CHAPTER TWO

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TABLES AND FIGURES

ABBREVIATIONS

BOD	Biochemical Oxygen Demand
CWB	Central Water Board
EM	Electromagnetic
FAO	Food and Agriculture Organisation
MDGs	Millennium Development Goals
NAWAPO	National Water Policy
NEMC	National Environment Research Council
PDF	probability distribution function
USBR	United States Bureau of Reclamation
WR	Water Right
WUCA	Water Utilization (Control and Regulation) Act

CHAPTER TWO - WATER SOURCES

2.1 INTRODUCTION

2.1.1 General

This Chapter contains some additions and minor changes to that in the previous version of the Design Manual. An introductory Section on Tanzