Water Master Plan in various regions including Mwanza, Mtwara and Lindi regions. For Morogoro, DHV-Engineers did make a good study of this during the preparation of Morogoro Domestic Water Supply Programme.

7.2 General Requirements for Wells

A successful well should generally meet the following requirements /9/:

- it should be within a walking distance from the consumers
- it should be accessible by trucks during construction and accessible on foot throughout the year

- it should yield enough water to meet a daily requirement of about 250 or more inhabitants, even during extremely dry periods (500 - 1 000 litres per hour)
- it must be away from polluting agents e.g. animal pans, compost areas, sanitary land-fill etc.
- if located on the river banks, it should be protected against floods and river meandering action
- if located in flood plains, the dangers of being flooded should be considered
- the subsoil should not render the construction of a well an impossibility, e.g. it is not feasible to dig a shallow well in rocky materials, even if these rocks contain sufficient quantities of water in their cravices or inbistices
- the location should not be in a depression but preferably on a slope or elevation so that spill water from the future well, as well as rain water will always drain away from the well.

7.3 Geological Considerations

The geological formations determine what type of ground water is available in a given area of study.

Detailed study of geological maps helps to know the different rock formations, consolidated or unconsolidated, those which come to the land surface or outcrop, their strikes or the direction in which they lie. Other useful information shown on geological maps would include the location of faults and contour lines indicating depth to bedrock throughout the area. Faults are lines of fracture along which the rock formations are relatively dislocated. Faults are also like sites for the occurrence of springs. The width of the outcrop and angle of dip to indicate the approximate thickness of an aquifer and depth it can be found. Figure 7-1 shows a typical geological map.

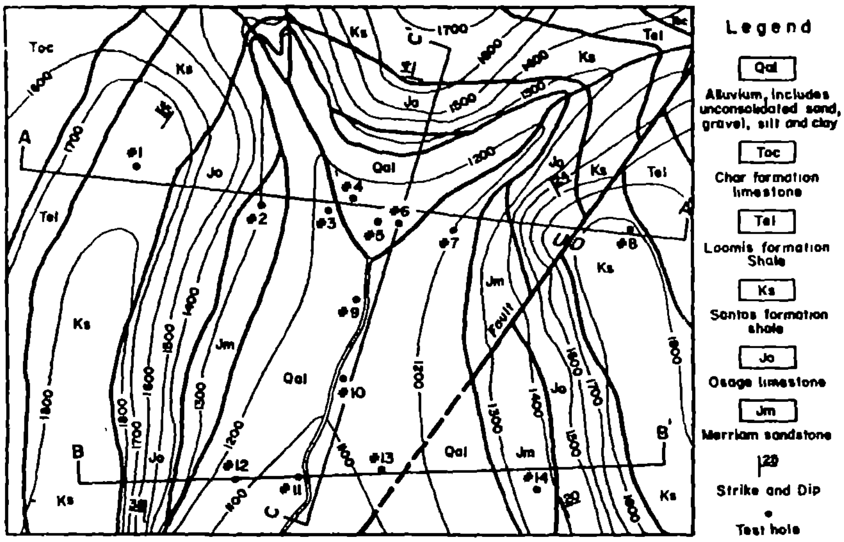


Figure 7-1. Example of a geological map showing test hole locations./16/

Another information important in locating well sites is Geologic Cross-Section as shown in figure 7-2. Cross-Sections provide some of the main clues to the ground water conditions of a locality. They indicate the character, thickness and succession of underlying formations and, therefore, the depth and thicknesses of existing aquifers and if water table or artesian conditions do exist in an aquifer /16/.

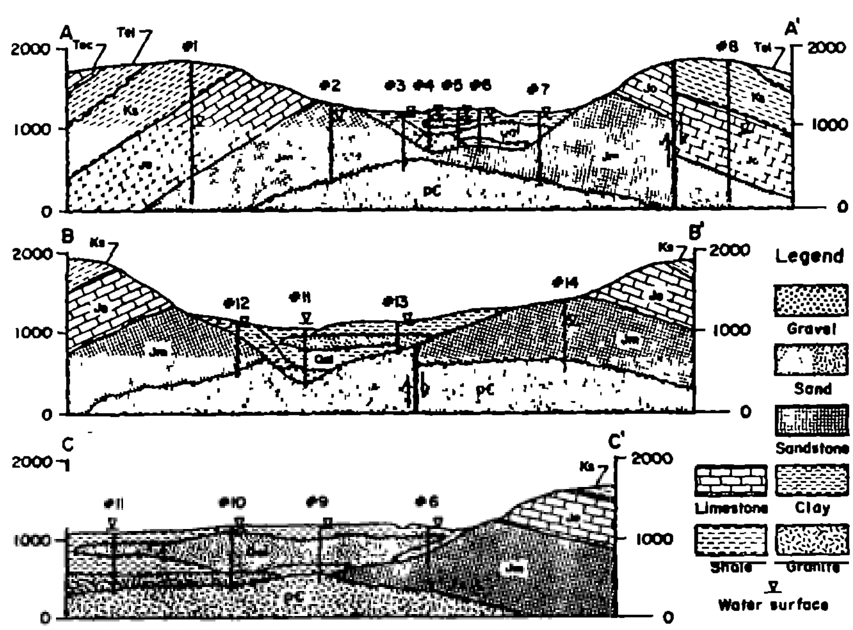


Figure 7-2. Geologic cross-section from the map of figure 7-1 ./16/

7.4 Surface or Topographical Considerations

Upon visiting the area of study, one takes a closer look at any surface evidence of ground water occurrences.

7.4.1 Valleys under Mountains Areas

Ground water is likely to occur in larger quantities under valleys than under hills. Valley fills containing rock waste washed down from mountain sides are often found to be very productive aquifers. The deposits may be by streams or sheet floods with some of the finer material getting into lakes to form stratified lake beds. These deposits are shown in figure 7-3.

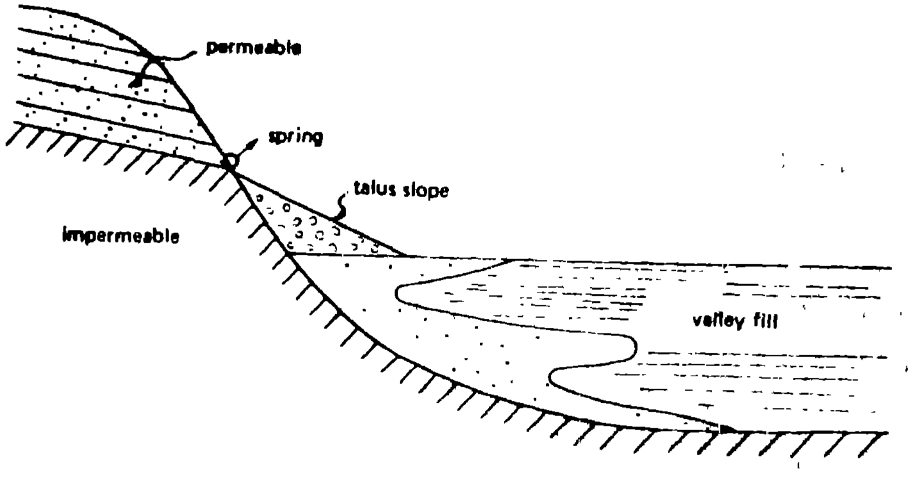


Figure 7-3. Valley under mountain areas. /9/

7.4.2 Alluvial Flood Plains

As the rivers flow down from mountains they form alluvial plains. In these areas it is always difficult to predict from the surface where the best locations are for well sites. These areas are very common in Morogoro region ; and DHV Engineers succeeded in getting good sites by drilling along parallel profiles to the river at relative distances of 50 to 200 m. In this way the hydrology of the area is clearly obtained and the best well site can be selected accordingly (see fig. 7-4).

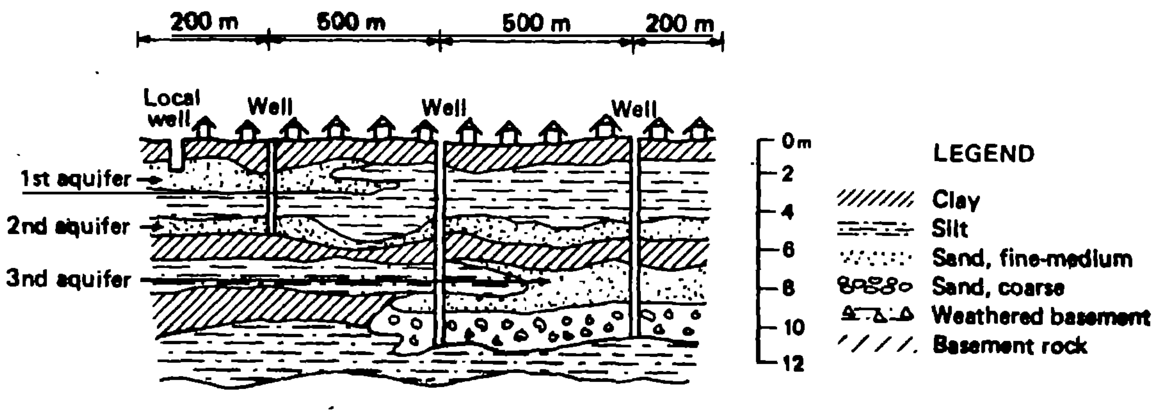


Figure 7-4. Alluvial plain./29/

7.4.3 Small Valleys

Small valleys are very common in Mtwara, Lindi and Morogoro regions or in all areas along the coast. In these valleys there are small perennial rivers of insignificant discharges in general. In these areas drilling is done across the valley, more or less at right angles to the riverbed. Great care must be taken to locate the wells a little high up from riverbed course to avoid flood. Figure 7-5 shows a typical small valley.

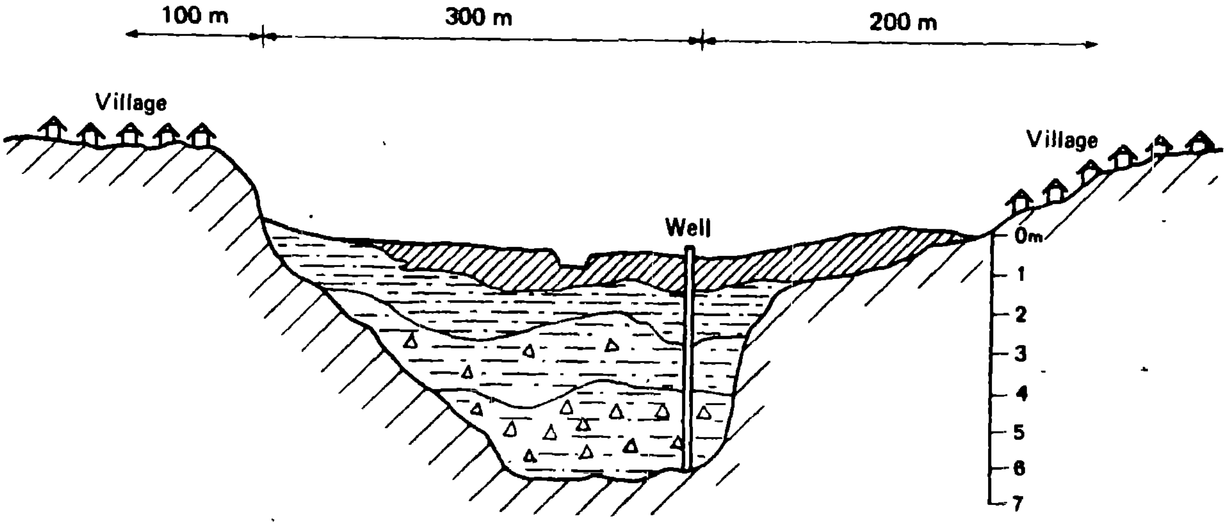


Figure 7-5. Small valley./29/

7.4.4 Seasonal River Plains or Terraces

Most of the rivers in Mwanza and Shinyanga regions are seasonal and very sandy. They are commonly dry for some part of the year and yet exploitable quantities of water may still be found. In wide river valleys the sandy deposits under riverbed and in the banks of existing and "buried" rivers offer good opportunities for shallow ground water.

As it can be seen in figure 7-6a and 7-6b, a walk along the river gives information of whether the river is eroding or depositing. Old river deposits may be found in this way. When bedrock is exposed on the riverbed, then the river is apparently eroding, but still old bends (cut-off meanders) of the river may offer good sites for shallow wells. As deeper sandy river deposits cannot be observed from the surface, exploratory drilling is quite necessary.

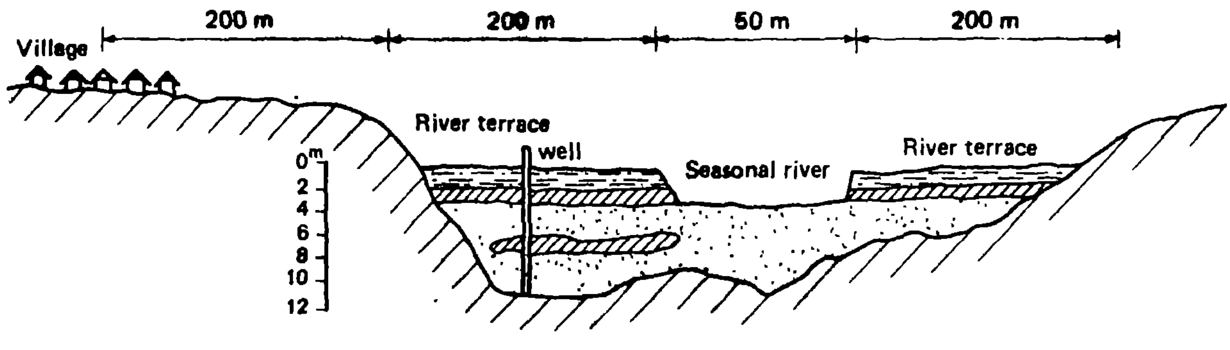


Figure 7-6a. River terrace. / 29/

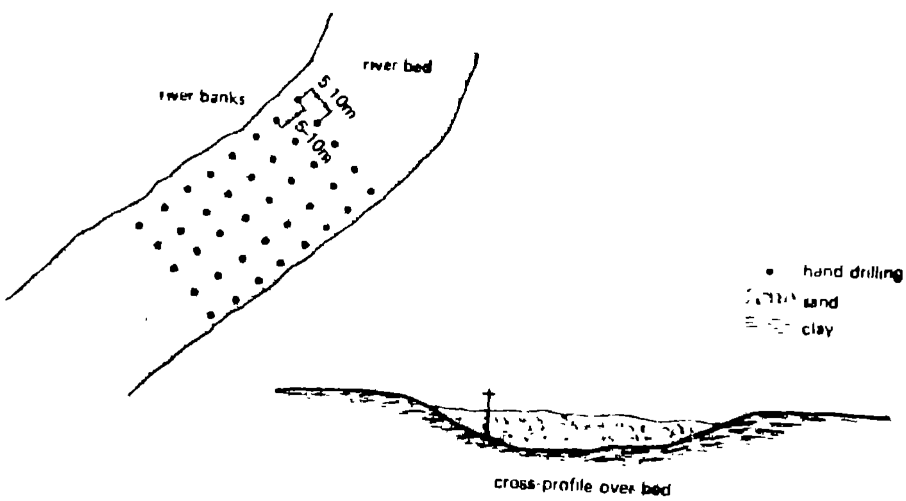
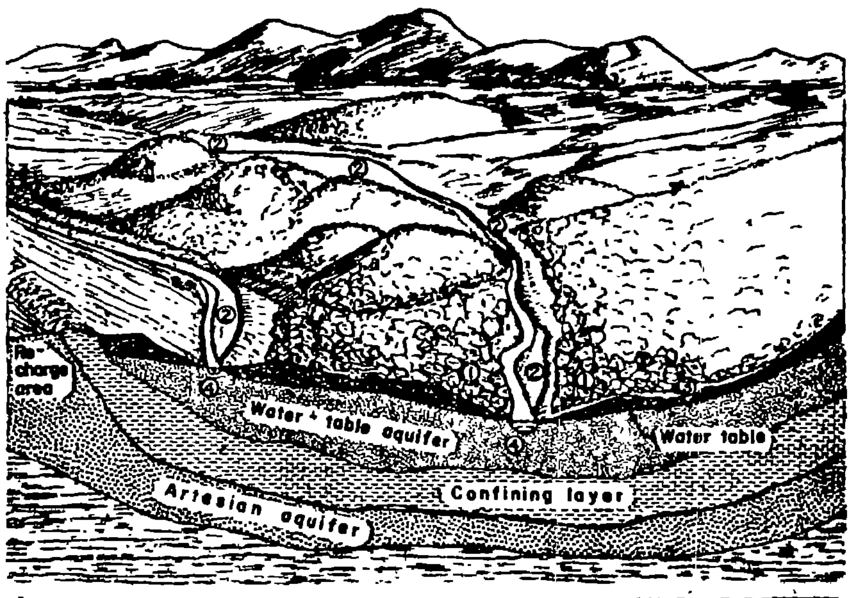


Figure 7-6b.

7.5 Climate and Vegetation

The influence of climate on ground water is very great, especially in areas with little rainfall ground water is essential for life. In those areas damming of rivers in order to create reservoirs is generally useless as the evaporation may as well exceed the rainfall.

Thus underground storage is useful, and this is provided by coarse layers in and under the river beds; and hence in arid regions ground water may be the only permanent water source. Especially the coarse river sediments may offer good opportunities for shallow aquifers. Figure 7-7 gives a pictorial view of vegetation and topography consideration in general for occurrence of ground water.



1 – Dense vegetation indicating possible shallow water table and proximity to surface stream.
2 – River plains: possible sites for wells in water-table aquifer.
3 – Flowing spring where ground water outcrops. Springs may also be found at the foot of hills and river banks.
4 – River beds cut into water-bearing sand formation. Indicate possibility of river banks as good well sites.

Figure 7-7. Surface evidence of ground water occurrence. (Adapted from fig. 4, Water Supply for Rural Areas and Small Communities, WHO Monograph Series No 42, 1959).

Vegetation such as banana trees, date palms, bulrush, sugar-cane etc. indicate the presence of shallow ground water (0 - 5 m). On the other hand some of the vegetation may indicate that water is brackish or saline (saltwater grass) /9/.

7.6 Site Location Practice in Selected Regions

All the three regions of study, Mtwara-Lindi, Morogoro and Mwanza regions follow the above procedure with slight variations depending on administrative system.

7.6.1 Mtwara-Lindi Practice

Survey team goes out on a pre-determined site and makes out a study for example the following report is for a particular village, Njengwa:

Short Story of Present Water Supply in Njengwa
12th February, 1983:

Njengwa has two subvillages, which are Tulinjengwa and Majengo. The total population of all the two villages is 965 people.

There is no any improved Water Sypply System. Only one open Ring Well is at Njengwa. This well is dry at present.

Possibility of Shallow Wells:

There is a possibility for hand pump wells in Njengwa and Majengo villages. There are good valleys with enough water.

In Njengwa, Villagers get Water from:

a) Local well about 1 1/2 - 2 km on the way to Chinindi village (there is permanent water)

b) Jihingu swamp 3 or 4 km on the way to Nangawanga Chini Village

c) Majengo village where some of the pits have permanent water.

In Tulinjengwa, people get water from Tuli river on the way to Tulihinju village. All the villages are recorded on the location map as shown in figure 7-8.

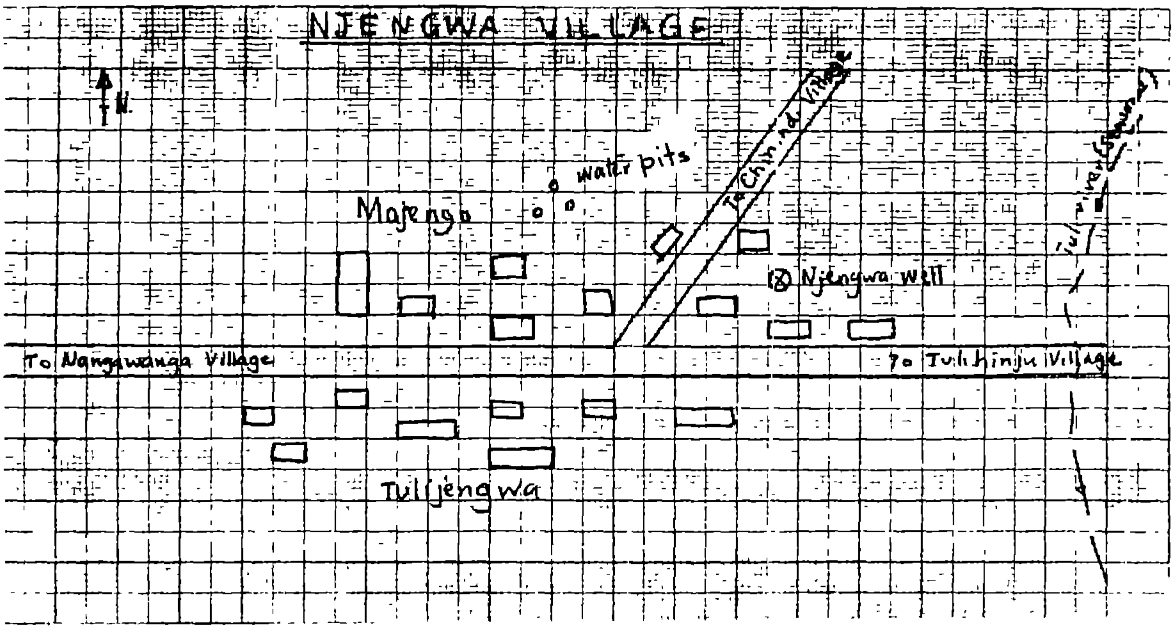


Figure 7-8. Village location map.

After such a report is obtained, then the area is checked against the available geophysical investigation data of the Mtwara-Lindi Water Master Plan, if not enough, then a fresh investigation is done. After that test drilling follows and subsequently construction of a shallow well.

7.6.2 Morogoro Region Practice

A survey team goes to a particular village where a shallow well is required to be constructed.

The surveyor goes around the village with the village official who shows him where the people are living, where they fetch water and any possible site they want a shallow well to be located. He then draws a sketch of the village on which he makes a planning for the locations of the sites he wants to survey (see fig. 7-9). He also records the number of people as well as the layout of the village which is taken into consideration. Usually the number of people to be supplied through one well is between 250 and 400.

MOROGORO WELLS CONSTRUCTION PROJECT

Village Sketch - Survey Section

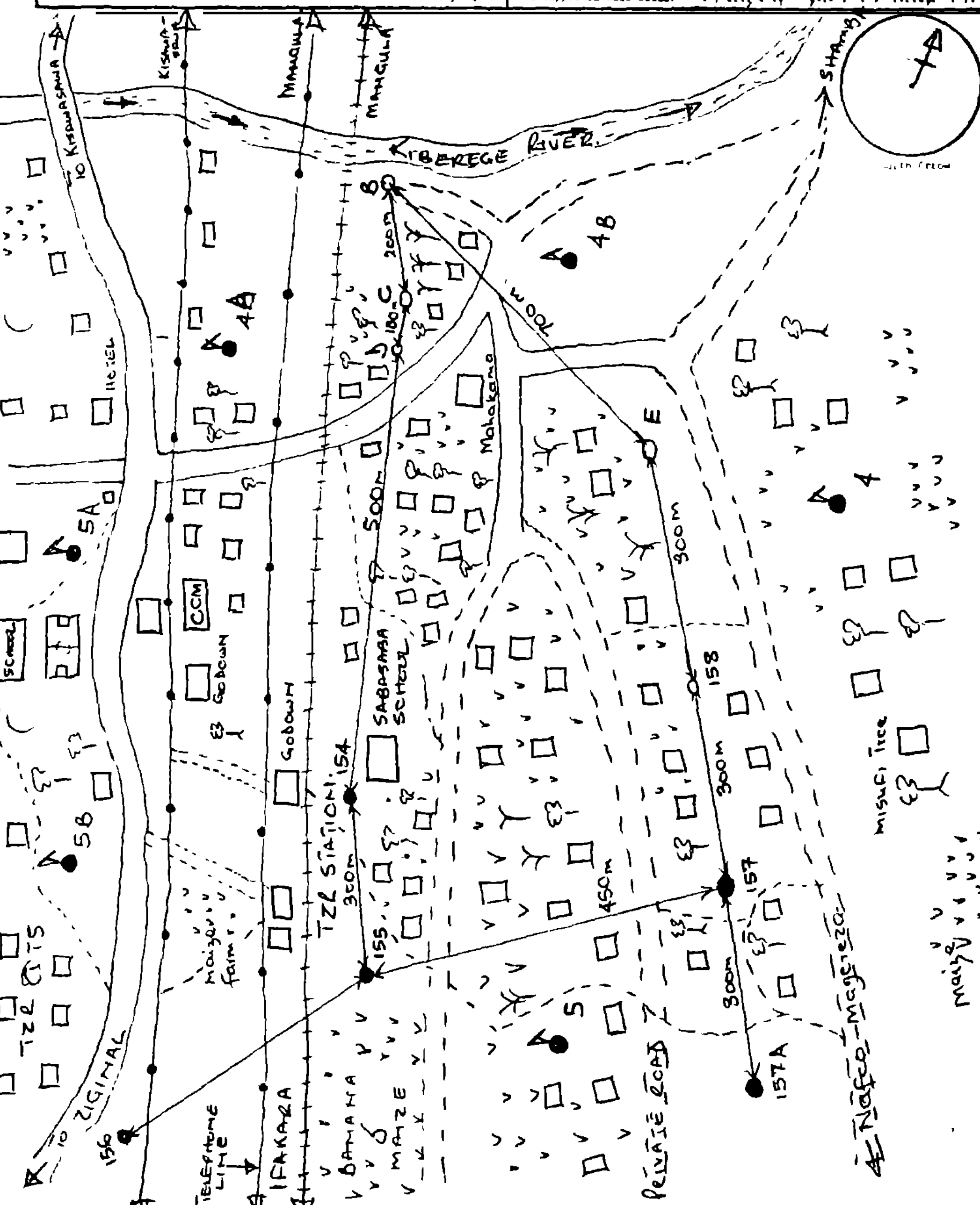
82

Date	26-3-82
Surveyor	A. Magalala

Village: KIBEREGE
Ward: KIBERREGE
Division: MANG'ULA
District: KILOMBERO

Appr. number of people	nr.
Planning/Review of sites	nr.

Approved well sites: 4A, 4B, 5A, 5B, 4 | Disapproved well sites: 154, 155, 156, 157, 157A



Mark. subvillages, important buildings, main roads with destination, approved sites, disapproved sites.

For legend see situation sketch forms

Figure 7-9.

7.6.3 Mwanza Region Practice

The shallow well investigation in Mwanza region is quite unique as it differs from the other two regions. The main difference is that, the survey team does no move from the office and go to locate a shallow well to any village of its liking. This is because the policy of the regional authorities is that the village must take initiative by making a contribution of Tsh 6 000 and paying this to the government. After the village chairman has presented the revenue receipt to the Regional Water Engineer, the survey team goes to the village to locate a suitable site for the well. The number of wells to be located depends on the contribution and not on the number of people. For each well required a sum of Tsh 6 000 has to be paid to the government regardless of what the final cost of the well is.

All other technical procedures are as given for Morogoro region practice because Mwanza regional practice was an extension of the Shinyanga programme which was initiated by the same DHV Consulting Engineers currently working in Morogoro region.

7.7 Test Drilling

After the well site has been located, it is usually advisable that before full scale construction and development of a well is done, test drilling of survey holes with hand operated equipment is carried out first. Normally motorized drilling equipment will be used when boreholes deeper than 10 m have to be made. However, hand drills are perfectly sufficient since the depth of shallow wells is less than 10 m in general /10/.

In Mwanza region generally a machine auger is used (fig 7-10) because of hard formations encountered in many parts of the region.

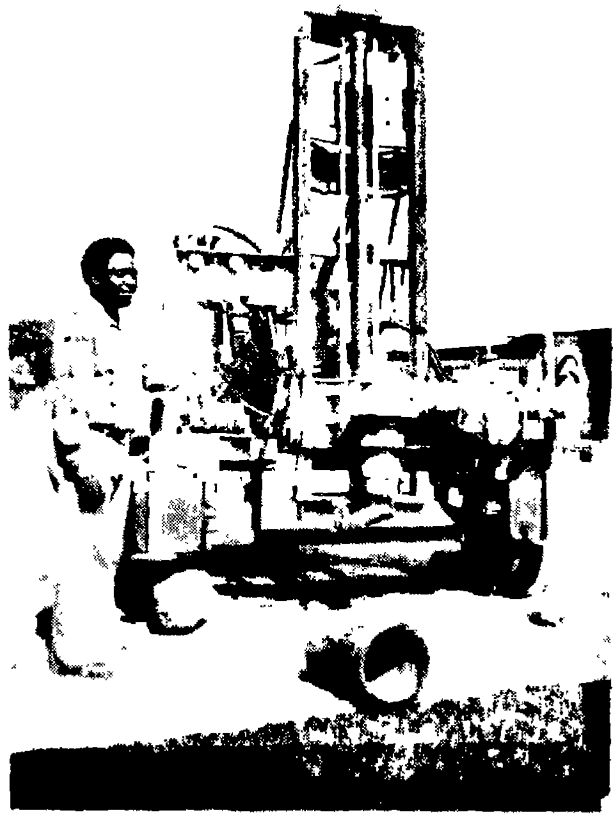


Figure 7-10. Machine auger.

7.7.1 Equipment and Its Use

Most of the equipment used in hand drilling are shown in the annex and as well as figure 7-11 below and they mainly comprise of:

- drilling rod and handles
- casing 10 cm dia and clamps
- riverside bit 7 and 10 cm dia
- combination bit 7 and 10 cm dia
- stone bit 7 and 10 cm dia
- screw bit 7 and 10 cm dia
- bailer 7 cm dia
- hand pump 7 cm dia

- hand pump with deep-well cylinder
- electrical conductivity meter
- water quality field test kit for the determination of fluoride content, pH etc.

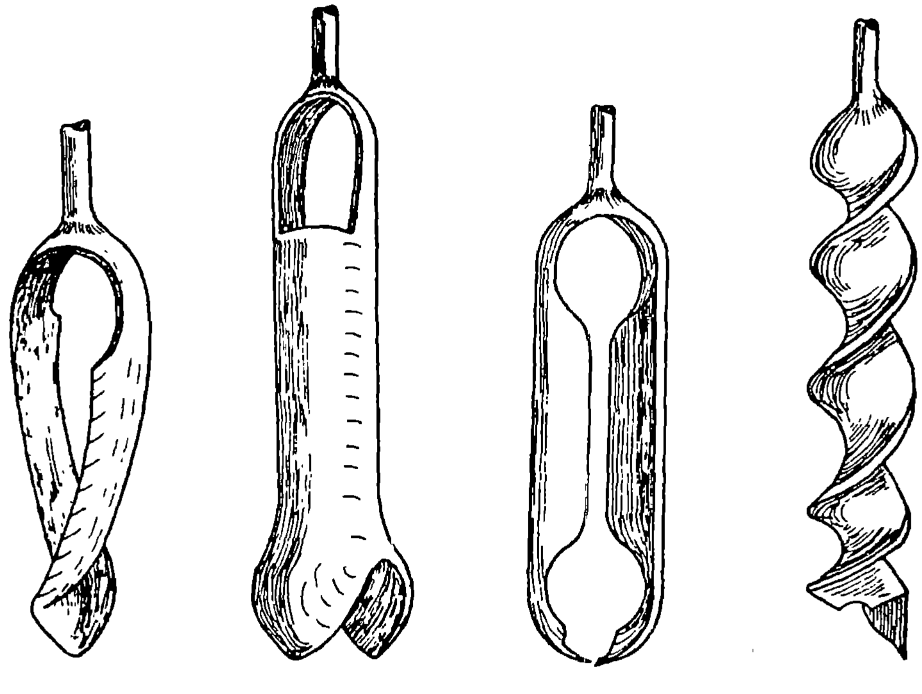


Figure 7-11. Hand auger equipment./ 8/

The purpose of various augers is as follows:

- Edelman auger (or combination auger)

  The body of this auger consists of two blades, the ends of which are forged into the augers end. The blades diverse gradually upwards to the desired diameter. This type of auger is generally suitable for clay, silt or sand soils. However, because of it having an average width it can be used in many kinds of soils.

- Riverside auger

  The body of this auger is a tube with two blades welded at the bottom. The blades are spoon shaped so that the soil is steadily pushed into the tube. This auger is very suitable for use in hard, stiff soils, in sand and soils mixed with gravel.

- Stone auger

  If the gravel content of the solid is so high that the riverside auger is not yielding adequate results, then sometimes the stone auger can be used to rift large stones that block the drilling operation.

- Flight auger

  This is a complete swivelled auger with a specially hardened bit, which makes the auger suitable for penetrating cemented soils and weathered rock.

- Spiral auger (or screw auger)

  This auger is made of a steel strip, forged into a spiral. With this auger hard layers e.g. laterite and calcrete can be broken loose and the material brought out with other auger types afterwards.

- Stone catcher

  This auger is made of an round iron bar forged in the shape of a spring. It can be used to remove large stones from the borehole and also as a fishing tool for equipment lost in the borehole.

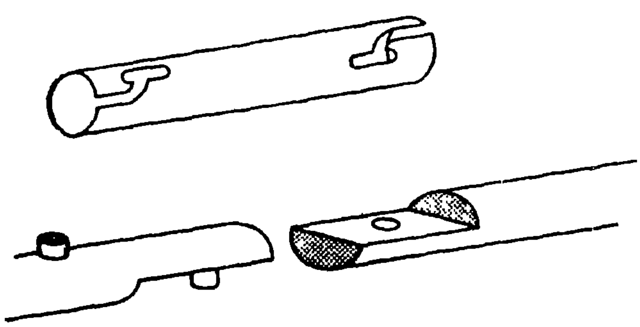
- Bailer

  The bailer or pulse is a tube, fitted with a valve at the bottom. It is used inside the casing for penetrating water-saturated sand layers by moving it up and down.

All these tools are available in various diameters. The small diameter bores are used for the normal drilling, the larger diameter ones for widening the borehole e.g. when a casing is used.

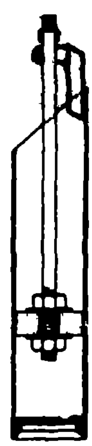
Augers are purchased with drilling rods of 1 meter length, which are calibrated in decimeters for easy measurement of depths of hole being drilled. These rods can be easily joined by means of quick coupling (fig. 7-12a).

When boring in (wet) sand casing is necessary to prevent the hole from caving in. The casing has a smooth inner and outer surface and is used in lengths of about 1 m. The inner diameter of the casing is slightly larger than the outer diameter of the smaller diameter augers. In sandy aquifers the sand can be removed from the casing by using a pump or a hand bailer. (Figures 7-12b and 7-12c) /29/.



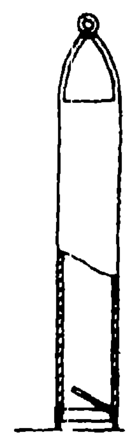
Coupling system for drilling rods.

Figure 7-12a.



Sandpump.

Figure 7-12b



Bailer.

Figure 7-12c.

7.7.2 Drilling Procedure

Briefly, drilling can proceed according to the following thumb rules /26/:

- An area of about 2 x 2 m is cleared around the drilling site. Drilling is started with a light-weight set using a 10 cm dia combination or riverside auger. In case a very hard and dry top soil is encountered, sometimes the upper 50 cm have to be broken up with a pick axe or hoe. If the soil is very hard to drill (e.g. stiff clays), first a pilot hole is drilled with a 7 cm dia augers and afterwards the hole is reamed with the 10 cm dia augers.

- When the water table is passed and the hole starts caving in or in case very loosed, dry material is encountered, a casing has to be placed. The lowest two casings are slotted and the upper ones are blind. At the bottom of the casings there is a casing shoe, the knife edge of toothed cutting which is slightly wider than the outer diameter of the casing.

- During lifting the drilling rod is to be disconnected in lengths of not more than 3 m to prevent bending of the extensions.

- If no progress is made anymore with the light-weight set, but drilling by hand is still possible, then heavy weight sets like flight augers are used.

- Drilling should be stopped when:

  a) a water bearing layer is encountered and a pumptest has to be done
  b) the hole is 16 m deep and no aquifer is found or expected at greater depth

c) coarse gravel, stones, very stiff clay or hard rock are encountered and further progress is impossible without damaging the equipment.

- The material from the borehole is laid out neatly in row in a sample box, each row representing a full meter of depth. (Figure 7-13)

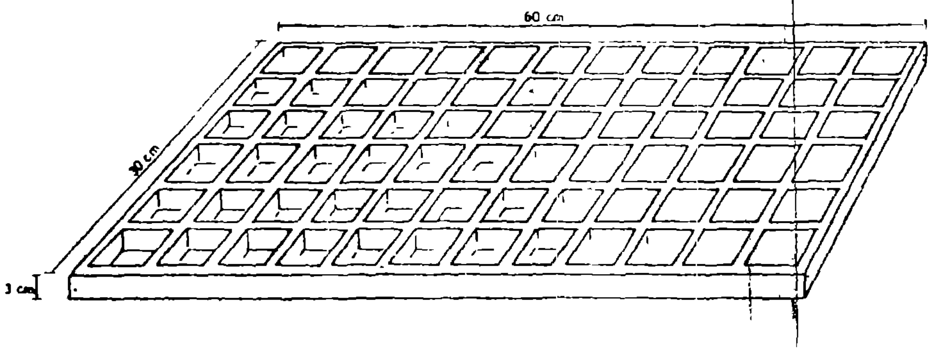


Figure 7-13. Box for rock/soil samples. /13/

- Immediately after finishing the drilling a borehole description is made using say a form like that one shown in figure 7-14.

7.7.3 Pump Testing

If in a survey drilling a water-bearing layer with some prospects have been found (e.g. confined aquifer of at least 1 m thickness), usually a pumping test will be carried out in order to get some insight into the yield of the test borehole.

A simple, hand-operated pump is lowered into the borehole. The depth at which the pump is operated can be adjusted by adding 1 m extensions to the rising main. After the static water level is recorded pumping can start. Pumping goes on for at least one hour provided that the pumping level of ground water does not descend below the pump intake in which case the pump intake would have to be lowered by adding more extensions to the rising main.

MOROGORO WELLS CONSTRUCTION PROJECT

Date	11 - 5 -1981	
Drill Equip	LSD	~~HCP~~
Surveyor	LYANGA	

Borehole Description - Survey Section

Village: KIBEREGE
Ward: KIBEREGE
Division: MANGULA
District: KILOMBERO
Co-ordinates: .. . .

Borehole number	MG/KL/81-4
Disapproved	Approved
Checked by	

Depth m-GL	Major Parts		Minor Parts		Consistency	Colour	Wet cont				EC µS/cm	Kind of auger	Profile m-GL
	lithology	gradation	lithology	gradation			dr	m	w	wb			
0.00-0.20	CL	-	-	-	LS	BLK	x					CL	
0.20-0.50	SD	FN	-	-	LS	BR			x			"	
0.50-1.50	SD	ME	-	-	LS	GY			x			"	
1.50-2.00	SD	ME	-	-	LS	BR				x	920	RS	
2.00-3.00	SD	ME	-	-	LS	BR				x	720	BA	
3.00-3.50	CL	-	-	-	STK	BR		x				CL	
3.50-5.00	CL	-	SD	ME	SFT	GY/BR	x					CL	
5.00-7.00	CL	-	-	-	STK	OG	x					CL	
7.00-8.00	SD	ME	MUCH CL	-	SFT	GY/BR		x				CL	
8.00-8.80	CL	-	-	-	STK	OG		x				CL	
8.80-9.70	SLT	-	-	-	LS	GY			x			CL	
9.70-10.00	CL	-	-	-	STK	GY	x					CL	
10.00-11.00	SD	ME/FN	-	-	LS	GY				x	720	RS	
11.00-12.00	SD	ME/FN	-	-	LS	YE				x	720	BA	
12.00-13.00	CL	-	SD	FN	STK	OG	x					CL	

INDEX

Lithology		Gradation		Colour	
clay	= cl	fine	= fn	black	= blk
silt	= slt	medium	= me	brown	= br
sand	= sd	coarse	= cs	grey	= gy
gravel	= gr	**Consistency**		blue	= bl
stones	= st	soft	= sft	green	= ge
sandstone	= sd.st	sticky	= stk	yellow	= ye
laterite	= lat	loose	= ls	white	= wh
calcrete	= cal	weathered	= wed	red	= red
mica	= mi	hard	= hd	orange	= og
basement	= bm				
very	= ve	**Kind of auger**		dark	= d-
much	= mu	clay	= cl	light	= l-
little	= li	riverside	= ri	mottled	= mot
layers	= lay	bailer	= ba		

water bearing — water level — ground level = GL — liters/hour = l/h

Total drilling depth: 13.00 m-GL
Aquifer(s) depth(s): 1.50-2.00 m-GL; 2.00-3.00 m-GL; 10.00-12.00 m-GL
Water level: 1.70 m-GL
Tested yield: 1904 l/h
Max drawdown: - m
EC at T_0: 720 µS/cm
EC at T_{60}: 300 µS/cm
Screen depth: 9.00-12.00 m-GL
Pump intake depth: 8.00 m-GL
pH: .... . m³/day

Figure 7-14.

During the test the yield, the water level and the electrical conductivity (to check salinity of the water) are measured and recorded every 10 minutes. After pumping has been stopped, immediately the recovery of the ground water level in the hole is measured for a period of about 5 minutes with intervals of one minute /9/.

From experience a well yield of more than 1 000 litres per hour during the survey pumping test is sufficient for construction of a hand-drilled shallow well. If the yield of the survey pumping test is between 500 to 1 000 litres per hour, then test drilling should be continued to find a borehole with a yield of at least 1 000 litres per hour. Should such a borehole not be found, then that one with the highest yield might be approved for construction of a hand-drilled or hand-dug well. Pumping test yields of below 500 litres per hour are usually disapproved /7/.

During the implementation of Shinyanga Water Master Plan, DHV-Consulting Engineers made a study and found out that a minimum of two minutes was needed to rinse, fill and replace a 20 l bucket. This means that the maximum amount that can be drawn from the well per hour is 600 litres.

The following daytime consumption may be assumed for a frequently used ring well:

6 - 9 h	100 %	of pump capacity used	= 1 800 l
9 - 16 h	50 %	of pump capacity used	= 2 100 l
16 - 19 h	100 %	of pump capacity used	= 1 800 l

That is a total of 5 700 l/day, which is sufficient for nearly 300 people. The demand was cumulatively plotted in relation to the time as shown in figure 7-15.

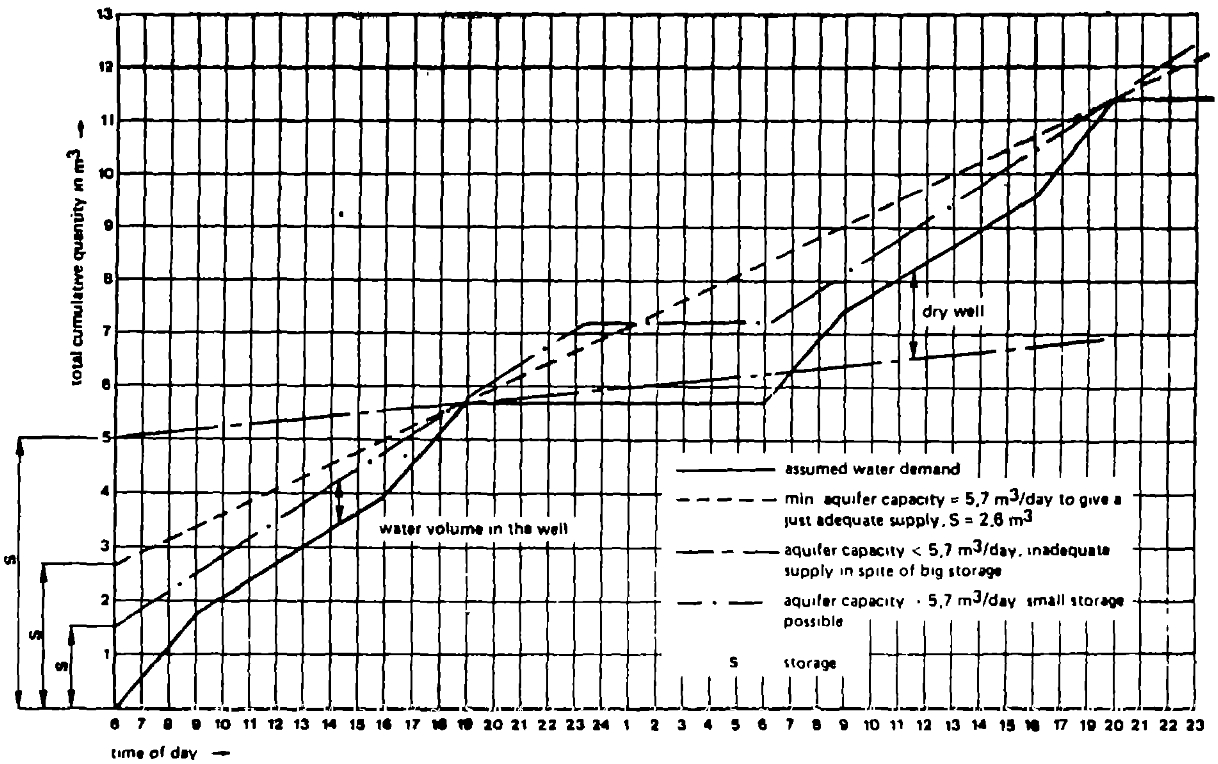


Figure 7-15. Storage in relation to demand and supply./8/

The minimum supply needed just to avoid a dry well was also plotted. This then showed that the supply must amount to 5.7 m^3/h with a storage of 2.6 m^3/h (supply during the 11 night hours). In the case of a smaller supply shortage of water will indubitably occur after a certain time irrespective of the storage volume (see graph). In the case of a larger supply a smaller storage of approximately 3 m^3 guarantees just sufficient water at the lowest possible supply and is therefore recommended.

The following standards are usually adhered to the depth of the well /11/:

a) The depth must be such as to allow a storage of 3 m^3 beneath the upper surface of the aquifer (about 3 m in depth)

b) Digging must continue through the aquifer until reaching at least the next solid layer.

If the capacity of the aquifer is not sufficient to recharge the well to a depth of 3 m in one night, the well is considered to be unsuccessful. An accurate well test during survey can prevent the choice of these unsuitable locations /8/.

7.7.4 Recommendation for Construction

The end products of survey and test drilling are approved well sites and information on:

- the location of the well site
- the type of well
- its construction particulars
- problems to be expected during construction
- the accessibility by a car or truck to the well site during different seasons /29/.

This information should further include:

- the benchmarks with identification numbers indicating the exact position of the approved well site in the field
- copies of the village sketch and the well situation sketches
- copies of the survey borehole description and recommendation on the type of well, total well depth, depth of screen and if necessary slot size of the screen and grain size of the gravel pack
- lithological profile of the approved boreholes.

The whole survey procedure is not rigid. The following flow chart (fig. 7-16) was derived by DHV Consulting Engineers /9/. It may be of general and/or can be adopted mutatis mutandis.

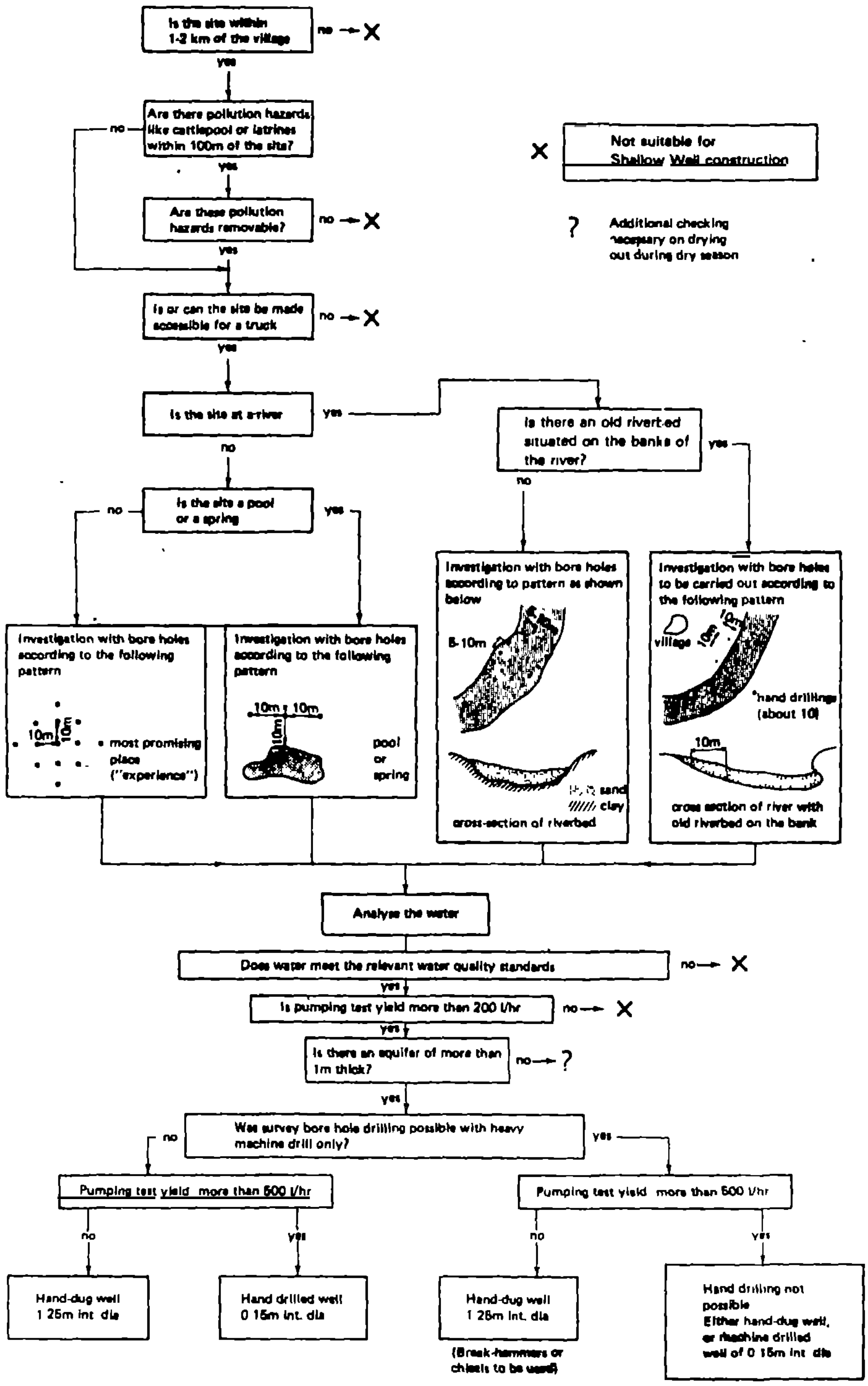


Figure 7-16. Flow sheet shallow wells site investigation /9/

7.8 Practice in Selected Regions

The test drilling follows the same procedure in all the selected regions of Mtwara-Lindi, Morogoro and Mwanza Regions.

8. WELL CONSTRUCTION

8.1 Type of Wells

Generally there are two types of wells:

- dug wells and
- drilled wells.

The obvious difference between them is the size of the holes. The method of sinking depends on the choice of the individual contractor or prevailing soil conditions. Wells may be dug by hand or by hydraulic excavator, drilled with hand tools or drilled by a machine auger.

Apart from other factors which may govern the choice of type of well to be constructed, the main factor is the geological formation. Table 8-1 shows the suitability of well construction methods to different geological conditions/5/.

Table 8-1. Suitability of well construction methods./5/

CHARACTERISTICS	TYPE OF WELLS		
	DUG	Hand drilled	Machine drilled
Range of practical depths (general order of magnitude).	0 - 30 metres	0 - 30 metres	0 - 300 metres
Diameter	1 - 6 metres	0,05 - 0.30 metres	0.1 - 0.5 metres
Type of geological formation:			
Clay	YES	YES	YES
Silt	YES	YES	YES
Sand	YES	YES	YES
Gravel	YES	YES	YES
Cemented gravel	YES	NO	YES
Boulders	YES	Yes, if less than well diameter	YES, when in firm bedding
Sandstone limestone	YES, if soft and/or fractured	Yes, if soft and/or fractured	YES
Dense igneous rock	NO	NO	NO

8.2 Dug Wells Construction

These wells are sunk by digging a hole as deep as possible or necessary to reach the water bearing aquifers. The aquifer must be penetrated as far as possible so that to maximise the yield of the well. These types of wells have both their advantages and disadvantages as advanced by R.E. Brush /5/.

8.2.1 Well Design

After the site has been chosen, before one starts digging the well should be designed and the following should be determined /5/:

- the size and shape of the hole
- which digging and lining methods will be followed
- how much water needs to be available, and therefore, how deep to the bottom section should go into the aquifer
- how the top section should be constructed to best protect the well from contamination, while allowing easy access to water by those who will use the well
- the anticipated well depth.

The well size and shape in Tanzania are between 1 m to 1.45 m and round respectively. Other design parameters are found during the locations of well sites and test drilling as earlier described in chapter seven. There are no rigid rules for the design of dug wells.

Advantages:

- The construction procedure is very flexible. It can be easily adapted with a minimum of equipment to a variety of soil conditions as long as cement is available.

- It provides a reservoir which is useful for accumulating water from ground formations which yield water slowly.

- Because the resulting well is wide-mouthed, it is easily adaptable to simple water-lifting techniques, if pumps are not available or appropriate.

Disadvantages:

- Hand dug wells take longer to construct than drilled wells.
- They are usually more expensive than drilled wells.
- They cannot be made into permanent water sources without the use of cement.
- Hand-digging cannot easily penetrate hard ground and rock.
- It may be difficult to penetrate deeply enough into the aquifer so that the wells will not dry up during the dry season.

A dug well

- must be lined with a hard and corrosion free material preferably with porous concrete rings
- must have sufficient internal diameter approximately 1.25 m to allow people to work inside to clean and deepen the well
- must be dug through the aquifer as far down as at least 3 m so that approx. 3 000 l of stored water will be available early in the morning even in a low yielding aquifer
- should be provided with a 10 cm thick layer of gravel at the bottom
- should be provided with a impenetrable concrete slab constructed so that all seams and cracks are filled with bituminous kit
- must be completely covered at the top.

8.2.2 Hand-digging

The main equipment and tools required for digging usually depend on the soil conditions, and they include:

- spades (shovels)
- pointed pick axes
- hoe pick axes
- sledge hammer
- mason hammer
- cold chisels
- bucket with 15-20 m rope
- tripode with pulley
- hand membrane dewatering pump
- plumb bob
- measuring tape.

The hole is dug in the following sequences with reference to figure 8-1.

- after locating the test hole with it as centre, a hole diameter of about 1.8 - 2.0 m is marked on the ground
- digging starts by removing a layer from 10 to 40 cm thick that comes to within 5 or 10 cm of the desired diameter (see fig. 8-1b)
- digging continues by removing layers until a depth of about a metre (see fig. 8-1c)
- then the step is trimed out at the same time making sure that the hole is plumb (see fig. 8-1d)

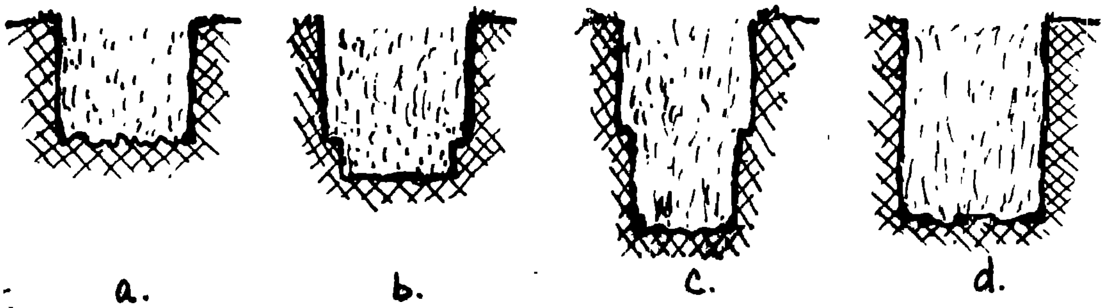


Figure 8-1.

- digging continues until the desired depth. When the required depth is reached then the bottom is levelled, a good coarse sand of about 10 cm in thickness is placed at the bottom. Thereafter a layer of 10 cm in thickness of gravel is installed ready to receive well rings. If the bottom is within a sand layer and it is suspected that there is a likelyhood of negative pressure so that sand will enter the well, the bottom should be sealed with lean concrete.

Problems encountered during digging are as follows:

- When the dug hole is deep it becomes difficult or even impossible for the digger to throw out the dug soil. If this happens, a tripod is erected on top of the hole with a pulley at the top and a rope and bucket are lowered into the hole with the aid of this pulley. Then a bucket is filled with soil, pulled up, emptied and the process continues until the hole is completed (see fig. 8-2).

Figure 8-2.
Bucket and rope.

- Another problem is caving in or falling sand. The best solution for caving in is to line the hole. In case of falling sand which behaves like thick liquid, it should be stopped otherwise the hole will end up V-shaped but even wider at the top than the hole in deep. In such a situation sand can be sometimes stopped by digging 10 to 15 cm and then splasing a mixture of cement and water on the wall. This will dry in minutes to form a thin hard layer. If that fails pour about 200 litres of water into the hole before digging the next metre. This saturates the sand to make it more stable./5/

- The problem of water seepage into the hole becomes iminent as soon as the aquifer is reached and it must be removed. At first this can be done with bucket as for removing the soil, but as the inflow increases one or more hand membrane pumps will have to be used. Figure 8-3 shows the combination of bucket and hand pump being operated by the author at Ibongoyo village in Mwanza region.

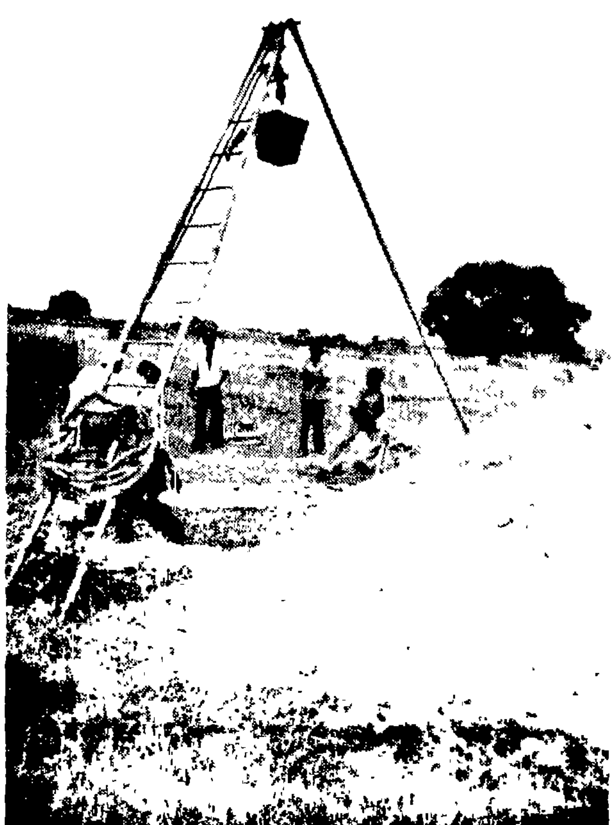


Figure 8-3.
Membrane pump.

- Where there is a deep lying aquifer, it also becomes difficult for man to go and come out from the hole. In this case a rope ladder as shown in fig. 8-4 is very useful.

Figure 8-4. Rope ladder.

8.2.3 Hydraulic Excavator Digging

In areas where accessibility by heavy trucks is possible, hydraulic excavators are well suited for digging the water holes.

These machines are quick and vesertile, however the holes dug are generally rectangular and large, so that in situ concrete rings will require double shuttering. Also when precast rings are used, care should be taken in backfilling. The backfill material should be a well compacted impermeable layer so that to avoid subsidence and thus ruining the surrounding of the well. Figure 8-5 shows a shallow ring-well in a machine dug hole, note the inclining original digging line.

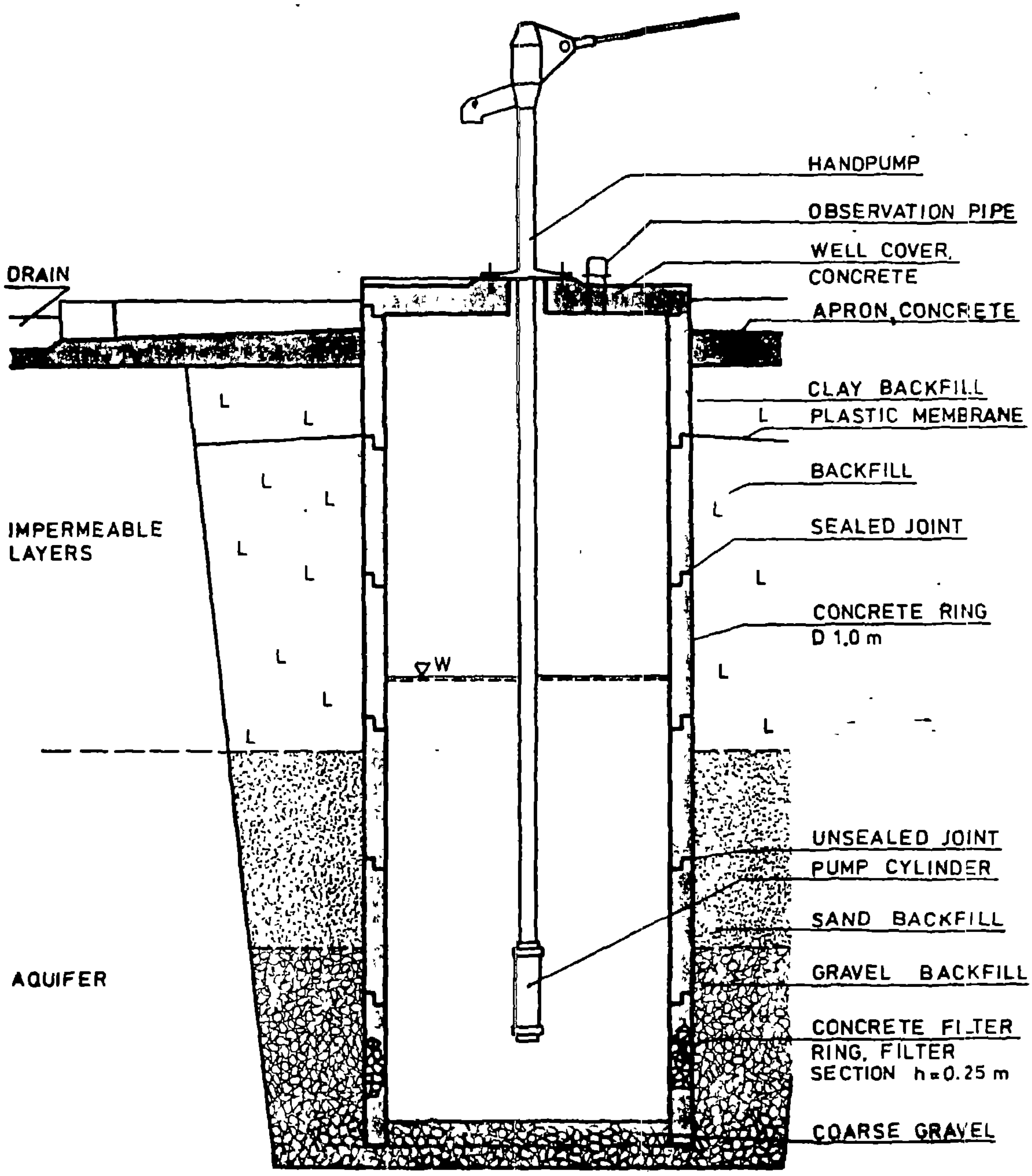


Figure 8-5. Machine excavated water well./29/

8.2.4 Regional Practices

Excavation practice of dug wells in the selected regions is that:

a) In Mwanza region only hand digging is used. There are no hydraulic excavators in this regional project.

b) In Mtwara-Lindi most of the ringwells were excavated by hydraulic excavator especially during the early days of the project. Recently the project has introduced the self help scheme where the villagers dig the hole first and the project management gives rings, pumps and installation labour free of charge.

c) In Morogoro, there are no dug wells being constructed for the time being. Only tube wells are constructed.

8.3 Manufacturing of Well Rings and Well Covers

Concrete well rings or cassions are usually pre-cast in a central workshop and then transported to the well sites for lowering into the dug up holes. Making of rings requires the use of inner, outer, top and bottom forms. These moulds are usually made of steel and fixed with clamps to keep the distance between the inner and outer moulds (see fig. 8-6) exact.

The rings are manufactured in two main ways:

- fully concrete rings of a 1:3:4 mix
- filter rings of the same mix but without sand i.e. 1:4 mix. The gravel used should fit in a sieve grade of 6 mm - 25 mm.

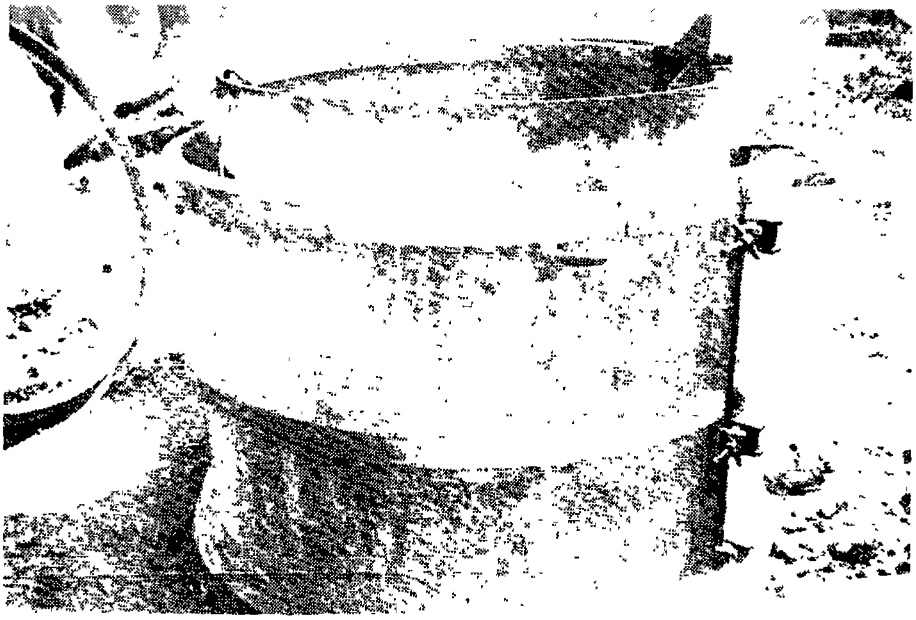


Figure 8-6. Steel moulds for concrete rings.

Concrete rings should be made so that they:

- can be easily stacked or attached one on top of another and thus they are given a 5 cm x 5 cm rebate with a sloping centre at top and bottom except for the cutting ring, which has a rebate at the top only. The rebate also helps to make the rings form a water tight joint when they meet.

- are strong enough to support weight of a high column of rings

- will not rot, corrode, rust or otherwise lose any of the above qualities

- will not react with water to make the water less desirable for consumption.

8.3.1 Regional Practices

Casting of well rings practice is nearly the same for Mwanza and Mtwara-Lindi regions.

a) Mwanza Region:

The rings in Mwanza are casted in the yard located some 8 km from Mwanza City.

There is no established quarry for the aggregates but they are bought from local suppliers and they are usually hand broken. Sand used is normally from river beds.

- The rings are usually 1 m high, and 80 cm of filter height is available for filter rings. The rings are reinforced with two steel bars of 6 mm diameter placed one at 10 cm from the top and another at 10 cm from the bottom.
- The concrete is poured into the mould and compacted by hand with a wooden stamper, after one hour the concrete is already set and the mould is then removed for re-use. The ring is left open for approximately 48 hours before it is cured in a water tank for about 4 days after which they are ready for transportation to the well sites.
- Quantity of raw materials required for rings commonly used /9/.

Ring dia (m)	Cement (bags)	Sand (m^3)	Gravel (m^3)
1.2	1.5 (1.5)	0.32(0.12)	0.12 (0.32)
1.0	1.5 (1.5)	0.15(0.06)	0.08 (0.15)

Figures in brackets are for filter rings.

a) Mtwara-Lindi Region:

- The ring and cover factory is situated at Nanganga quarry which is owned and operated by the project. Like Mwanza sand is obtained from riverbeds.

- The rings are usually 0,53 cm high and they are reinforced with three pieces of reinforcing steel of 6 mm diameter, one at the top one in the middle and one at the bottom.

- The concrete is poured into the moulds, and then compacted by vibrator. They are let to set for one to two hours, then the moulds are removed and the rings are sent for curing before they are transported to the respective well sites.

- Quantity of raw materials required for rings commonly used.

Ring dia (m)	Cement (bags)	Sand (m^3)	gravel (m^3)
1.2	1.25(1.25)	0.06(0.05)	0.08(0.07)
1.0	1.0(1.0)	0.04(0.03)	0.06(0.05)

figures in brackets are for filter rings.

8.3.2 Concrete Ring Covers

These are also manufactured along with the well rings. They are always in various types depending on the type of well and pump to be used.

- In Mwanza they vary in thickness from 12 cm to 32 cm. They are usually reinforced with 10 mm Ø bars.
- In Mtwara-Lindi they are of uniform thickness of 15 cm and they are reinforced by 5 Nos 10 mm Ø bars.

8.4 Handling and Transporting of Well Rings

The weight of each ring is very high, e.g. 1,2 tons for those manufactured in Mwanza. They require careful handling as they are easily damaged.

The transport trucks should be filled with a 5 cm thick layer of sand in order to smooth out bumps during transport. Then the rings are loaded onto the truck by use of tripods or by a crane loader. The same procedure is followed when unloading the rings at the well sites.

8.5 Lowering of Well Rings and Completion of the Well

When the necessary rings, a well cover, some bags of cement and a load of sand and gravel have been delivered at the well site, the well to be constructed can be completed./9/

The first ring to be sunk (the cutting ring), is rolled to the well and on top of a sling, the tripod is being positioned almost exactly over the well opening (fig. 8-7). This distance between the ring and the well edge is 1.5 m, the top of the ring facing the opening of the well.

In the next phase the ring is pulled upwards slightly and thus it moves slowly to the edge of the well opening, hanging somewhat askew due to the accentric position of the sling.

The underside of the ring is now pushed towards the edge of the well, while at the same time the tackle is pulled away from the well and the tackle rope is paid out. Thus the well ring is put in a horizontal position right next to the well (figures 8-7b and 8-7c) /9/.

Figure 8-7. The well ring installation by using a tripod.

Figure 8-7a.

Figure 8-7b.

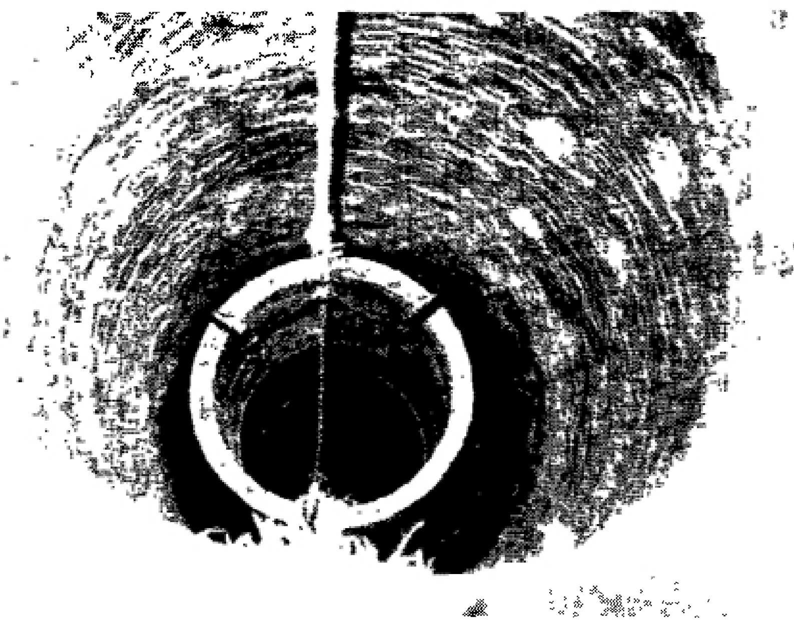


Figure 8-7c.

The position of the tripod is now changed in such a way that the tackle is exactly over the centre of the hole. Then the 7 m long sling is fastened around the ring. A rope is attached to the pulley hook and by pulling the tackle rope upward, at the same time paying out the rope, the ring is carefully put into position over the well. Then the guide is removed and the ring is lowered to the bottom of the well (figures 8-7d and 8-7e).

When the ring has reached the bottom, its position is checked with a water level. If it is not exactly horizontal, the ring can be lifted slightly, some soil removed from underneath, etc. until it is exactly in level.

In the same way the other rings are put into position, the filter rings being used at the depth of the aquifer only. A cover is put on top of the uppermost ring.

Then the space between the undisturbed soil and the outside of the filter rings is filled with gravel up to the upper boundary of the aquifer, some concrete is poured on top as a seal, and the remainder is filled with earth (figure 8-8).

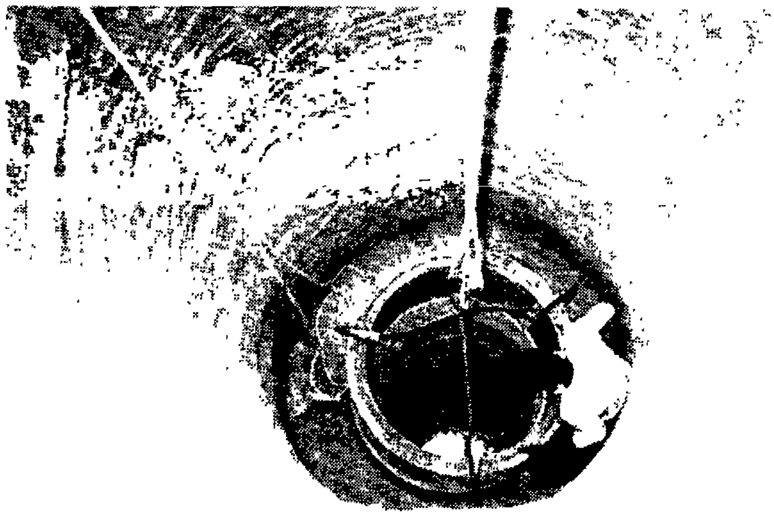


Figure 8-7d.

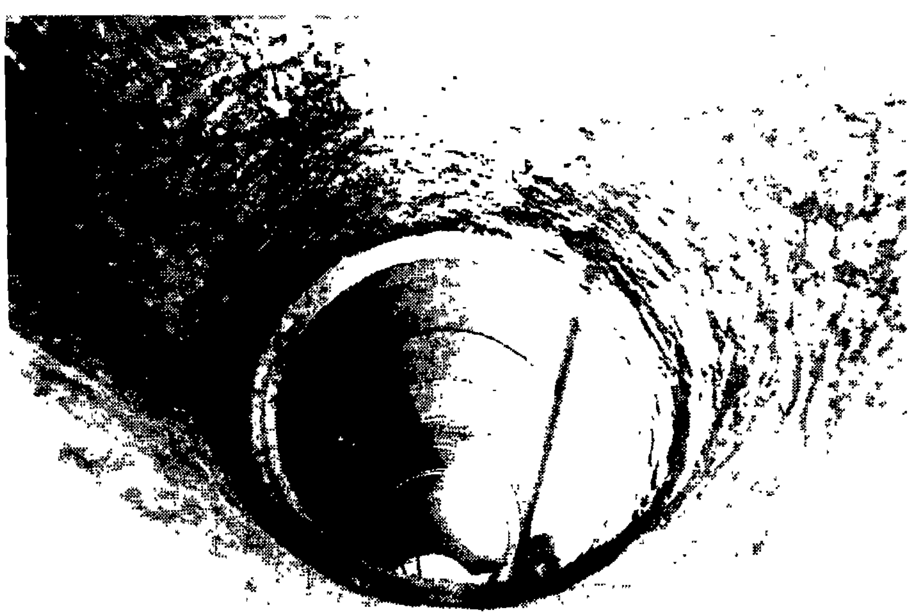


Figure 8-7e.

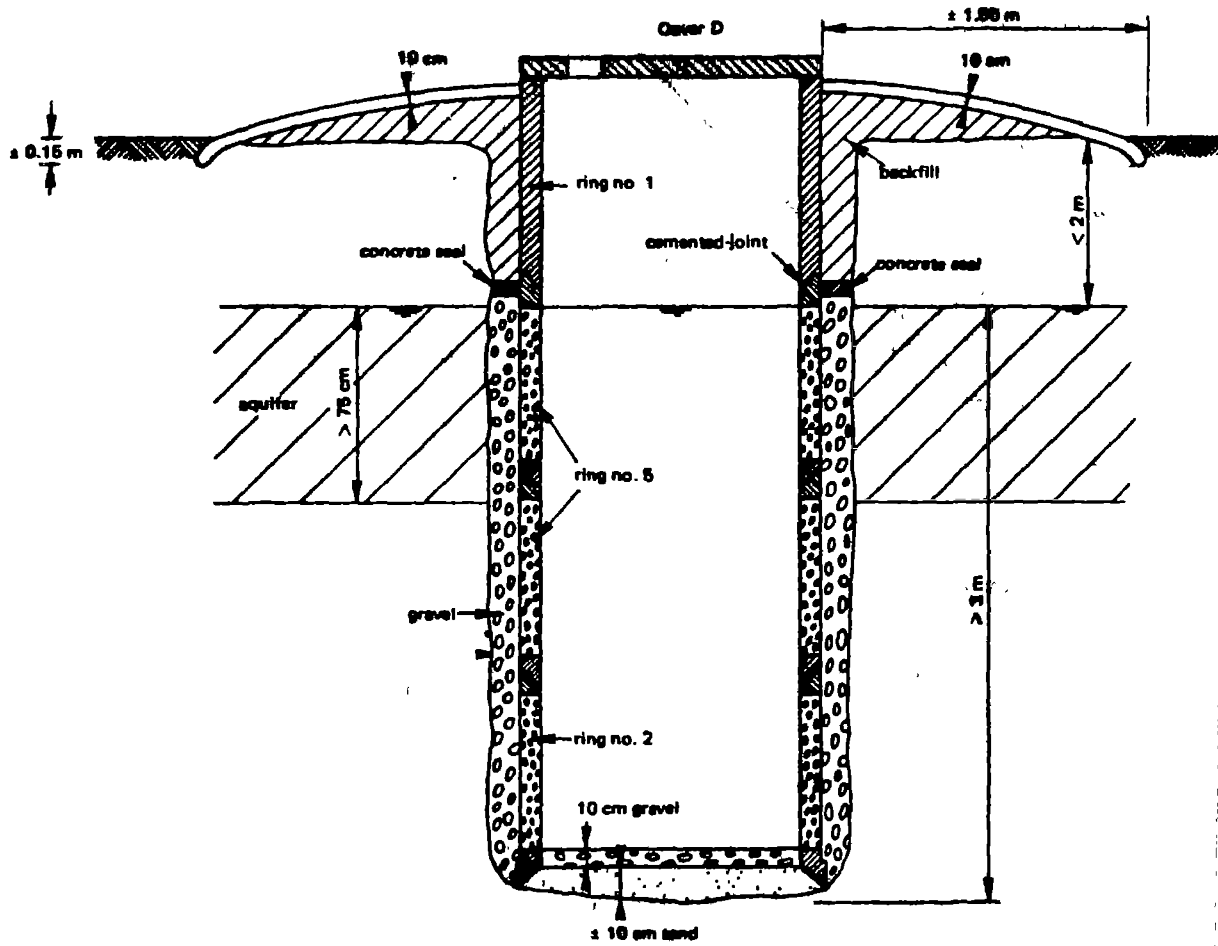


Figure 8-8. Standard well./5/

8.5.1 Wells in Loose Soils

In loose soils it may not be possible to dig deep without a well lining, because of caving in of the walls. Therefore a cutting ring is lowered into the hole and digging is continued by people standing inside the ring. They dig the soil away from underneath the cutting edge, thus the ring is slowly sunk and additional rings can be put on top until the described depth is reached.

It has often been experienced that in these loose soils (mostly sands) the rings sink askew, which provides problems especially when the thickness of the loose layer is about

4 m or more. In less thick layers (about 2 m) the best way is to continue digging as fast as possible until firmer layers are struck. Even if the rings are standing askew they may be put in an upright position again, as follows:

If the rings are in the position indicated in figure 8-9a, the soil is dug away as much as possible at the lowest side and behind the ring. Next at the higher points of the bottom of the hole the earth is removed and the rings can be slid back into a vertical position (figures 8-9b and 8-9c) /5/.

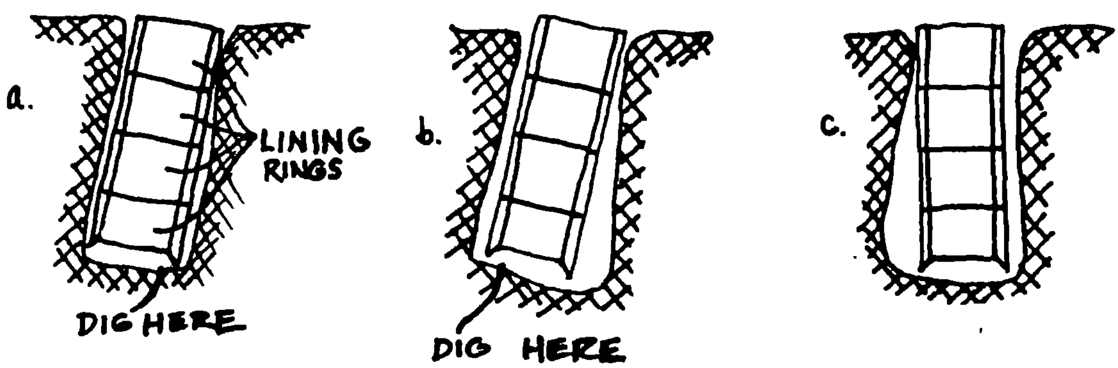


Figure 8-9. Straightening well rings in loose soils./5/

8.6 Drilled Shallow Wells

Drilled wells can either be machine auger wells or hand auger wells, depending on the tools used in drilling the well itself. The choice of drilling tools and method is governed by the geological formation of the well site.

Drilled wells like any other wells have also both advantages and disadvantages.

Advantages:

- They are fast to construct.
- They do not require much cement, and they can be sunk.
- with locally made drilling equipment and lined with local materials.
- While not easy, it is possible to penetrate hard ground and rock formations that would be very difficult to dig through.
- Drilling usually requires fewer people than hand digging with shallow water table.
- Drainage slab is easily constructed because of the small diameter of the tube well.

Disadvantages:

- There are a number of different hand drilling techniques that are suitable for a wide range of ground conditions. However, each requires special equipment.
- Pumps almost always have to be used because buckets are too large to be lowered into the well.
- Limited depth can be reached with hand powered drilling equipment.
- Low storage capacity, thus they cannot be constructed in areas with low transmissibility aquifers.

Drilled Wells:

A drilled well should have the following specifications:

- should be drilled perfectly vertical
- should consist of a thick walled casing of 100 mm internal diameter at a minimum (suitable for lowering a 75 mm pump cylinder)
- the lowest 6 m of the casing should be of screen or slotted pipe, slot size of 0,5 mm, to guarantee sufficient inflow of water even when a substantial part of the slots are clogged.

- should have a minimum gravel pack of 30 mm around the filter, 3 - 5 mm gravel size, and a sealing layer of clay or cement on top of this gravel pack to prevent pollution from above
- should be provided with a bottom plug underneath the filter.

8.6.1 Machine Auger Wells

Machine auger wells are mainly constructed where the soil conditions are favourable for the natural development of the well, i.e. where coarse gravel and sand layers saturated with water are available and/or deeper than 10 m below surface. The structure of a machine auger well is shown in figure 8-7. The practice was common in Mtwara-Lindi region, the steel casing and stainless steel well screen are flushed down the hole with compressed air and water. The bottom of the well is always sealed with concrete, and finally the well is developed with compressed air. This method is cheap and quick in favourable conditions. Due to its smallness in diameter an artificial filter (gravel packing) cannot be used. This method is not suitable for silt, fine sand formation or alluvium. Figure 8-8 shows one type of well drilling machines.

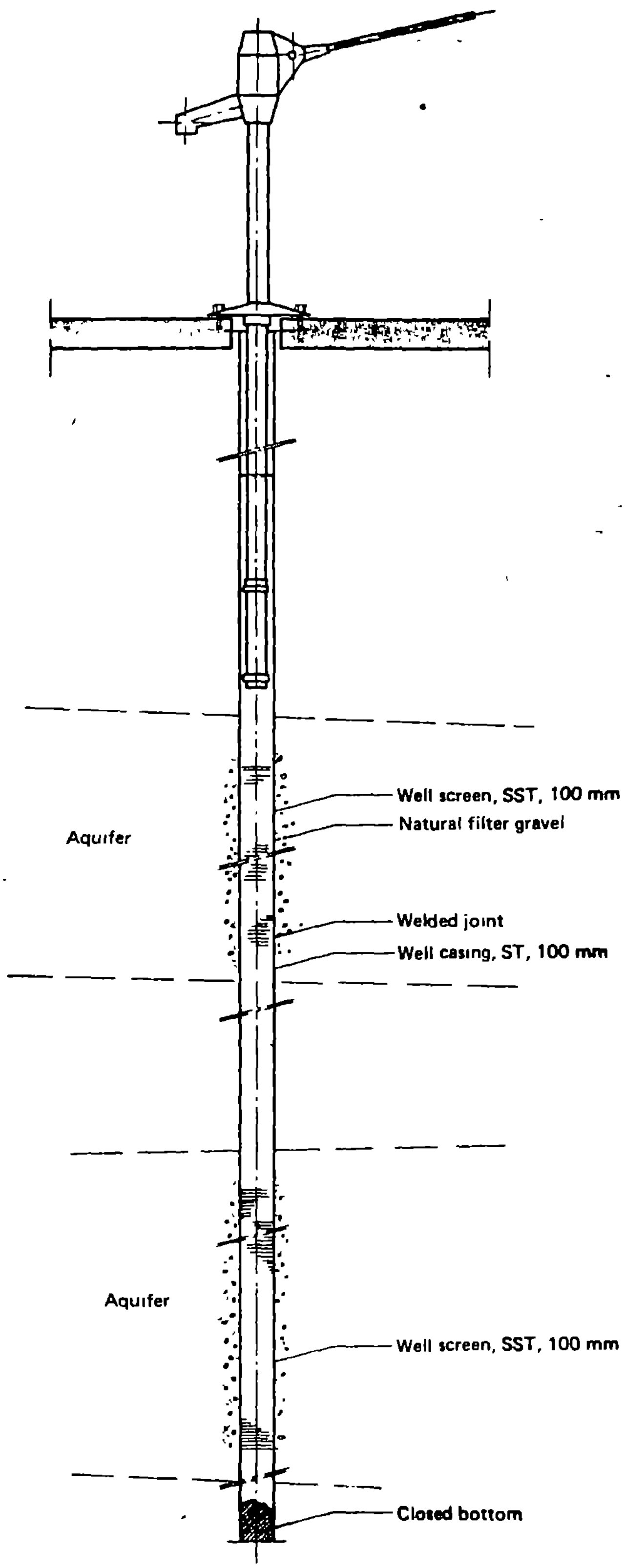


Figure 8-10. Machine auger well./29/

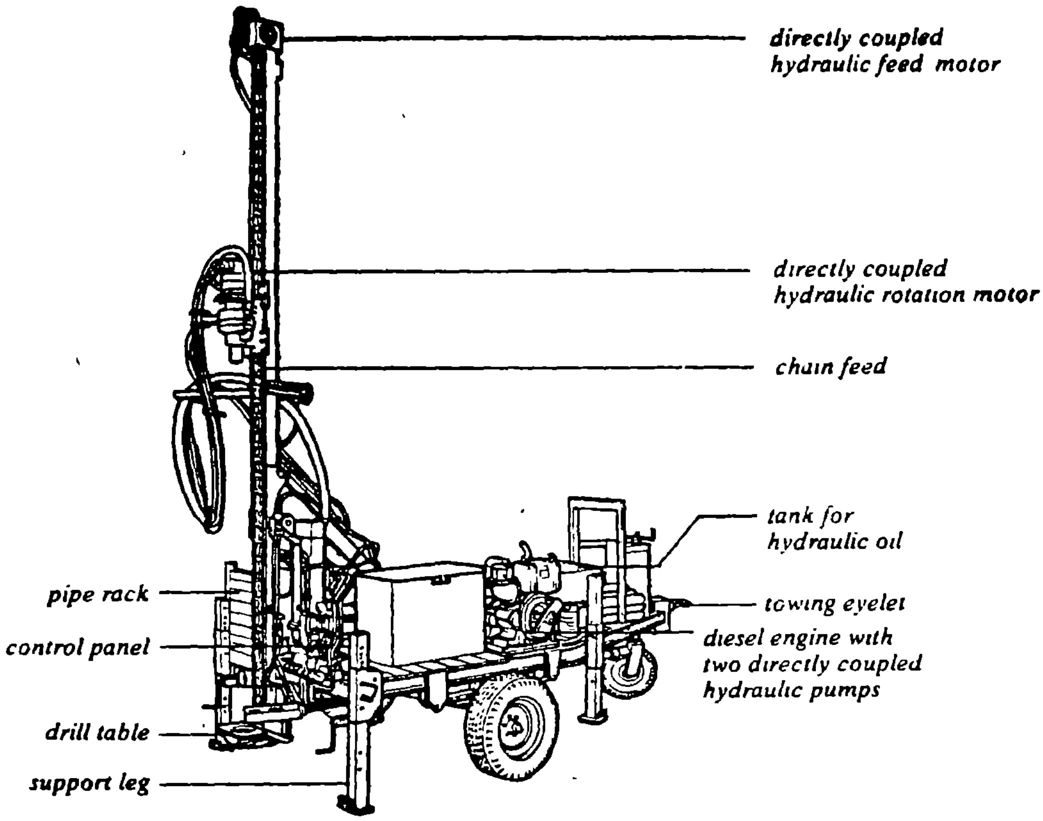


Figure 8-11. Water well drilling machine.

8.6.2 Hand Auger Wells

There are four basic operations involved in the construction of tube well. These are the drilling operation, casing installation, grouting of the casing when necessary and screen installation.

Drilling

Hand drilling is the most economical way to construct water wells, as long as the ground water level is not too deep (approx. 10 m) and the soil is not too hard.

For a standard tube well of about 200 mm dia, a hand drilling set consists of the parts shown in table 8-2. Hand auger wells are mainly constructed in areas where machine auger wells are not practical due to silt and fine sand. They are also suitable in areas where ground water table is too deep for a ring well and too shallow to warrant a machine auger.

Table 8-2. Hand drilling equipment.

Description	Size (mm) dia	Quantity
Bit for flight auger	230	1
Bit for flight auger	180	1
Conical bit	180	1
Flight auger	230	1
Flight auger	180	1
River side auger	180	1
bailer with spare valve	165	1
drilling rod	76 x 500	1
drilling rod	76 x 1000	3
drilling rod	76 x 1500	5
drilling rod	76 x 2000	3
drilling rod	76 x 3000	1
stabilizer	180 x 1000	1
piece complete	76 x 1000	1
drilling rod catcher		1
bolt M16 x 80 with chain		40
drilling rod hanger		1
casing	220/200 x 1250	18
thread protectors	220/000 (female)	18
thread protectors	220/200 (male)	18
casing shoe	220/200	1
casing clamp	30-220/200	2
lowering pipe	220	2
chain spanner	220	2
tripod, complete		1
winch, complete with spare cable	10	1
pulley block with swivel hook		1
knives for auger bits	230	
Knives for auger bits	180	
coupling hexagonal forthimbles	76	Set
pulley block with flap door		1
swivel hook	3 tons (capacity)	1

Drilling procedure is the same as earlier explained in test drilling. However, in this case bigger diameter augers are used in reaming the approved test hole. Figure 8-12 shows hand drilling in operation and figure 8-13 shows a completed hand auger well.

Figure 8-12. Hand drilling in operation in Morogoro.

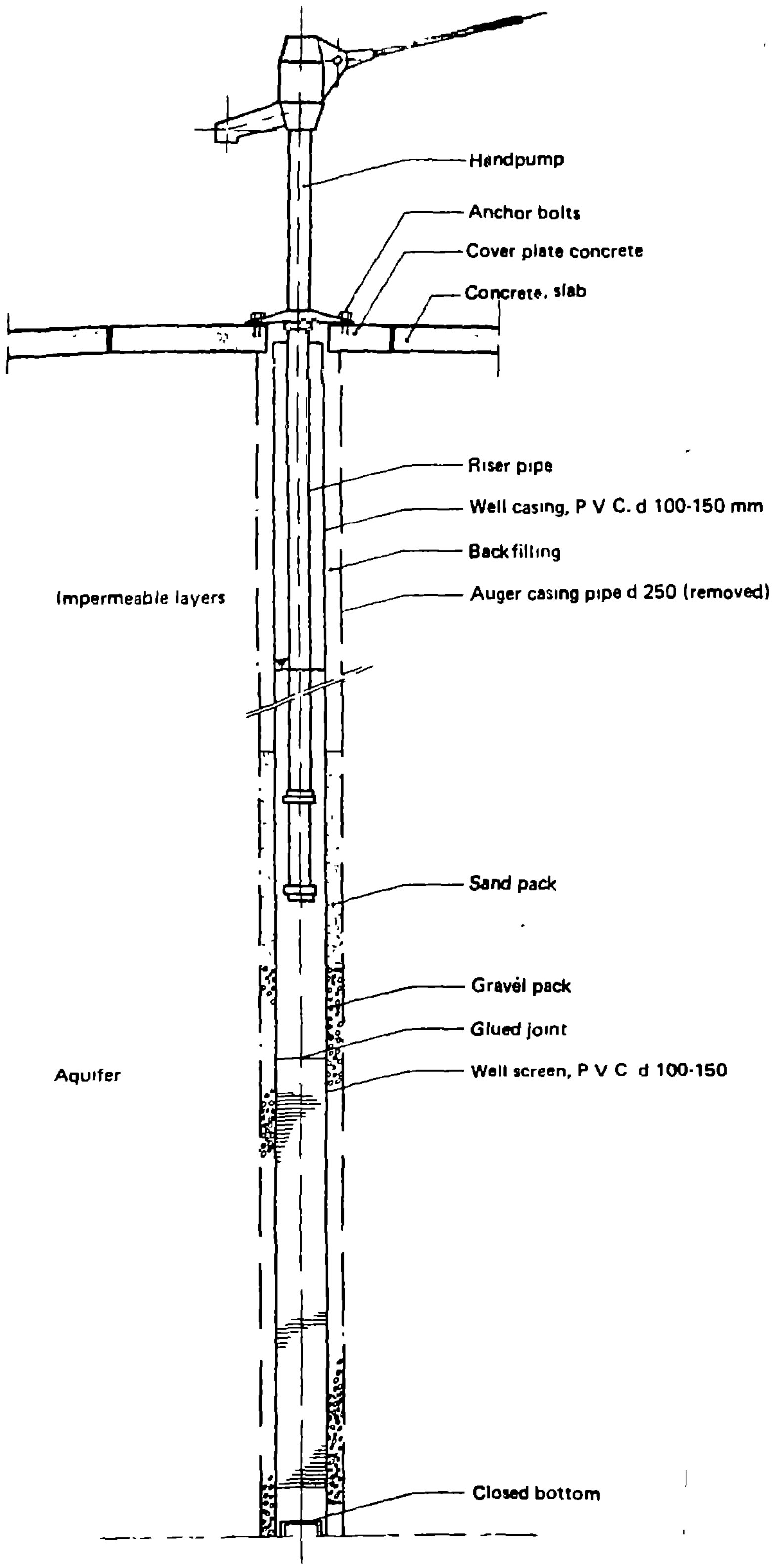


Figure 8-13. Hand auger well./29/

8.7 Tube Well Design and Construction Principles

8.7.1 Tube Well and Lining Diameter

Lining and hole diameter depend on many factors, and both should be kept as small as possible in order to minimize cost.

a) The internal diameter requirement of a well after completion should be 100 mm to accomodate a hand pump cylinder, which may be up to 90 mm OD. If the material is unconsolidated or semi consolidated a lining will be required to prevent the bore hole from collapsing. This needs a pipe of 100 mm ID. If the bore hole is machine drilled in hardrock and no casing or screen is necessary, the hole diameter should be at least 100 mm.

b) If the formation is unconsolidated or semi consolidated and contains more than 10 % material smaller than fine sand a graded gravel pack will be required as well as a lining to prevent in flow of fine material into the well. This is commonly the case in alluvial aquifers of Morogoro and weathered basements in Mtwara.

c) Effect of hole diameter on yield is verified by the equation

$$Q \text{ x } \frac{1}{\log {r_o / r_w}}$$

where Q = bore hole yield

r_o = radius of cone of depression

r_w = radius of bore hole.

With r_o varying typically from 100 mm for inconfined conditions to 200 m for confined conditions it can be shown that doubling bore hole diameter will only increase yield by about 10 %. This important observation shows that the search for the minimum possible bore hole diameter is wholly justified as it is the basis for storage capacity of the well./19/

8.7.2 Gravel Pack

One of the basic important parameters of well design is the choice of the pack size, which is based on the grain size characteristics of the aquifer. A properly designed gravel pack will, however, serve as a filter in preventing fine material from migrating from the formation through the screen, infilling the well and damaging the pump. On the whole gravel pack serves several functions:

a) The slot sizes of the screen should be smaller than the size of gravel pack so that the gravel which surrounds the screen cannot enter the well and also cannot clog the slots, the optimum size is that the gravel size should be at least 1.5 times as big as the width of the slots.

   For example if the grain size of gravel is in a range of 1,2 to 4,5 mm, the slots width would then be 1,2/1,5 = 0,8 mm./2/

b) The slot size should be such that the fine particles from the aquifer can pass the screen during the development of the well. A gravel pack of 1,2 - 4,6 mm grain size will be able to retain particles of 0,2 mm from the aquifer. This means that particles of 0,2 mm and smaller can pass the gravel. A slot size of 0,8 mm will easily allow these particles to enter the well and be pumped out when the well is being developed.

c) The length of the slots is mainly determined by the strength requirements of the screen. This distance between two rows of slots should be wide enough to give the pipe resistance against bending.

Practice in screen manufacture from PVC pipes in Morogoro has shown that:

a) it gives a zone of increased permeability immediately around the screen, thereby reducing ground water flow velocities and as a result decreasing head loss

b) it prevents the movement of fine material through it into the bore hole. But simply the gravel pack is designed in such a way that the pores between the gravel pack grains are small enough not to allow movement of formation grains.

c) it allows a larger slot size in the bore hole screen thereby permitting a higher open area and lower entrance velocity of water into the well without an unacceptable reduction in pipe strength

d) it fills the space between the hole wall and lining pipe, preventing formation slumping and possible pipe damage.

8.7.3 Screen Design

It is recognised now that screen design is a significant factor even for a low-yielding rural water supply well and as such.

When the velocity flow into the well through screen is equal or less than 3 cm/s there is always a negligible extra drawdown due to energy loss. The rate of corrosion and incrustation are also minimum (when steel screens are used), PVC screens are however, always free from corrosion and incrustation.

Furthermore, steel screens are very costly as compared to those of PVC pipes. While steel screens and casings need welding machines and air compressors to join and install them, PVC screens are easily jointed by special jointing cement usually supplied together with the pipes from the manufacturers.

8.7.4 Screen Location

The most important thing is that at least the screen section should occupy at least 6 m from the bottom of the well, or the entire aquifer. The screen must stand in the centre of the bore hole otherwise the gravel cannot be poured equally in the space between the casing and the PVC pipe. This may result to some places to have no gravel and that there might be some direct contact between the aquifer and the rising main.

In such a situation, particles from the aquifer would not be retained by the gravel pack and would enter the well. This is especially true for aquifers consisting of fine to very fine sands and silt.

A simple way to keep the PVC pipe in the centre is that /1/:

- At several heights three small blocks of wood are fixed to the pipe, for instance at the top and the bottom of the screen. They are kept at their place by means of thin iron wire. The wooden blocks are so small that they will not obstruct the gravel when it is being poured in.

- If the pipe is very long a third point should be fixed. At the top it can be kept in the centre by hand.

8.7.5 Well Development

Upon completion of the bore hole the well must be developed to increase its specific capacity, prevent sanding and obtain maximum economic well life.

Three beneficial results are brought about:

1. Development corrects any damage to or clogging of the water bearing formation which occurs as a side effect from the drilling.

2. Development increases the porosity and permeability of the natural formation in the vicinity of the well.

3. Development stabilizes the sand formation around a screened well so that the well will yield water free of sand.

Development methods can be by over pumping, surging, injection of compressed air, backwashing etc./19/

8.7.6 Pumping Test

After the tube well is completed the next step before pump installation is pumping test. Proper pumping test is very important as it provides information on the hydraulic conditions or efficiency of the tube well itself and also the hydrogeological characteristics of the aquifer, its hydraulic properties and the long term effects of water abstraction. / 17/

Pumping test procedure is as earlier explained in the well site test drilling.

8.8 Regional Practices

8.8.1 Mtwara-Lindi Regions

For almost ten years now, drilled wells have been constructed whenever favourable along with dug ring wells.

In most of the wells constructed, stainless steel screens were installed, PVC slotted pipe screens are however now being used because they are cheaper as compared to stainless steel screen which require welding among other things for their installation.

The reporting of construction and maintenance procedure is as shown in figure 8-14.

8.8.2 Mwanza Region

Presently there are only a few drilled wells constructed in Mwanza region. Plans are under way (under SIDA Regional Concentration Programme) to construct them in large scale in areas where the shallow ground water potential is quite high.

8.8.3 Morogoro Region

All the shallow wells constructed in Morogoro region are hand drilled. This has been so because of the favourable soil conditions. The alluvium formations commonly found in many parts of the region.

Unlike Mtwara-Lindi regions; mainly uPVC slotted screens have been extensively used. The pipes are slotted in the projects central workshop and then sent to site. The reporting of construction and maintenance procedure is as shown in figure 8-15.

Finnwater

Well No Mt1406
Investigation No CA NO I

AUGER HOLE REPORT

Region Mtwara District Mtwara Village Mkangala
Sheet No 296/3 Location E 623,9 N 8855,4 Altitude 100 f

Hand auger / Machine auger Bore dia 10" Bore depth 12 m
Date 6 / 2 1980 Driller A Masudi Drilling time 8 days

Depth	Strata	Lithology	Colour	Consistency	Water content (increases) 1	2	3	4	Remarks
0 – 0,5		sand	Brown	soft	x				
0,5 – 1		clay	"	"	x				
1 – 1,5		"	"	Hard	x				
1,5 – 2		sand + clay	"	"	x				
2 – 3		clay	Black	"	x				
3 – 3,5		Sand + clay	Brown	"		x			
3,5 – 4		clay	"	"		x			
4 – 5		sand	"	Soft			x		
5 – 5,5		sand + clay	"	"				x	
5,5 – 6,5		Sand	"	"				x	
6,5 – 7,5		Sand + Clay	"	"		x			
7,5 – 9		"	"	"			x		
9 – 10		"	"	"				x	
10 – 11,5		Sand	"	"			x		
11,5 – 12		Gravel + Sand		Soft				x	

Slab ☒
Static GWL 5,5 m EC ______ μS/cm 14 / 2 1980
Plains dia 4" Depth 8 m SST / PVC
Screens dia 2" Depth 4 m SST / PVC
Filter gravel ☒ Artificial ☐ Natural
Development/ pump test 4 h 15 / 2, 1980
Yield ______ m³/h Drawdown ______ m EC ______ μS/cm
Pump installation ☐ Hand ☒ Motor NIRA
Cylinder depth 3m+3m+3m+1,5m+0,5m / 0,5+3+3+3+0,75+0,5 15 / 2, 1980 / 13 / 4, 1982
Water sample No ______ Remarks ______

Sketch map

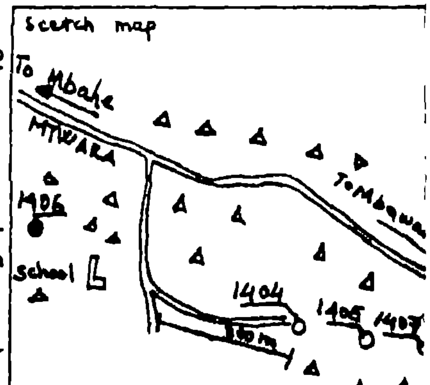


Figure 8-14.

MC/KL/81-4

MOROGORO WELLS CONSTRUCTION PROJECT

Well number	

Well Description - Construction Section

Village : KIBEREGE
Ward : KIBEREGE
Division : MANGULA
District : KILOMBERO

Date start : 9/7/81
Date completion : 11/7/81
Operator : MINANGO 81
Total Well Depth : 12.60 m-cover level
Water Level : .... m-cover level
EC : .... µS/cm

1 Borehole description

Depth m-GL	Major Parts lithology	Major Parts gradation	Minor Parts lithology	Minor Parts gradation	Consistency	Colour	Wet.cont. dr	Wet.cont. m	Wet.cont. w	Wet.cont. wb	Drill diam cm	Drill type
0.00 – 0.30	cly		FN SILT	-	STK	BK/BR		X			⌀30	AUGER
0.30 – 0.95	SILT				SFT	BR		X			-"-	-"-
0.95 – 1.30	SAND	FN	FN SILT		SFT	BR		X			-"-	-"-
1.30 – 1.80	SAND	FN	FN SILT		SFT	BR			X		-"-	-"-
1.80 – 2.40	CLY		FN SILT		STK	GY/RED		X			-"-	-"-
2.40 – 4.05	CLY				STK	GY/BR		X			-"-	-"-
4.05 – 5.30	SAND	CS	FN SILT		LOOSE SFT	GY/BR				X	-"-	-"-
5.30 – 6.25	CLY		FN SD	FN	STK	GY/BR		X			-"-	-"-
6.25 – 7.10	CLY	-			STK	GY/BR		X			-"-	-"-
7.10 – 8.25	CLY		FN SILT		STK	GY/BR		X			-"-	-"-
8.25 – 8.90	SAND	FN	FN SILT		SFT	GY/BR			X		-"-	-"-
8.90 – 10.15	SAND	ME	FN SILT		LOOSE	GY				X	⌀20	BAILER
10.15 – 10.90	SAND	FN	FN SILT		LOOSE	GY				X	-"-	-"-
10.90 – 11.25	SAND	FN	FN CLY/SI		LOOSE	GY				X	-"-	-"-
11.25 – 12.40	SILT		FN SD	FN	SFT	GY			X		⌀23	AUGER
12.40 –												
–												
–												
–												
–												

INDEX

Lithology		Gradation		Colour			
clay	= cl	fine	= fn	black	= bl	dark	= d-
silt	= slt	medium	= me	brown	= br	light	= l-
sand	= sd	coarse	= cs	grey	= gy	mottled	= mot
gravel	= gr	Consistency		blue	= bl		
stones	= st	soft	= sft	green	= gn	very	= ve
sandstone	= sd st	sticky	= stk	yellow	= ye	much	= mu
laterite	= lat	loose	= ls	white	= wh	little	= li
calcrete	= cal	weathered	= wed	red	= red	layers	= lay
mica	= mi	hard	= hd	orange	= og		
basement	= bm					ground level	= GL

Figure 8-15.

cont.

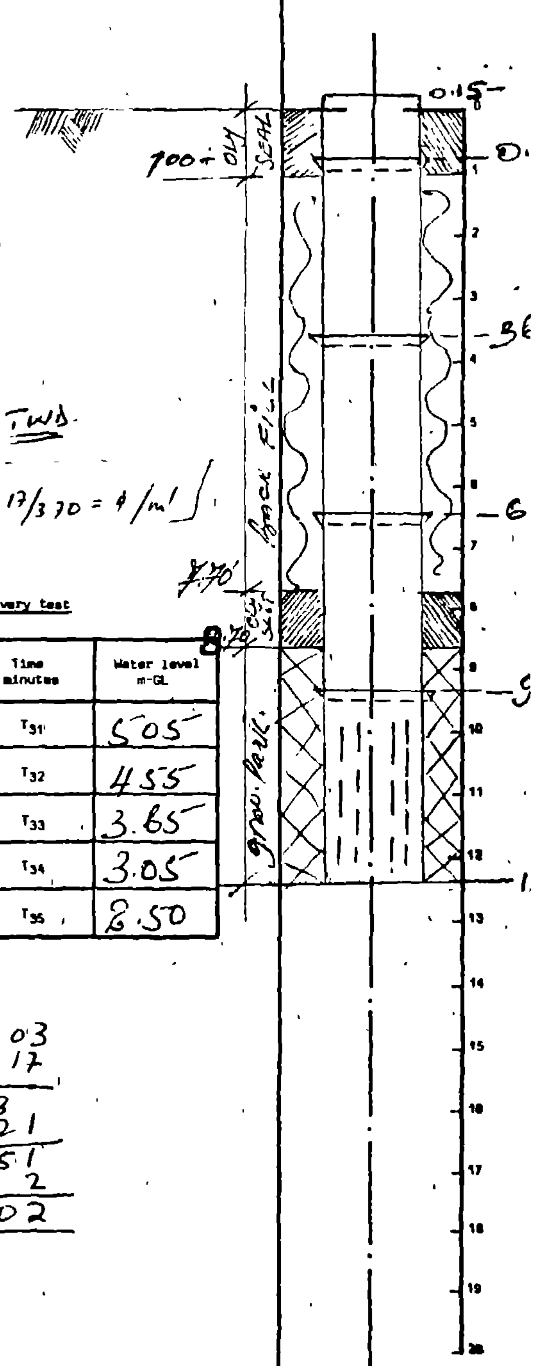
continued

2. P.V.C. Installed

Diameter	117...125...mm
Slot size	...0.8.....mm
Screen	...1... x 3.00 m + ..—.....m
Casing	...3... x 3.00 m + 0.95...m
Sockets	...—.......
Cover	WOODEN I

3.00
9.00
12.00
.95
12.95
-.40
12.55
.15
12.40
+0.20
12.60 TWD.

3. Sketch P.V.C.



4. Gravelpack

Size	2... - ..5..mm
Karai	..17............
Depth	From 12.40...... to 8.70...m-GL

12.40
8.90
3.70 (17/3.70 = 4/m')

5. Pumptest

time minutes	Water level m-GL	Drawdown m	Number of buckets
T_0	1.60		
T_5	5.25	3.65	35
T_{10}	6.45	4.85	35
T_{15}	7.00	5.40	34
T_{20}	7.50	5.90	33
T_{25}	7.50	5.90	33
T_{30}	7.50	5.90	33
			203 x
		Content of 1 bucket in litres:	17 x
			3,457
			2 x
		Yield in L/hr:	6,902

203
17
203
1421
3451
2
6902

6. Recovery test

Time minutes	Water level m-GL
T_{31}	5.05
T_{32}	4.55
T_{33}	3.65
T_{34}	3.05
T_{35}	2.50

Type of pump: ..BANBOO.......................................

If pump test fails, give the reasons:

....

....

8. Slab construction

Material	Unit	Number
Cement	bag	8
Sand	box Drum	1-3
Stones	box	3
Cement block	—	NIL

7. Pump installation

Date	Pump type	Cylinder		Rising main								Socket
		Diam. mm	Type	4.00	3.50	3.00	2.50	2.00	1.50	1.00	0.75	
22/1	HAND	25	PVC	2		1				1		3

Pump attendants: .... [illegible] -5

Figure 8-15

9. PUMPING EQUIPMENT AND WELL COMPLETION

After the well has been constructed, it is imperative that a pump is installed to lift water from the well to the surface. Nearly all the wells constructed in the country have been fitted with a manual pumping device often referred to as: "Hand Pump".

9.1 Types of Pumps

The most commonly manufacture pumps and suitable for small rural community water supply are as follos and they are basically either lift or suction type.

9.1.1 Reciprocating Pumps

This is the type of pump frequently used in many of small water supplies. It is generally grouped as:

- suction; lift
- delivery; force
- single acting; double acting.

a) Suction Pumps (shallow well)

In suction pumps, the plunger and its cylinder are located above the water level usually within the pump stand itself. (Figure 9-1)

The suction pump relies on atmospheric pressure to push the water upwards to the cyliner. In the course of action the pump reduces the atmospheric pressure on the water in the suction pipe and the atmospheric pressure on the water outside the suction pipe pushes the water up. It is because of this reliance on atmospheric pressure which makes the pump to be used only where the water table is within 7 m of the suction valve during pumping /22/.

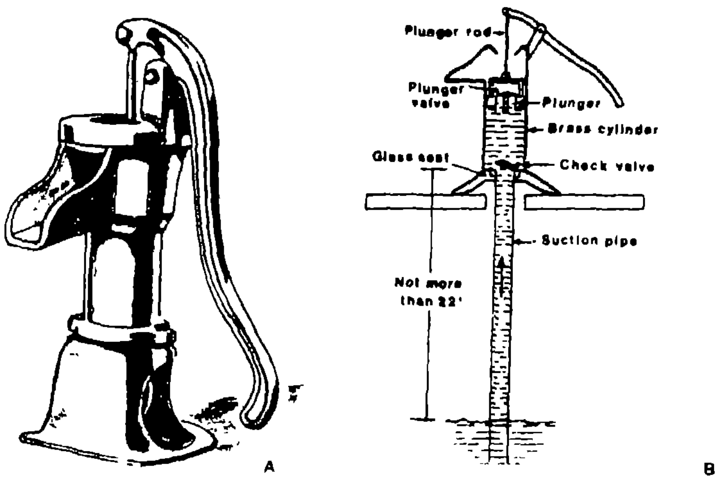


Figure 9-1a. Typical shallow well lift pump./22/

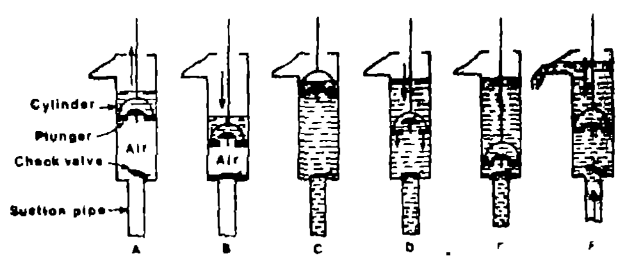


Figure 9-1b. Illustration of operation of plunger-type pump./22/

b) Lift Pump (deep well)

Deep or shallow well in terms of pump selection refers to the depth of the water level in the well, not the depth to the bottom of the tube well or the length of the well casing.

The principal characteristics of all (deep well) lift pumps is the location of the cylinder. The cylinder and plunger are located below the water level in the well in order to assure the priming of the pump /22/.
An example of a deep well lift pump is shown in fig. 9-2.

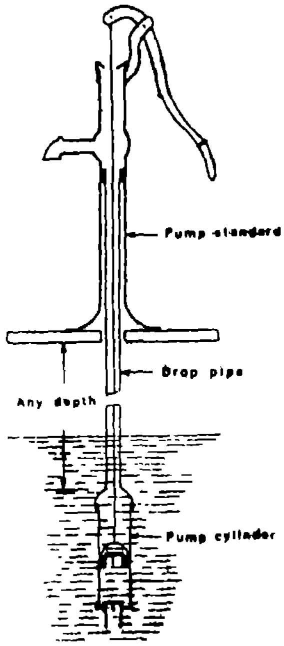
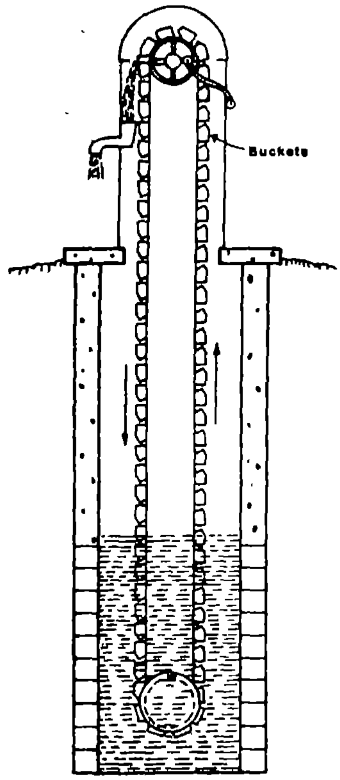


Figure 9-2.
Deepwell lift pump./22/

9.1.2 Rotary (Positive desplacement) Pumps

In the chain pump, discs of suitable material attached to an endless chain running over a sprocket at the top, are pulled through a pipe to lift water mechanically up to the spout. This type of pump can only be used on cisterns and shallow dug wells /22/. See figure 9-3. And the bucket pump has a series of buckets, attached to an endless chain which is rotated over a sprocket, and deeps into water where buckets fill with water and then carries to the top for free delivery into the spot /22/. There is a big similitude between the two pumps.



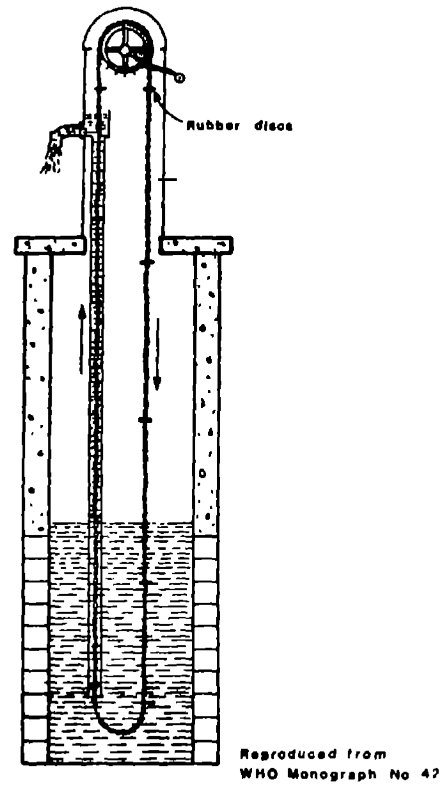


Figure 9-3a. Bucket pump /22/ Figure 9-3b. Chain pump/22/.

9.2 Makes of Pump Used in the Country

The commonly pumps used in the country are:

- NIRA Pump from Finland
- KANGAROO Pump from The Netherlands
- SWN 80 and 81 Pumps form The Netherlands
- SHINYANGA Pump from Tanzania/The Netherlands.

9.2.1 NIRA Pump

This is a deep and shallow well hand pump which is manufactured in Finland. Over 2 000 pieces have been in continuous controlled use in Mtwara and Lindi regions. The pump also has been tested by the Consumers Associations Testing and Research Laboratory in England for the World Bank and has been classified as one of the best pumps.

The pump stand is made of tubular steel with a cast iron base handle, mount and spout assembly. The nominal diameter of the pump is 76 mm of seamless brass tube. The cup washer and plungs valves are combined in a single rubber moulding. The foot valve is of similar design, also moulded in rubber. The pump stand weighs 29,5 kg and the cylinder assembly 40 kg. The pump uses 10 mm stainless steel rods within 50 mm diameter galvanised rising main. The maximum outside diameter of the below-ground assembly is 95 mm. Figure 9-4 gives the outline features.

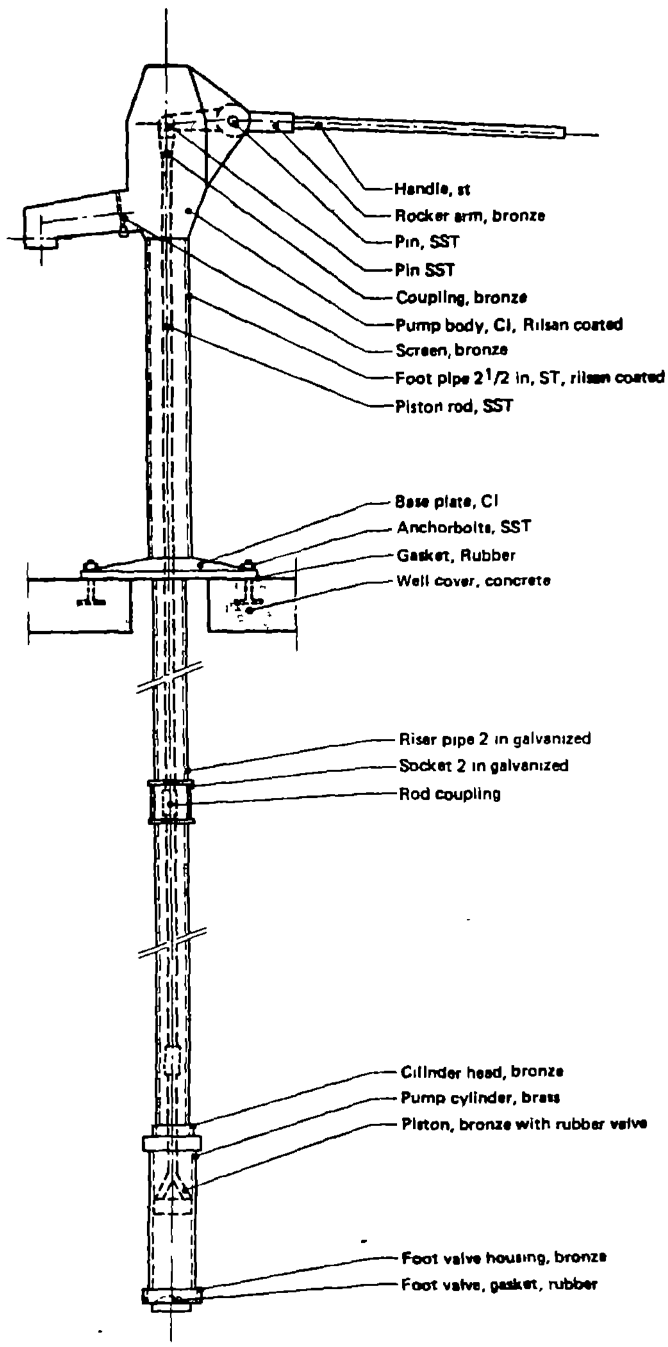


Figure 9-4.
NIRA hand pump./20/

9.2.2 Kangaroo Pump

This pump has been tested in several water supply projects including those in Tanzania. It is manufactured and marketed by a Dutch manufacturer. The pump is foot-operated.

The pump head consists of two pipes sliding over each other, with a spring fitted in between. The outside sliding pipe is connected to the pump rod, and operates the piston in the pump cylinder.

Normal cylinder diameters are 100 mm for 6 m deep wells 76 mm for 10 m wells and 50 mm for 20 m wells. The capacity range is 600 - 2 000 litres/hour. Figure 9-5 shows the Kangaroo pump with its main components. Kangaroo pumps are presently manufactured at Morogoro shallow well projects workshop.

9.2.3 SWN-80 and 81 Pumps

These pumps are hand or foot operated. They have been introduced in the country by DHV-Engineers in Morogoro region.

These pumps have proved to be quite good and many users in Morogoro prefer them to Kangaroo pumps, because they deliver more water at less effort applied. Figures 9-6 and 9-7 give clear description of the pumps.

They are presently produced at Morogoro shallow well project factory.

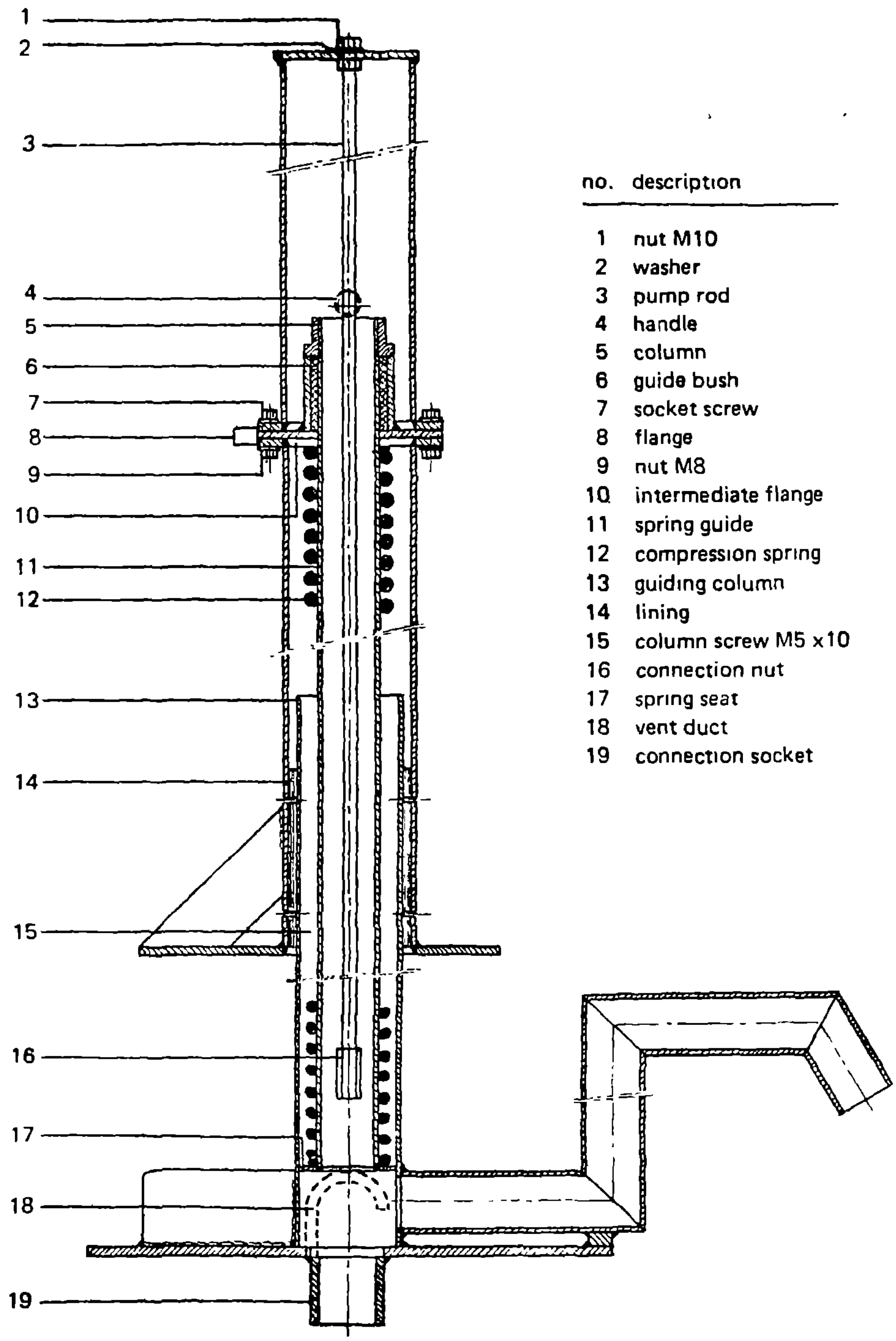
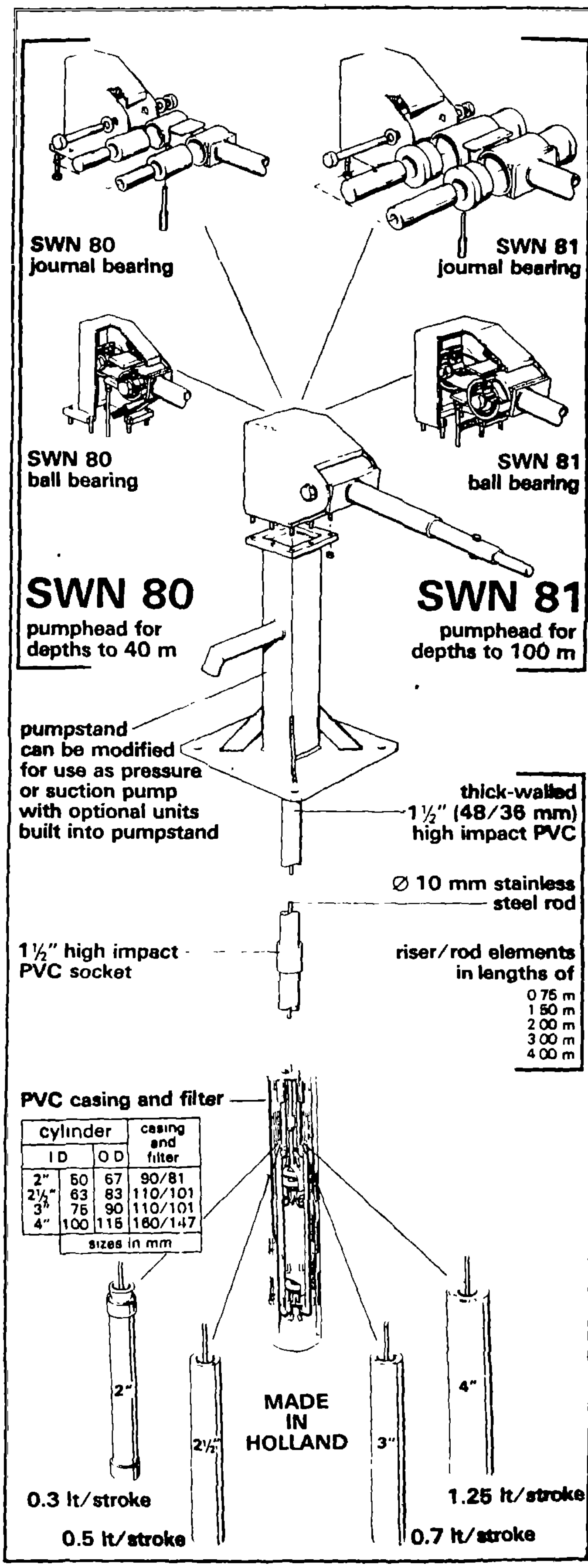


Figure 9-5. KANGAROO MK 1 cross-sectional view.



cylinder			casing and filter
I D		O D	
2"	50	67	90/81
2½"	63	83	110/101
3"	75	90	110/101
4"	100	116	160/147
	sizes in mm		

Figure 9-6/9-7. SWN-80 and SWN-81 pumps.

9.2.4 Shinyanga Pump

This pump was introduced along with the shallow wells programme in Shinyanga district in 1974.

The pump has a wooden pumping head which closely resembles the Uganda pump widely used in East Africa (see fig. 9-8). The pump uses a polyvinyl chloride plastic cylinder.

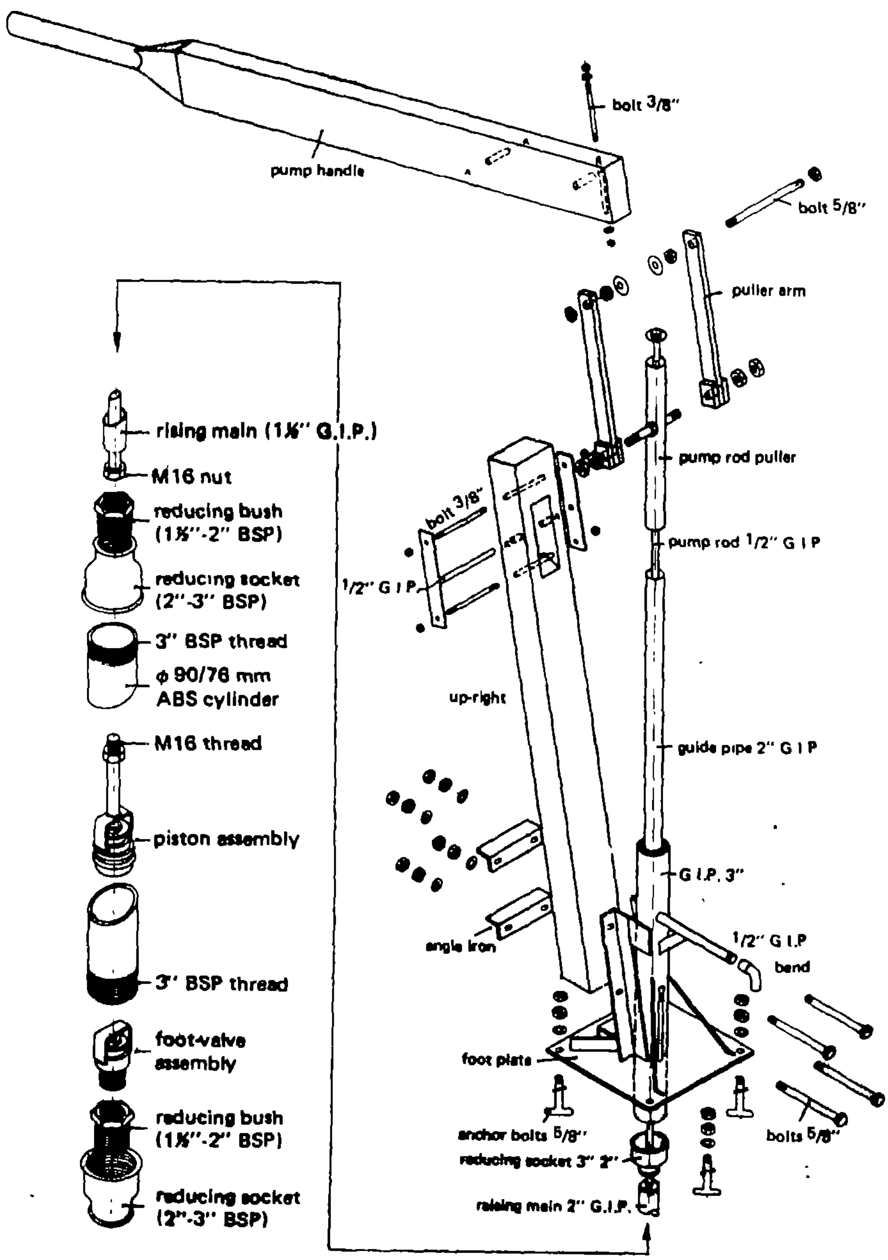


Figure 9-8. Shinyanga pump./9/

The Shinyanga cylinder also uses a rubber double ring cup seal with an internal, shape retaining stainless steel ring. The cylinder also uses neoprene ball valves.

9.3 Pump Installation Procedure

As the Shinyanga pump was the first hand pump to be manufactured in the country, it is better to talk of its installation because it is well known among the people especially in areas around Lake Victoria.

At least three people are needed to mount a hand pump i.e. a pipe fitter and two labourers equiped with the following materials and tools:

- one pipe cutter 50 mm to 12 mm
- two spanners 20 mm
- two spanners 10 mm
- one hacksaw with spare sawblades
- one file
- one trowel
- one bucket
- rope 15 m
- measuring rod or tape
- cutting oil
- pump unit
- machine oil and grease
- bituminous paint
- 12 mm galvanised iron bar for pump rod
- 62 mm galvanised iron pipe for rising main
- rod holder as shown in figure 9-9.

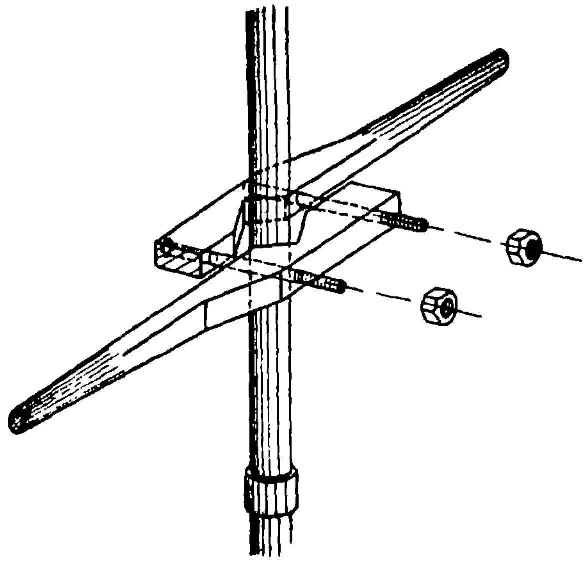


Figure 9-9. Rod holder./7/

9.4 Rounding Off Well Construction

After a water well has been constructed there is nothing to see except a pump protruding from the ground. Despite all the efforts that go into the construction of a well-designed tube well or dug well, it is the above the features i.e. the pump and its surroundings that are in daily use and in view of the village community that matters.

The pump actually delivers the water to the ground level, and without any surround but a pump plinth, the vicinity soon becomes a muddy, unhealthy place which is unpleasant to visit and certainly no place to spend longer than necessary.

Standing water around a pump will result in mosquito breeding, attract flies and animals and be a potential health hazard to some extent negating many of the benefits that the improved water supply should provide. Furthermore the risk of standing water getting back into the bore hole or well, particularly if the pump plinth is cracked, and thus polluting the water at source is greatly enhanced.

So it is important to minimise standing water to eliminate the health hazard /17/.

9.4.1 Sanitary Protection of Wells

Wherever ground water pumped from a well is intended for human consumption proper sanitary measures must be taken to protect the purity of that water. Contamination sources may exist either above or below ground surface. Precautions apply equally to supplies obtained from springs.

Sub-surface sources of contamination can result from privies, septic tanks, sewers, cess-pools, barnyards and livestock areas. Ordinarily, wells should be located at least 30 m away and not on the downhill side of such sources. Rock aquifers such as limestone, require particular attention as they are capable of transmitting pollutants much greater distances than unconsolidated formations.

Surface contamination can enter either through the annular space outside the casing or through the top of the well itself. To close avenues of access for undesirable water outside of the casing, the annular space should be filled with cement grout. Entry through the top of the well can be avoided by providing a water-tight cover to seal the top of the well casing. Corners around the well should be made of concrete and be elevated above adjacent ground level, and should slope away from the well. So far structural and hygienic reasons an apron has to be built at the pump site, and must fulfill the following requirements /9/:

- the part on which the pump is fixed must be stable and after pump installation the filter pipe should be completely covered, so that splashing water cannot enter the well from above
- the diameter of the apron must be relatively big so that:

  1. all operations (cleaning of buckets, pumping, putting the bucket on the head) can be performed while standing on the apron,

2. a rim can be built on top of it to collect most of the spill water.

- the apron must be strong so that it can easily bear its own weight and that of a number of people without breaking

- as much of spill water as possible must be collected and guided towards a lower drainage area.

Standard construction of a concrete slab is as shown in figure 9-10. In order to avoid unhygienic conditions near the well (and especially from animals) the well site should preferably be fenced or special vegetation like sisal be planted around it. This will make it difficult for grazing cattle or goats to enter and pollute the well area.

9.4.2 Disinfection of the Well

During construction, workers handle rings and stand in the well; it cannot therefore be assumed that the ground water in the well is still bacteriologically safe. After the pump has been installed, the well should be disinfected. The commonly easily available disinfectant is Sodium Hypchlorite (bleaching powder) of 25-35 % strength.

The amount needed for this purpose is 100 g of bleaching powder per m^3 of water in the well.

The powder is dissolved in water (about 100 g of bleaching powder to one bucket of water) and then poured into the well. The water in the well must be well agitated to ensure good mixing, this is better done by pumping the water around with a motor pump. The strongly chlorinated water is then left to settle in the well for at least 12 hours.

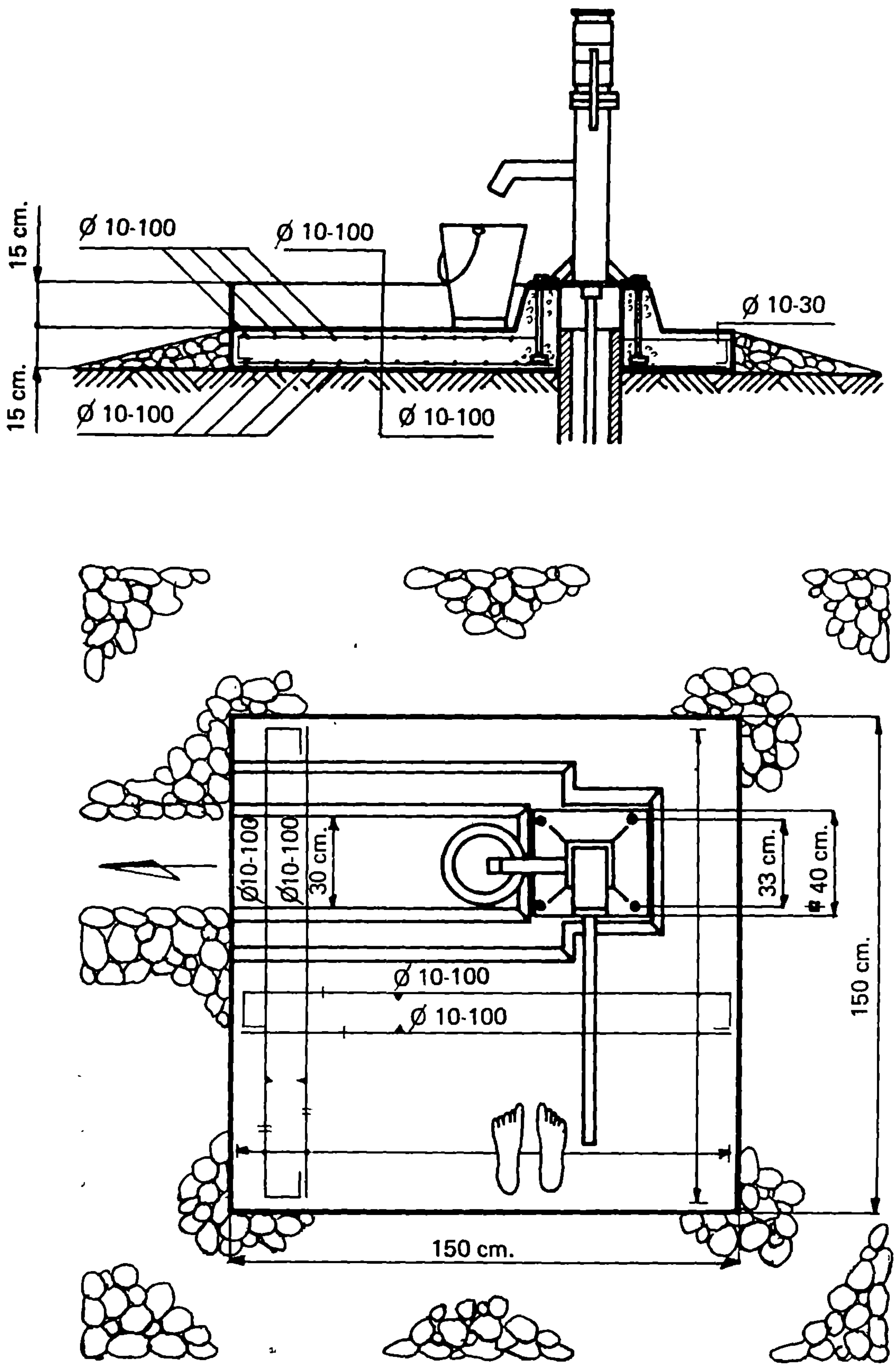


Figure 9-10. Example of a superstructure for a SWN hand pump consisting of a reinforced concrete slab, a pump base with anchor bolts and a gutter.

During this time water should not be used. After 12 hours, the water is pumped to waste while the chlorine content is regularly checked, pumping can be stopped when chlorine content drops below 1,0 mg/l./9/

9.4.3 Abandoned Wells Protection

Wherever a well is drilled and then abandoned for whatever the reasons, it should be sealed by filling it with clay, concrete or compacted earth. Not only is that surface contamination unable to enter the well, but sealing serves two other useful purposes: prevents accidents, avoids possible movement of inferior water from one aquifer to another, and conserves water in the flowing well.

10. SPRING WATER TAPPING

Springs are mainly found in mountainous or hilly terrains, a spring is defined as a place where a natural outflow of ground water occurs. There are two types of springs in Tanzania i.e. gravity springs and springs of deep-seated origin (see chapter 4.3).

10.1 Spring Tapping in Tanzania

Spring tapping is very common in many parts of the country. Nearly half of the water requirements for Arusha town come from springs and so is the total water supply of Moshi town. In Mtwara region there are many tapped springs in the footing of the Makonde plateau, in Lindi region Mmongo, Kitunda, Kimbunga and Mchororo springs feed the town of Lindi. Some of the springs in Lindi measured have yields as follows:

Kitunda spring	12,5 l/s
Milola spring	43.9 l/s
Nyangao spring	18,9 l/s

Figure 10-1 shows a typical spring tapping structure.

10.2 Basic Consideration for Spring Tapping

When a spring has been accept to yield enough and good quality water, it can be harnessed for water supply. The following four factors should be given careful consideration /18/:

1. Sanitary protection to prevent contamination of spring water in the tapping structure.

2. The quality of spring water is of importance. Particularly with artesian springs, the water will generally be free

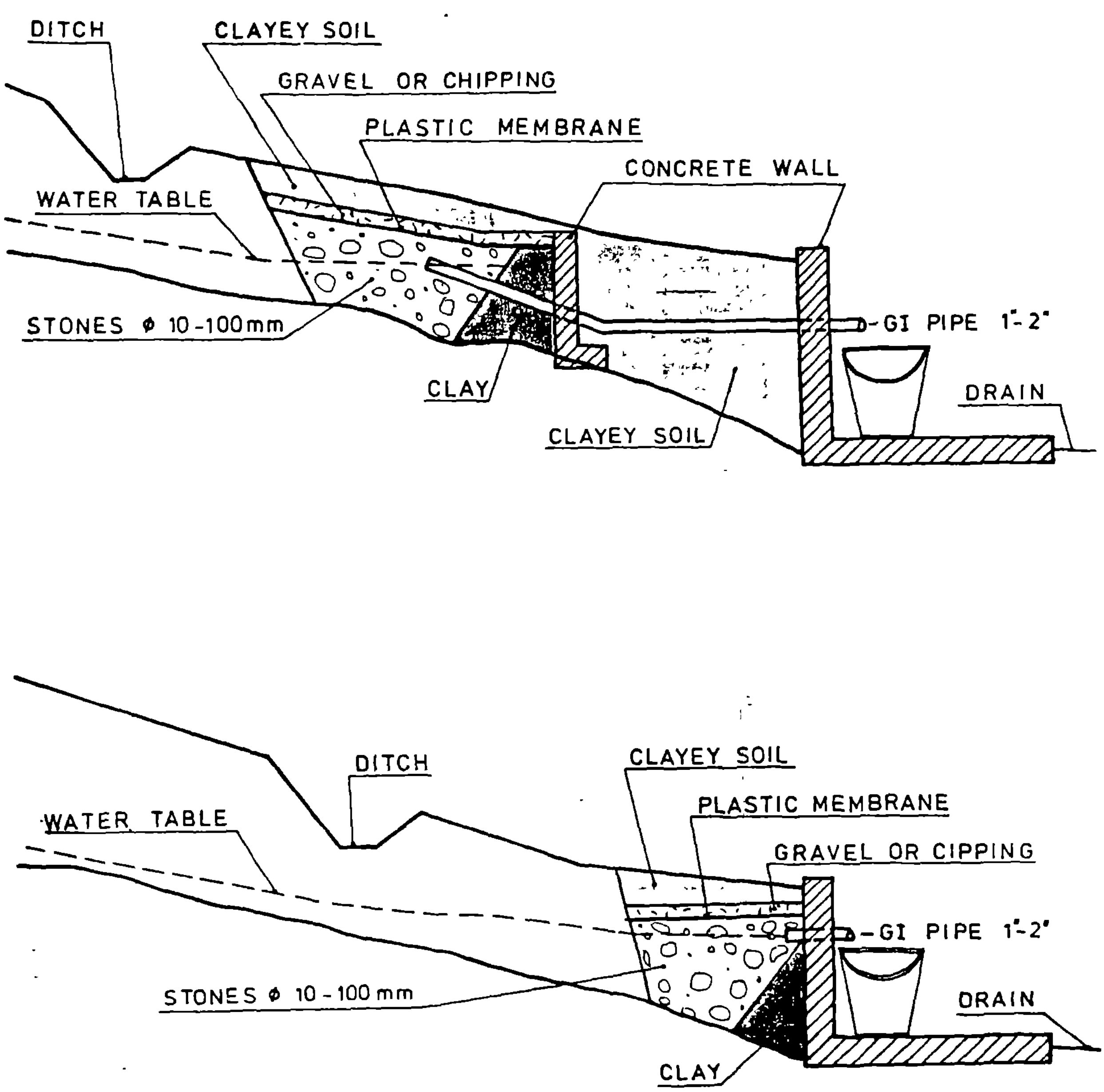


Figure 10-1. Spring protection./20/

from pathogens. If there is a difference in water temperature during the day and night, then water quality is suspect.

3. In granular aquifers, the outflow will vary little with distance along the contour. To tap this, infiltration galleries of considerable length will be required. With fractured rock aquifers however, the outflow will be concentrated where water carrying fissures reach the ground surface. Small scale catchment works will probably be adequate but they need to be sited with care.

4. An assessment of the yield of the spring and its seasonal variation of flow are needed. The yield and the reliability of a spring can only be ascertained by spring water collection works /6/.

10.3 Tapping Gravity Springs

Gravity springs occur in unconfined aquifers. Where the ground surface dips below the water table. Gravity depression springs usually have small yield and a further reduction is likely when dry season conditions or nearby ground water withdrawals result in lowering of the ground water table.

Gravity outflow springs in granular formations can be tapped with drains consisting of pipes with open joints, placed in gravel pack (see fig. 10-2). The drains must be laid so deep that the deep saturated ground above them will act as a storage reservoir compensating for fluctuations of the deep ground water table. The water collected by drains is discharged into a storage chamber as shown in figure 10-3 /18/.

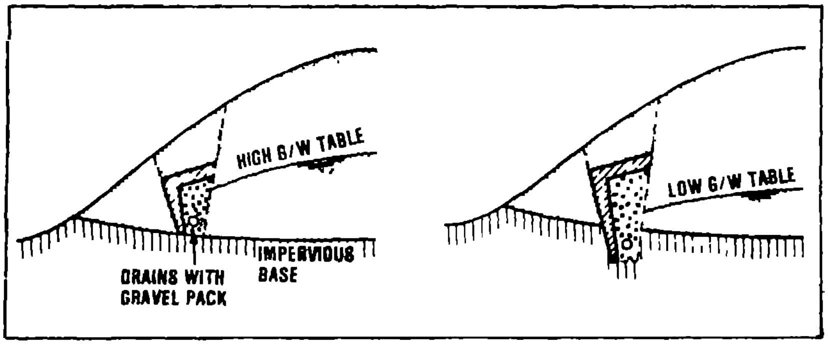


Figure 10-2. Tapping of a gravity spring./18/

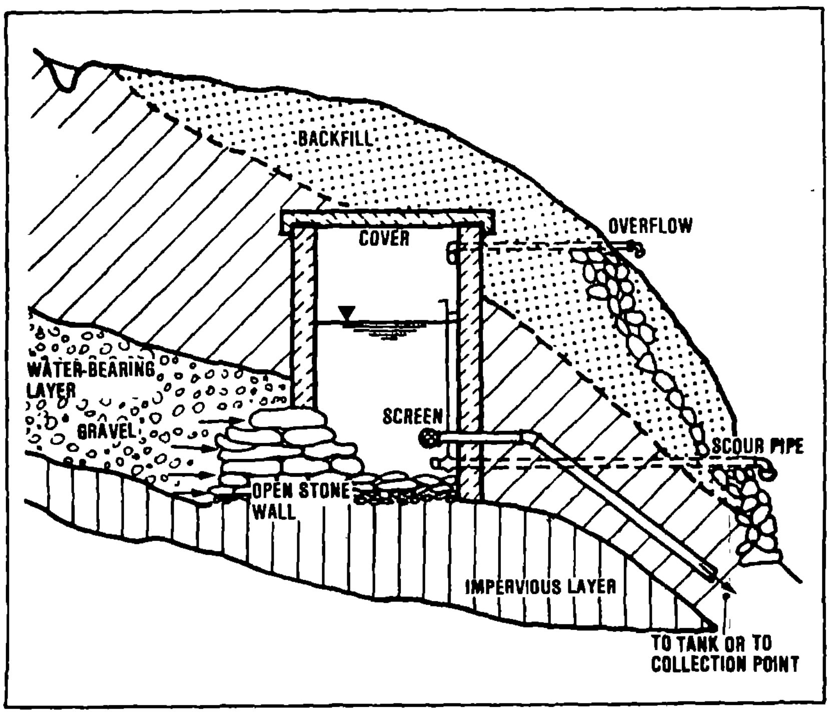


Figure 10-3. Spring water storage chamber ('spring box')./18/

10.4 Tapping Fissure Springs

These springs have nearly the same characteristics as artesian depression springs, but the water rises from a single opening so that catchment works are small (see fig. 10-4). Some increase in capacity may be obtained by removing obstacles from the mouth of the spring or by enlarging the outflow opening as in figure 10-5. Due to localised outflow of water from springs, sanitary protection is easy to arrange /18/.

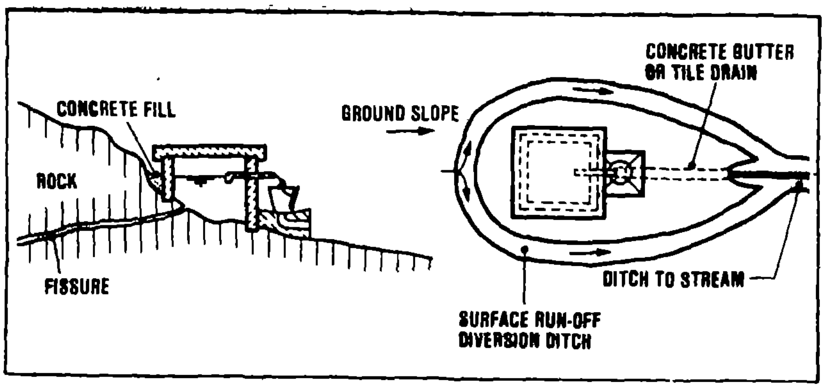


Figure 10-4a. Fissure spring of small capacity./18/

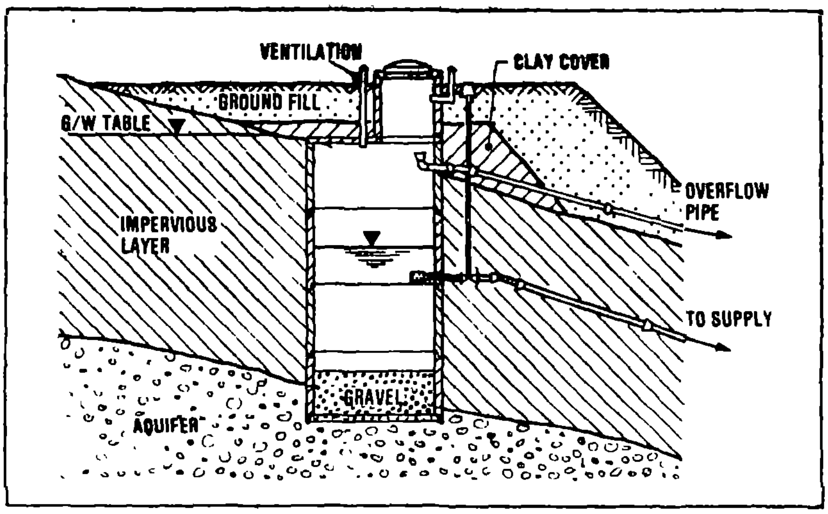


Figure 10-4b. Fissure spring of large capacity./18/

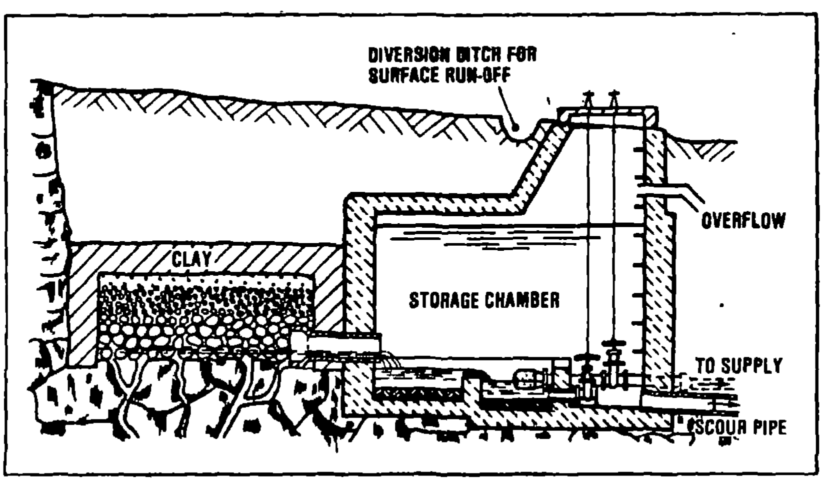


Figure 10-5. Artesian depression spring./18/

10.5 Small Springs in Sandy Rivers

In some areas of the country there are some sandy rivers with small springs which sometimes dry up, whenever there is long spell of dry season.

In such cases, it is sometimes advisable to construct small clay dams as shown in figure 10-6, then these dams will hold water back when springs or streams dry up. Water can then be drawn by constructing river wells as shown in figure 10-7./ 8 /

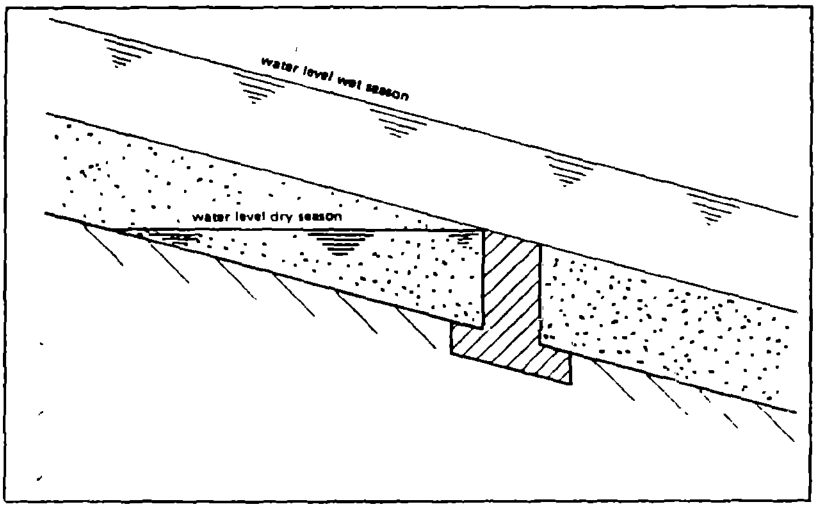


Figure 10-6. Small clay dam in a sandy riverbed./ 8 /

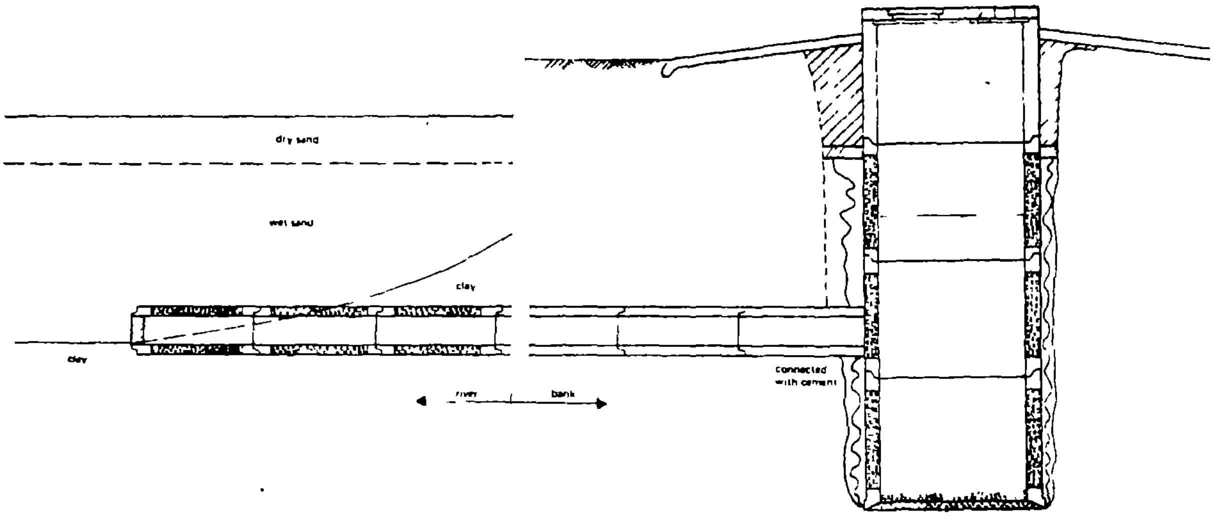


Figure 10-7. River well with small concrete rings in the trench./ 8 /

11. PROJECTS MANAGEMENT AND WELL CONSTRUCTION COSTS

Since the introduction of large scale shallow wells construction in Shinyanga region by the Dutch DHV-Engineers, many a region has followed the suit and started construction of shallow wells in addition to piped domestic water supply programmes.

Presently shallow wells are being constructed in the Coast, Arusha, Singida, Morogoro, Mwanza, Lindi, Mtwara and Tabora regions to mention but a few. However, with the exception of Coast region alone, shallow well programmes in the other regions are donor sponsored both financially and technically.

The Ministry of Water and Energy does not at present have shallow wells construction projects within its water development programme. To illustrate the construction of the shallow wells the following three regions projects are given as an example of what is happening in the country.

11.1 Mtwara-Lindi Regions

The project started in 1974 with the preparation of a Water Master Plan for the two regions, with both financial and technical assistance from the Government of Finland. The Tanzanian government also contributes funds for local expenses of the project.

After the completion of the Water Master Plan in 1977, the consultants Messers Finnwater Consulting Engineers of Finland started the implementation of project which includes both piped water supplies and shallow wells. The projects organization chart is as shown in figure 11-1. This set up is more or less separate but linked to the Regional Water Engineer by a local Project Coordinator. The entire senior staff of the project consists of expertriate personnel only.

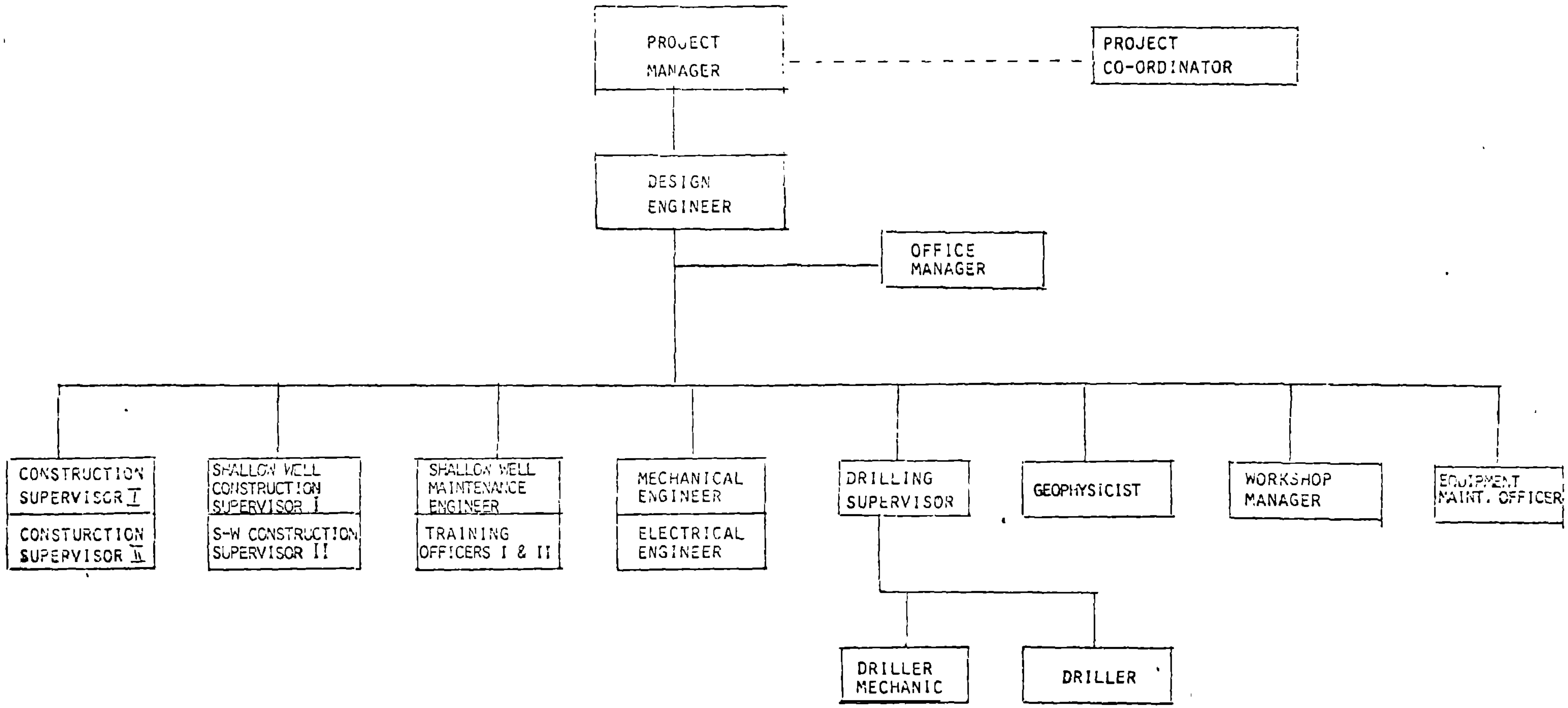


Figure 11-1. Organization chart for Mtwara-Lindi project.

The project is capital intensive, much of the excavation, drilling and manufactures of concrete well rings is normally done by machines. The project owns a stone and aggregates quarry at Nanganga.

The hand pumps mainly used are NIRA hand pump imported from Finland. At present not a single part or element for these pumps is locally manufactured. NIRA hand pump has been previously described in detail.

Apart from sinking of shallow wells, maintenance of already constructed wells and water works is being carried out. Also included in the project is the training of artisans, craftsmen and maintenance techniques to the villagers.

Up to the end of 1983, more than 1 500 wells have been constructed since 1978 and including quite a good number of wells constructed during the preparation of the Water Master Plan. Each well serves about 300 to 400 people.

Table 11-1 and 11-2 give the detailed costs of ring wells and auger wells respectively, on the average.

Table 11-1. Ring well costs.
Mtwara-Lindi Project
(All prices are 1980 TShs)

ITEM	QUANTITY	Unit Rate	Final Costs
A. MATERIALS			
Cement	350 kg in concrete rings 250 kg in slab and plinth	2.28	1368
H.T. Reinf. Steel	25 kg.	8.00	200
Plastic cut off sheet	10 m^2	15.00	150
Ring Sealant	10 m	15.00	150
Aggregate	4 m^3	250	1000
Gravel Surround	3 m^3	150	450
Hand pump	Finnish manufacture Local assembled	3300	3300
	TOTAL MATERIALS		6618
B. LABOUR			
Unskilled Labour	54 men @ 360 man hrs/well	6	2160
Skilled labour	6 men @ 40 man hrs/well	8	320
Supervision & Training	4.9 million TShs x 100% of 16 " " Total cost	8000	8000
	TOTAL LABOUR		10480
C. PLANT			
Excavator	500,000 Capital over 4 years 150 wells p.a incl. maint.	1300	1300
Fuel & Oils		300	300
10T truck	350 km	13	4550
Landrover	350 km	5	1750
	TOTAL PLANT		7900
	SUB TOTAL		24998
	+ 15% O/H and CONT.		3750
	GRAND TOTAL		28748

For Recurrent costs see table: 11-2.

Table 11-2. Hand auger costs.
Mtwara-Lindi Project
(All prices are 1980 TShs)

ITEM	QUANTITY	Unit Rate	Final Costs
A. MATERIALS			
Cement	250 kg in slab & plinth	228	570
Screen & Casing	10 m	20	200
Sand & gravel pack	0.5 m^3	250	125
Hand pump	3300	3300	3300
	TOTAL MATERIALS		4195
B. LABOUR			
Unskilled labour	8 men @ 320 man hrs/well	6	1920
Skilled Labour	2 men @ 80 man hrs/well	8	640
Supervision & Training	34% of total cost	7400	7400
	TOTAL LABOUR		9960
C. PLANT			
Transport	Same as ring wells		6300
	SUB TOTAL		20455
	+ 15% O/H & CONT.		3068
	TOTAL		23522
D. MAINTENANCE			
Skilled Labour	12 men x 2500 h/a/1100 wells	8	218
Spare parts	450 TAS/well/a	450	450
Transport	40,000 km per year spread over 1100 wells	5	180
	TOTAL MAINT.		790

E. OPERATION ZERO

Apart from its other activities, Finnwater is running a Rural Water Supply Hand Pumps Project for the World Bank. The aim of the project is to evaluate, compare, analyse and promote the improvement of hand pump technology. It has been agreed so far that a total of 165 pumps should be installed for monitoring, evaluation, compare and promotion of hand pump technology.

The pumps are:

25 NIRA (old type) pumps
75 NIRA (new type AF 76) pumps
20 Zimbabwe Blair shallow lift pumps
20 Malawi Afridev deep-lift pumps
20 SWN 81 pumps of the Netherlands
5 KANGAROO pumps of the Netherlands.

The installation of pumps was started in May, 1983 and a total of 72 pumps were already installed by the end of June, 1983./15/

11.2 Mwanza Region

The Mwanza region shallow well programme was funded by the World Bank under the Water Component of the Mwanza Regional Integrated Development Programme (RIDEP), at present however the project is being funded by the Prime Ministers Office.

By the end of 1983, a total of 200 wells with hand pumps were already constructed, since the project started three years ago. Its organizational chart is as shown in figure 11-2. The project is integrated within the Regional Water Engineers Office, formerly it had additional accounting and procurement via World Bank Financial Controller in the office of the Mwanza Regional Development Director.

The methods of construction, are survey by a machine auger and hand digging for wells. The project mainly sinks ring wells though some trial tube wells have been constructed too. Both Kangaroo and Shinyanga types of hand pumps are used. They are purchased from Morogoro Shallow Wells Project and Shinyanga Shallow Wells Project respectively.

Tables 11-3 and 11-4 show the cost of a tube well and a ring well respectively.

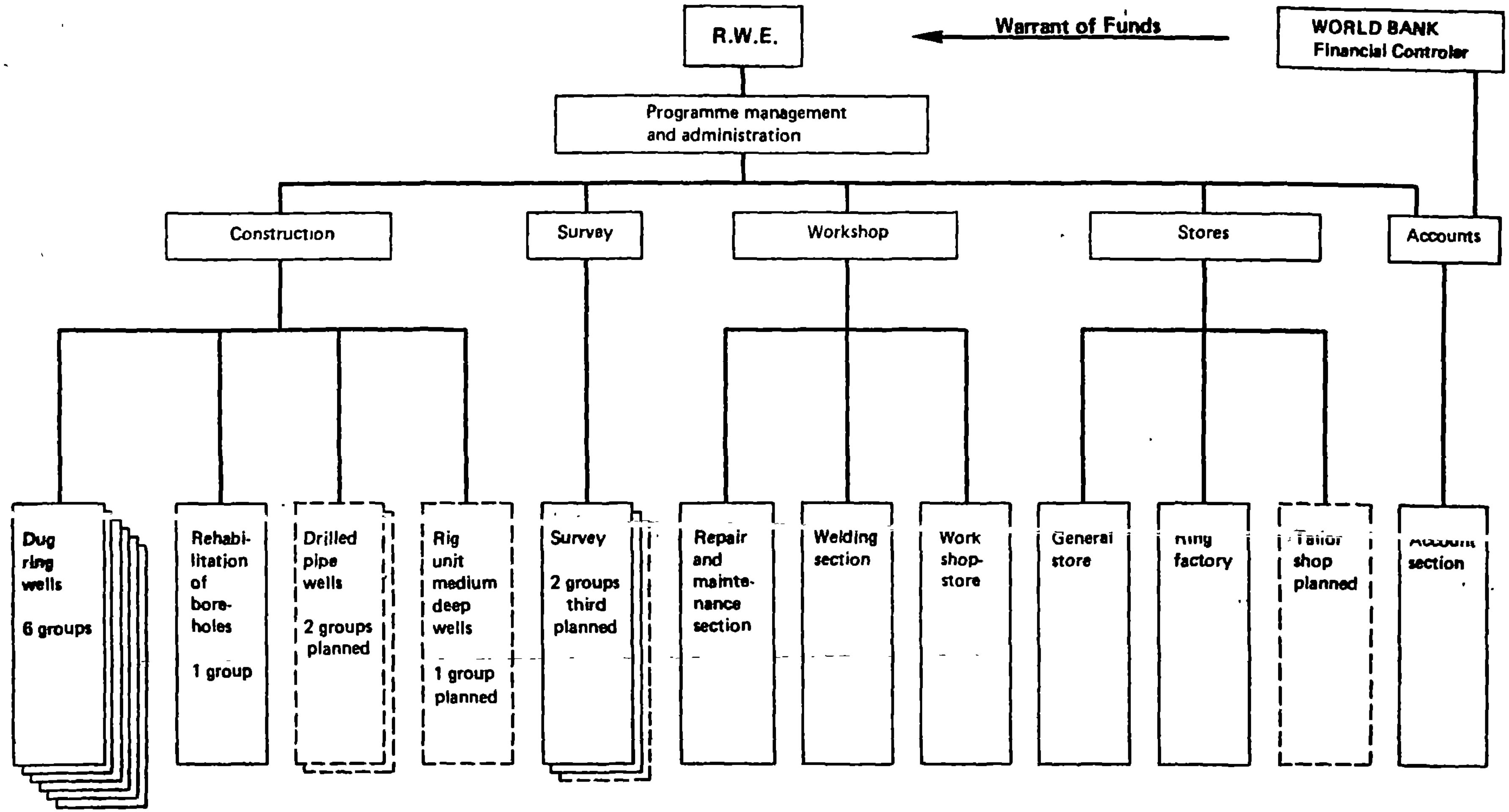


Figure 11-2. Organization chart for Mwanza project./29/

Table 11-3. Cost calculation form for wells
Mwanza RIDEP Shallow Wells

GENERAL

SHALLOW WELL NO.34/3 - 67 **TYPE OF WELL: TUBEWELL**

DISTRICT	MISUNGWI	CONSTRUCTION STARTED	27/6/82
DIVISION	MISUNGWI	" FINISHED	30/6/82
WARD	MABUKI	WELL CAPACITY	1700
VILLAGE	MABUKI STOCK FARM	DATE SIGNED VISITORS	-
UNIT LEADER	ISHENGOMA	-	-
GROUP LEADER	KABABI	-	-
WELL DEPTH	15.20m	-	-

LABOUR:

Salaries and nights for well sinders and others

WORKING DAYS 1st MONTH	18
WORKING DAYS 2nd MONTH	-
TOTAL WORKING DAYS 18 x 35/- = 630/- INCL. NIGHTS	

TRANSPORT

TRANSPORT 1st MONTH 547 km TRANSPORT 2nd MONTH - km TOTAL 547 km	(Incl. Working days for drivers workshop and materials for maintenance etc).
TOTAL TRANSPORT 547km x 5/-	2735/-

MATERIALS

ITEM	UNIT	SHS	QUANTITY	MISC.	SHS.
RING NO. 1,2,3,5	EACH	700	-	-	-
RING NO. 4	EACH	550	-	-	-
RING NO. 10, 11	EACH	350	-	-	-
COVER	EACH	250	-	-	-

Cont.

ITEM	UNIT	SHS	QUANTITY	MISC.	SHS
CEMENT	BAG	60	10	-	600
PUMP	EACH		1	Lever TYPE	6,500
AGGREGATE	TON	200	3	1 Load 8 TONS	600
PETROL	LITRE	6.50			
DIESEL	LITRE	4.50			
STONES/BAND	LOAD/TON	100	6		600
PUMB STAND	EACH	450	1		450
PUMP ROD		100	15		1.500
STORES					1.000
TOTAL MATERIAL					11,250
TOTAL LABOUR					630
TOTAL TRANSPORT					2,735
TOTAL MATERIAL					11,250
SUBTOTAL					14,615
OVERHEAD 10%					1,462
GRANT TOTAL/WELL					16,077

Table 11-4. Cost calculation form for wells
Mwanza RIDEP Shallow Wells

GENERAL:

SHALLOW WELL NO. 34/2 - 78 TYPE RING WELL

DISTRICT	MAGU	CONSTRUCTION STARTED	10/1/1983
DIVISION	ITUMBILI	CONSTRUCTION FINISHED	30/1/1983
WARD	ITIMBILI	WELL CAPACITY	1783
VILLAGE	MAGU TOWN	DATE SIGNED VISITORS BOOK	-
UNIT LEADER	A. MASHISHI	-	-
GROUP	C. SAHAM	-	-
WELL DEPTH	8.20m	-	-

LABOUR:

Salaries and Nights for well sinders and stores

Working days 1st month	200 Mondays
Working days 2nd month	-

Total working days 200 x 35/- = 7000 incl. nights out allowance

TRANSPORT

Transport 1st month 535 km	including working days for drivers.
Transport 2nd month	and materials for maintenance etc.

Total transport 535 km x 5/= = 2675/-

continued

MATERIALS Tab.11.4 cont'd.

ITEM	UNIT	SHS	QUANTITY	MISC.	SHS
Ring No.1,2,3,5	EACH	750/-	8		6,000/=
Ring No. 4		600/=			-
Cover	EA	300/=	1		300/=
Cement	Bag	75/=	10		750/=
Pump Kangaroo/ Level Type	EA	5,700/=	1		5,700/=
Aggregate	Ton	200/=	2		400/=
Sand	Ton	100/=	2		200/=
Stones	Load	100/=	10		-
Pump stand	EA				
Pump rod	Meter				
Stores					1,000/=
Total materials					14,350/=
Total Labour					7,000/=
Total Transport					2,675/=
TOTAL Materials					14,350/=
SUBTOTAL					24,025/=
Overhead 10%					2,403/=
Grand Total					26,428/=

The Project Engineer Mr. S.N. Shoo says that the costs can be reduced by:

- constructing more number of wells at a time
- concentrating the construction teams in one area at a time so that transport costs are reduced
- obtaining the necessary materials and equipment in time i.e. good logistic support
- constructing tube wells only and sinking ring well when necessary.

11.3 Morogoro Region Project

Unlike the Mtwara-Lindi project, the Morogoro project was set up mainly:

- to execute a construction programme of medium depth wells with manually operated pumps in the region and to train personnel in the siting and construction of such wells
- to undertake research into the development of new or adopted well siting and construction methods and into the development and eventual local production of alternative power sources
- to develop a programme providing on the job training in Morogoro for the regions and to assess the scope of a self-supporting supply organization for tools, equipment and materials specific to well construction and not generally available in Tanzania.

The project started in 1978; with preparatory works which included construction of workshops, stores and staff houses, recruitment of local personnel and planning of the wells construction programme. The projects presently continues with well siting and construction, manufacturing and supply of basic equipment, tools and materials for other regions which require to develop shallow wells. Another important aspect is training of construction team for other regions too.

The shallow well project is financed by the government of the Kingdom of Netherlands and its organization set up is shown in figure 11-3.

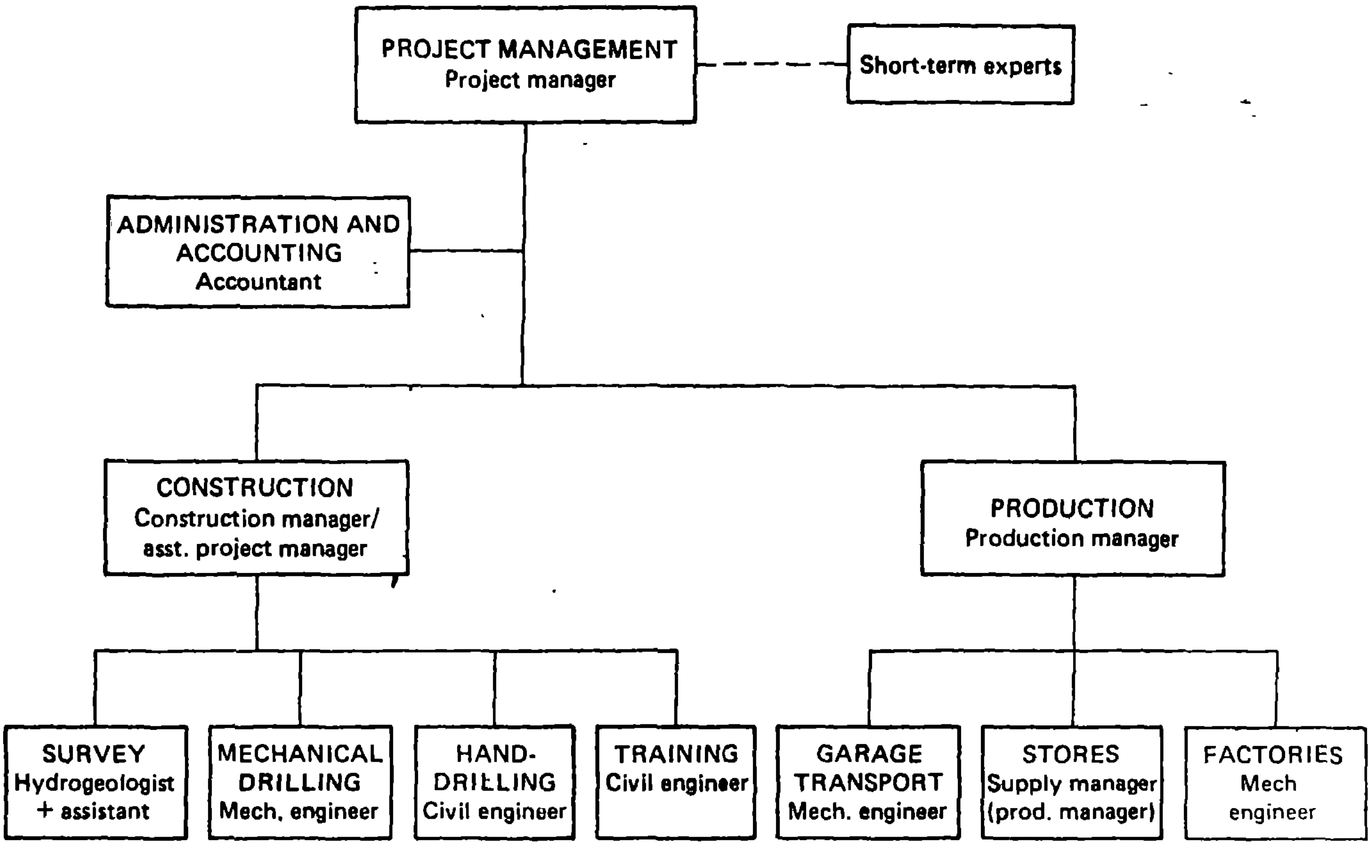


Figure 11-3. Organization chart for Morogoro project.

Another aspect of the project is that shallow well construction in Morogoro is carried out by two separate organizations. The Regional Water Engineer has his own programme which is being financed by the Ministry of Water and Energy. Its organization is as shown in figure 11-4. It works parallel to Morogoro shallow well construction programme.

As the construction system is in both cases the same the well costs are also the same. However, it should be mentioned that the expatriate staff costs are not included in case of DHV-Engineers part. If they are to be included the cost of the wells will naturally be more than those of the Regional Water Engineers side. Tables 11-4 and 11-5 show the lowest and the highest costs respectively.

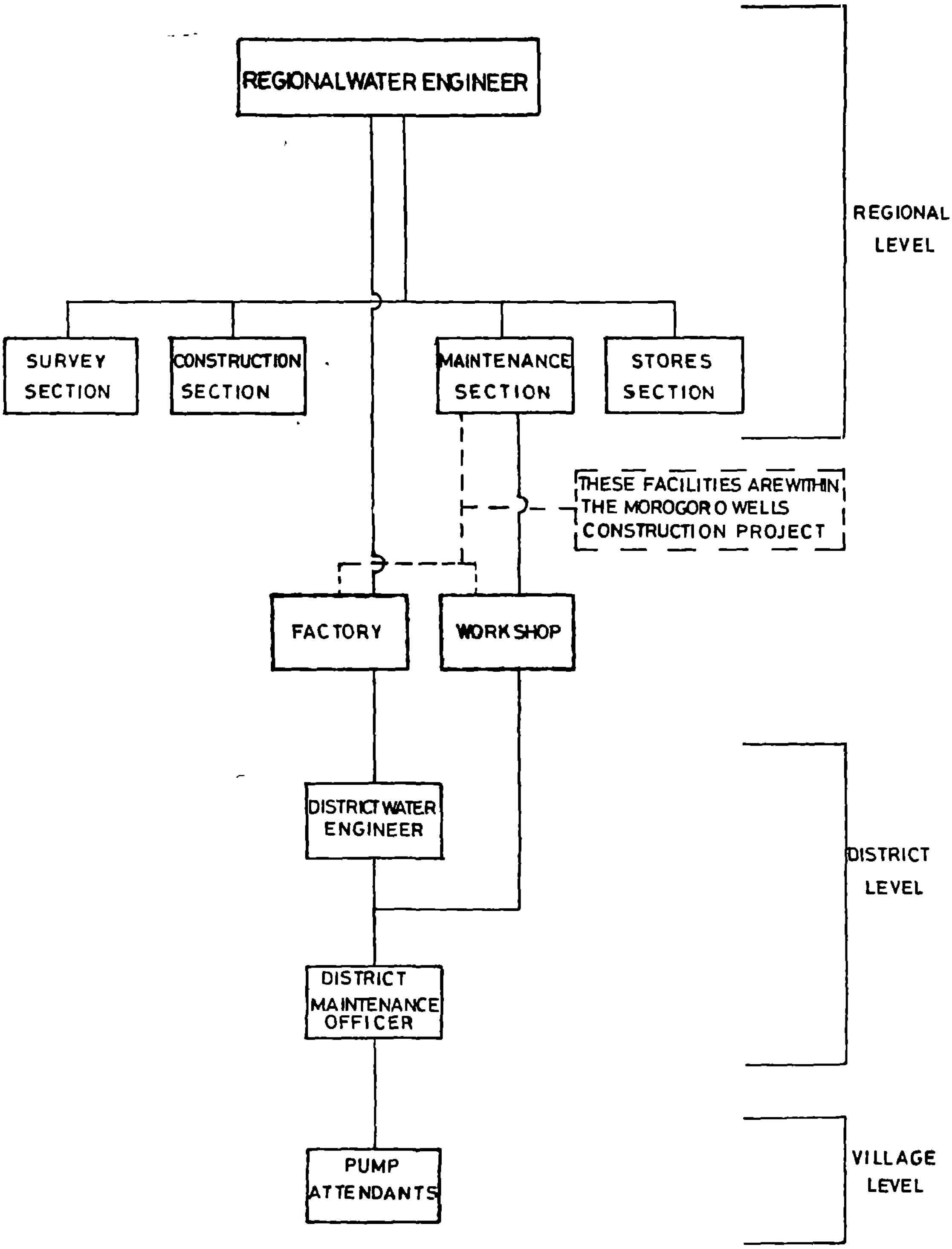


Figure 11-4. Shallow well organization chart.

Table 11-4.

MOROGORO WELLS CONSTRUCTION PROJECT

Well report - Construction Section

~~Well Number~~	~~MG/WL/81-1~~

Village : KIBEREGE .... ..
Ward : KIBEREGE .... ..
Division : MANGULA ....
District : KILOMBERO . . .

Date start : 9 - 7 - 81
Date completed : 11 - 7 - 81
Date Pump Installation : 15 - 7 - 81
Group + Operator : L2 : MWANGOSI

Date		10/7 1/7	11/7 2/7	12/7 3/7	14/7 4/7	15/7 5/7	6/7	7/7	8/7	9/7	Qty	Unit Price	Total —
Labour Man days	M.W C.P.	5/3	3/5	5/3	5/5	3/3	5	3	5	3	56	50/=	2800,00
	Local	8/	8/	1/	8/	8/	—	—	8	8	49	18/=	882,00 +
												Total Labour Tsh	3682,00

Transport Kilometers											Qty	Unit Price	Total
	TZ No. 43038	104/	22/	/403	109/	66/			64	137	925	12/=	11100,00
	TZ No. 43038 42507				253 269						253 269	12/= 6/=	3036,00
	No. TZ 34927					125	17	14C	135		423	6/=	1614,00 +
												Total Transport Tsh	18288,00

Materials		Unit	Qty	Unit Price	Total
P.V.C ⌀ 125 mm	screen	m'	3.00	171,05	513,15
	casing	m'	9.95	119,35	1167,65
	socket	EA	–	–	–
Cover PVC/Wood		EA	1	15,40	15,40
Gravel pack		Karai	17	25,00	425 +
				Total Borehole Tsh.	2121,20
Concrete cover		EA.	1	242,00	242,00
Cement		EA	8	65,00	520.00
Cement block		bag	–	–	–
Stones		box	2	80,00	160,00
Sand		box	2	30,00	60.00 +
				Total Slab Tsh.	982,00
Pump WANGAROD		EA	1	2950,00	2950,00
Cyl PVC mm 2½"		EA	1	1720,00	1720,00
Rising Main		—	—	—	1859,00
Socket ⌀ 1½"		EA	3	44,00	132,00
Grease		kg		–	–
Oil		ltr		-	+
				Total Pump Tshs Tshs	6661,00 +

Rising main + Pumprod			
Length	Qty	Unit Price	Total
6,00			
4,00	2	564,00	1128,00
3,50			
3,00	1	445,00	445,00
2,50			
2,00			
~~1,50~~ BANDS	2	53,00	106,00
~~1,00~~ WASHERS	5	1,00	5,00
0,75	1	175,00	175,00 +
		Total Tsh	1859,00

Total Materials [illegible]	Tshs	9764,20
Total Labour costs	Tshs	3682,00
Total Transport [illegible]	Tshs	18288,00 +
Subtotal	Tshs	31734,20
Overhead 15%	Tshs	4760,15 +
Total [illegible]	Tshs	36494,35

Table 11-5. **MOROGORO WELLS CONSTRUCTION PROJECT**

Well report - Construction Section

Well Number	MG	KL	81-29

Village : VIWANJA SITINI

Ward : VIWANJA SITINI

Division : IFAKARA

District : KILOMBERO

Date start : 14-9-81

Date completed : 14-9-81

Date Pump Installation : 15-10-81

Group + Operator : L3- SINAHELA

		Date	14/9	15/9								Qty	Unit Price	Total
Labour	Man days	M.W.C.P.	5	5								10	55/=	550/=
		Local	5	5								10	24/=	240/= +
													Total Labour Tsh.	790/=

Transport Kilometers	No ST 7144	–	–							–	–		
	No STG 1295/2572	17	20/–							37	6/=		222/=
	No 12 STG 43038/2573	14	92							106	12/=		1272/= +
												Total Transport Tsh.	1494/=

		Materials	Unit	Qty	Unit Price	Total
P.V.C	ϕ 125 mm	screen	m'	300	171,05	513,15
		casing	m'	5,35	117,35	627,80
		socket	EA	–	–	–
Cover PVC/Wood			EA	1	15,40	15,40
Gravel pack			Karai	17	25,00	425,00 +
		Total Borehole			Tsh.	1581,35

	Unit	Qty	Unit Price	Total
Concrete cover	EA.	1	242/=	242,00
Cement	EA	7	65/=	455,00
Cement block	bag	3	5/=	15,00
Stones	box	3	160/=	480,00
Sand	box	2	50/=	100,00 +
Total Slab			Tsh.	1292,00

	Unit	Qty	Unit Price	Total
Pump KANGAROO	EA	1	2460,00	2460,00
Cyl. PVC. mm 3"	EA	1	1980,00	1980,00
Rising Main	—	—	—	1290,00
Socket ϕ 1¼"	EA	2	44,00	80,00
Grease	kg			
Oil	ltr			+
Total Pump Tshs			Tshs	~~5827,00~~ +

Rising main + Pumprod

Length	Qty	Unit Price	Total
6.00			
4.00	1	564,00	564,00
3.50			
3.00	1	445,00	445,00
2.50			
2.00			
1.50	4	1,00	4,00
1.00	2	53,00	106,00
0.75	1	180,00	180,00 +
Total		Tsh.	1299,00

Total Materials cost	Tshs	8700,35
Total Labour costs	Tshs	790,00
Total Transport	Tshs	1494,00 +
Subtotal	Tshs	10984,35
Overhead 15 %	Tshs	1647,65 +
Total	Tshs	12632,00

In Morogoro only tube wells are constructed and SWN 80 and 81, and Kangaroo pumps are used. One of the very interesting thing in this project, is that nearly 50 % of pumps' elements are locally manufactured in the projects workshop in Morogoro.

In total more than 1 000 shallow wells have been constructed by the end of 1983. Each well serves about 250 to 300 people.

11.4 Discussion

For the past five years Tanzanian rural water supply development budget has been declining. This is because of the economic difficulties the country is passing through. It will take another couple of years before the situation changes to better conditions. This deficit budgeting is presented in table 11-6.

Table 11-6. Rural water supply budget of Tanzania TShs x 1 000 000

Financial year	78/79	79/80	80/81	81/82	82/83	83/84	84/85
Rural water supply budget	319,2	297,5	245,5	230,2	172,7	168,5	161,2*

* 1983 estimate

On the average only 400 000 people living in rural areas are being supplied with clean water per year. This is far below than the nations target of supplying 1 600 000 people per year. In order to supply a large number of people per year there is a dire need to review the technology involved in rural water supply engineering.

One of the most appropriate technology that should be applied is that of shallow wells with hand pump.

This has been demonstrated by the remarkable change in the standard of living of the people, and especially that of women, in areas where there are shallow wells. Admittably, piped water supply is prefered to shallow wells but nowadays women spend less time in fetching water than before when there were no shallow wells in those areas.

Presently there are several regions constructing shallow wells, and the regions of Mtwara, Lindi, Mwanza and Morogoro are well organized as compared to others. The shallow wells constructed in these regions are either dug ring wells or drilled tube wells. The choice between the two types depends on many factors, the main ones being those of geological and hydrogeological formations. In Mtwara, Lindi and Mwanza regions both the two types of wells are constructed while in Morogoro only drilled tube wells are constructed.

It is worthwhile here to discuss the costs involved in constructing shallow wells. The costs of wells are relative to various factors that include costs of materials, labour, transport and etc. Cost comparison in the three regions mentioned above can be seen as follows:

Table 11-7. Cost comparisons.
1 = dug ring well, 2 = drilled well
nm = not mentioned

	Mtwara/Lindi		Mwanza		Morogoro	
	1	2	1	2	1	2
Material	6618.-	4195.-	14 350.-	11 250.-	-	9232.-
Labour	2480.-	2560.-	7 000.-	630.-	-	2236.-
Transport	7900.-	6300.-	2 677.-	2 735.-	-	9891.-
Experts	8000.-	7400.-	n.m	n.m.	-	n.m
Maintenance	790.-	790.-	n.m	n.m	-	n.m
Subtotal	24998.-	21245.-	24 027.-	14 675.-	-	21 359.-
Add 15% contigencies	3868.-	3187.-	3 604.-	2 201.-	-	3 204.-
Total	29 656.-	24 432.-	27 631.-	16 876.-	-	24 563.-

From the above costs it can be seen that drilled wells are generally cheaper as compared to dug wells. This is so because in dug wells you require cement concrete which is quite expensive.

The cost of wells in Mtwara are "expensive" because the costs of salaries for experts have been included while in other regions they are not included. When overheads are included, especially in the case of Morogoro the cost per well will be very much more expensive than in other regions.

Again the cost analysis for Mtwara include the costs of annual maintenance which is not the case in other two regions. In the final analysis the costs are nearly the same with a small variation depending how far the region is from the coast where most of the imports come through.

It is therefore not easy to have a clear cut between the two systems, though it would be of general interest to use drilled wells because they are easy to construct. In Mwanza region they are planning to construct dug wells only when necessary and deal mainly with drilled wells. Morogoro region opted for drilled wells right from the beginning of the project. It is also envisaged in Mtwara and Lindi that in future mainly tube wells are to be constructed.Figure 11-5 shows the cost comparisons between dug wells and tube wells.

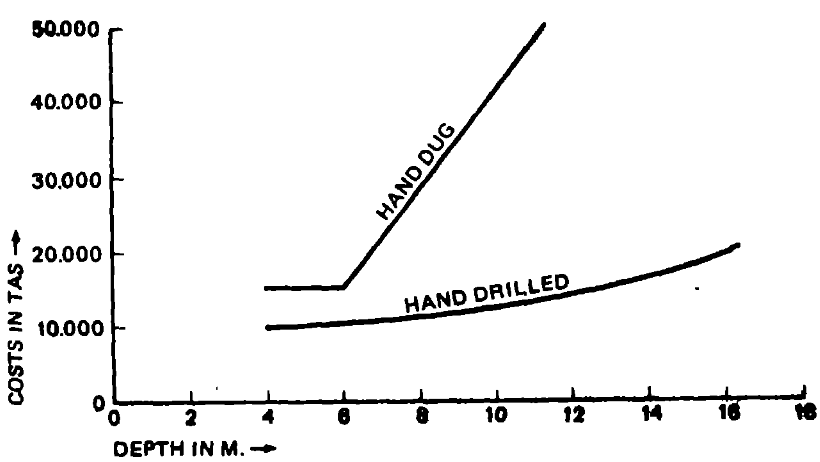


Figure 11-5. Cost of shallow wells./29/

11.5 Recommendations

11.5.1 Construction of Dug Wells

In areas with deep lying aquifers and it is not possible to construct tube wells for some obvious reasons deep dug wells will be necessary. Such wells are very costly because of the concrete rings required. In many of developing countries the cost of cement is getting higher and higher and as a result concrete cost go higher also, and this is not going to get better in the near future.

In order to reduce these costs, the construction of deep dug wells should be constructed as shown in figure 11-9 /17/. The system is that only filter ring is used in the aquifer zone and then covered by a reinforced concrete cover slab. Then a telescopic draw up pipe is installed to hold up the drop pipe and pump. The rest of the excavated hole is then backfilled with compacted soil and thus avoiding the use of more concrete rings.

Whereas in some areas there is a possibility of getting burnt clay bricks. These bricks can be used for lining the wells. This practice has proved to be cheap in Western Kenya, where the cost of a brick lined well is about 40 percent cheaper than concrete lined well /20/.

However it has been observed that in some cases brick lined wells cost more especially when the well site is far away from the brick factory. Another important setback is that brick lined wells take much longer time to construct and it has not been established what is the life span of the wells.

Figure 11-7 shows the construction of a brick lined well.

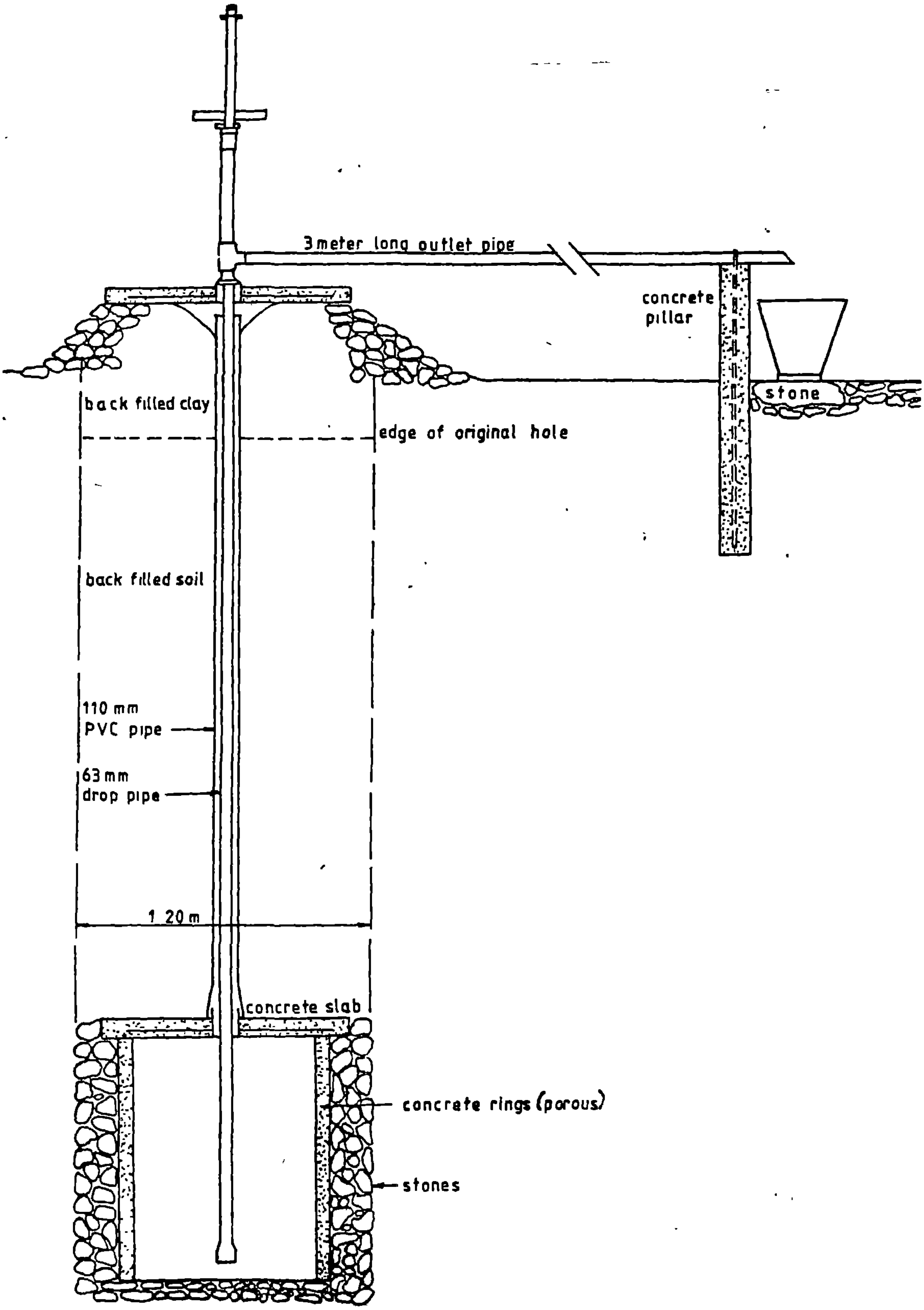


Figure 11-6. Recommended dug well construction./17/

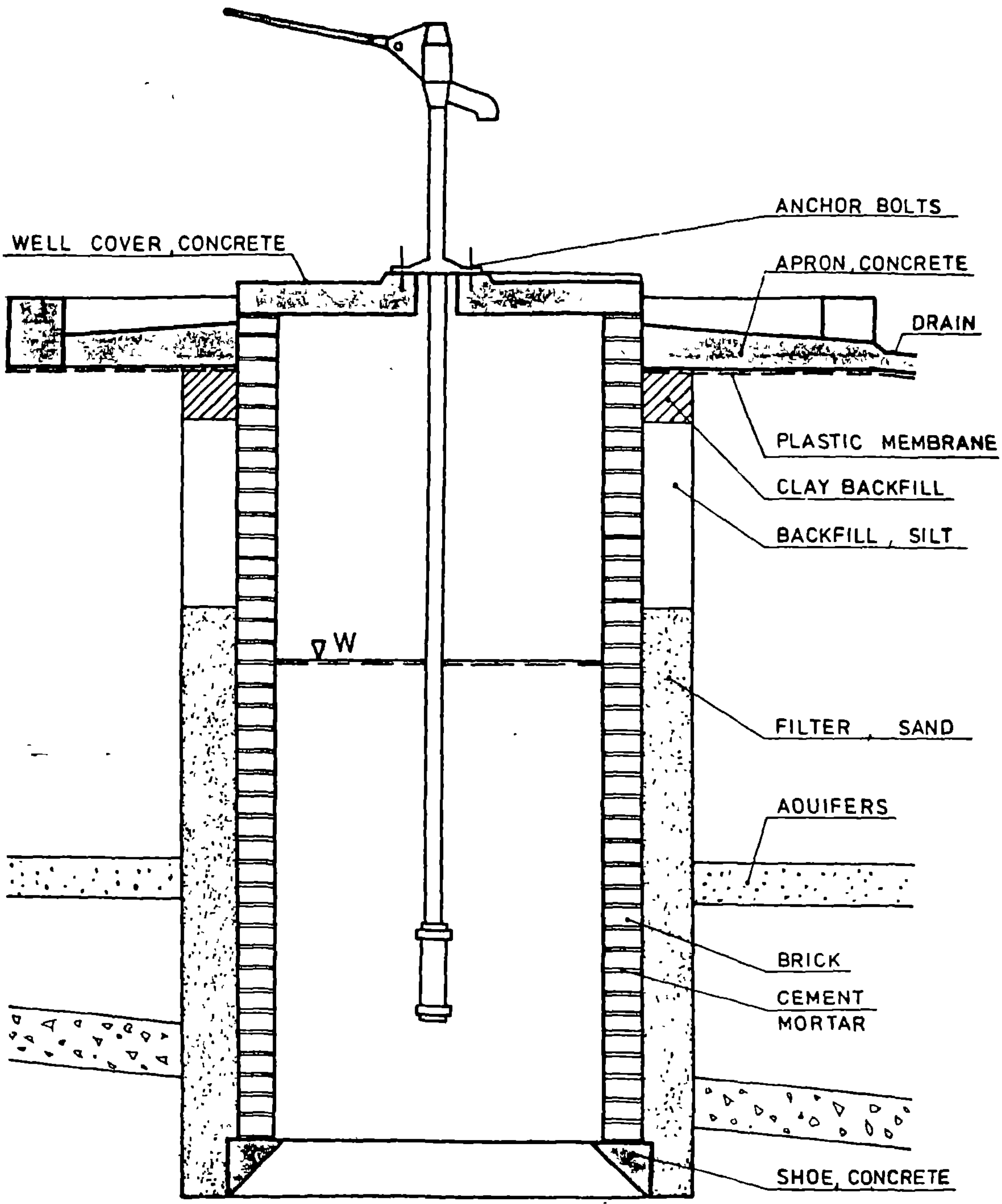


Figure 11-7. Shallow well lined with bricks./20/

11.5.2 Finishing Up of the Well Surroundings

Apart from the measures given in chapter ten, coming up with a pollution resistant backfill is next to an impossibility. Secondly, the area around the well slab may have some faults and gravel soils such that vertical movement of water is very easy. This could also lead to some stagnant water to percolate and enter into the well and subsquently polluting the water in the well.

In order to keep water away from the pump plinth, the use of a 3 to 4 m extension pipe to take the water away from the pump outlet to a purposefully constructed apron as shown in figure 11-8, is recommended. This system was adopted in Malawi after much considerations as it somehow increases the final costs of the well /17/.

Other features in this design may be equally adopted depending on the financial situation. Actually in Morogoro region they are providing a washing slab constructed at a distance of 4 to 6 m away from the well.

11.5.3 Community Participation

In recognizing the desirability of village self help, all efforts are required to assure village participation in the construction of wells. The objective of getting a long operating life for the well is hopefully met by building up a sense of community ownership of waterpoint so that there is an incentive to maintain them. Among other things which could be done in Tanzania are:

- involving of women as the focal point of the water utilization in a household
- involvement of the users in the villages and their participation for the maintenance of the schemes
- the necessity of ensuring that the schemes function continuously

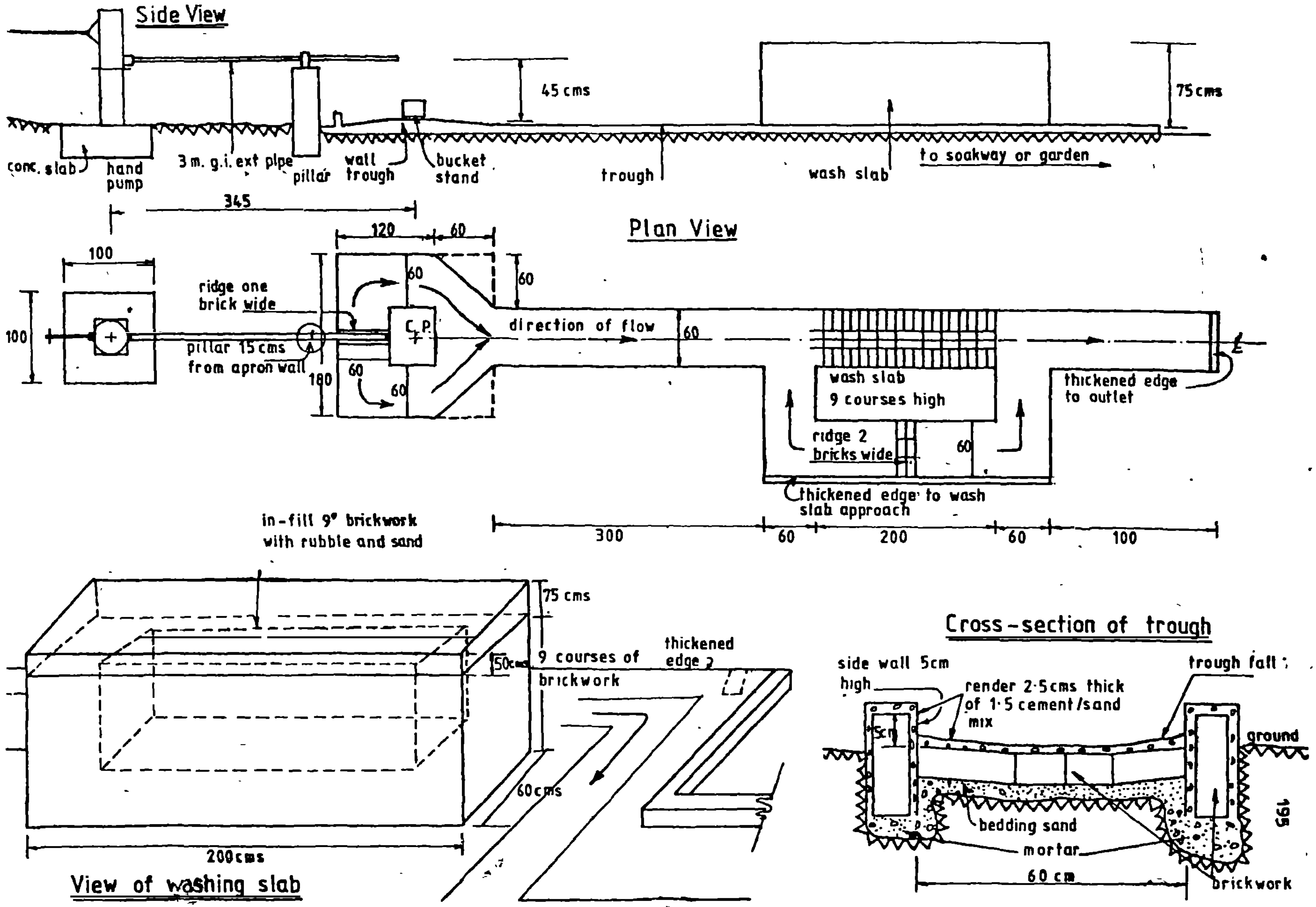


Figure 11-8. Typical hand pump installation in Malawi./17/

- effective utilization of the assistance from various donors, and
- necessity of the implementors to adequately understand the sociological aspects of the villagers in the project area.

Table 11-8 could act as one way of management guide to staff deployment on technical activities in well construction, so that there is transfer of technology to the villages for construction, operation and maintenance of shallow wells /17/.

Table 11-8. Management guide to staff deployment on technical activities./17/

Technical Activity	Professional Management	Technical Supervisor	Skilled Teams	Unskilled Village Participation
1. Well Sitting	1			1
2. Tubewells				
(a) drilling	1	2	1	
(b) design	1			
(c) casing installation		1	1	
(d) gravel packing	1	1	1	
(e) developing	2	1	1	
(f) test pumping		2	1	
3. Dug-Wells				
(a) digging				
(b) deepening		2	1	1
(c) design	1			
(d) lining		2	2	1
(e) completion		2	2	1
4. Pumps				
(a) design sitting	2	1		
(b) installation		2	1	1
5. Apron (slab) Construction		2	1	1
6. Maintenance Training	1	1	1	1

Key: 1 = full-time involvement
2 = partial involvement - occational suppervision

In case of Tanzania, implementation of community participation will however be difficult unless the government reconsiders the policy that water is free so that consumers can contribute to the development of water projects. At present not only the villagers are refering to the policy of free water, also Regional Authorities are finding it difficult to implement community participation effectively.

11.5.4 Shallow Wells Project Organization

When the District Councils are full re-established, they should take up the responsibilities of construction of shallow wells. The government should set up a autonomous nation institution which will look after the construction activities of shallow wells by providing logistic support which will among other things include:

- setting up of factory to manufacture equipment which should be standardized and used throughout the country, especially pumps

- formulation of design manual and norms, thus the choice of technology

- to act as central office for supplies and procurement

- coordinate shallow wells development strategies between the Ministry of Water and Energy, The Prime Minister's Office, the Regional Development Directors and the Regional Water Engineers.

12. CONCLUSION

The oil crisis in the early seventies, still affects the economics of most developing countries and even including some of developed ones.

In Water Supply Sector, the use of piped supplies required either electric pumps or diesel engine pumps. This is very expensive especially when it is coupled to high initial investment: costs of pipelines, storage, development of clean water supplies especially in rural areas will be very much delayed if not completely grounded.

In order to meet the urgent and immediate needs of clean water for the rural areas, one of the most appropriate step to be taken is the extraction and use of shallow ground water using shallow wells with hand pumps for the time being, shallow wells provide a good possibility of giving villages clean water with minimum costs, as far majority of the rural villages properly constructed shallow wells is the optimum solution to the clean water supply problem. Among the outstanding merits of shallow wells are:

- speed and ease of construction
- exploitation of a supply of clean, accessible water which would otherwise be wasted. Risk of contamination is reduced and many of the wells combine a filtering and storage capacity at no extra cost.
- there is adequate knowledge of construction methods and suitable hardware. Without belabouring the appropriate technology aspect any observer can and will see that shallow wells and hand pumps are right for rural villages as their construction and operation is understood by the village people and they deliver the right amount of water at the right place and at the right price.

- most maintenance can be done by villagers and spares for repair are cheap enough for villagers to keep them
- no operational costs of e.g. diesel costs, no need to support a pump attendant and his assistant
- if several wells are constructed in a village, the breakdown of a pump does not cut off the supply as the other wells will still give water. Time is gained to facilitate the repair.

On the other hand proper investigation should be made before construction programme starts. This can be easily included in the hydrogeological studies of Water Master Plans. In order to avoid false aquifers, construction of wells should always take place during dry seasons so that one can at least be assured of water being available all the year round. All the same shallow wells should be constructed whenever possible e.g. in areas with good rainfall and shallow lying aquifers.

All in all, not a very distant future we will have to provide the villages with piped water. Shallow wells are just a stepping stone towards the ultimate goal of clean piped water supply and house connections.

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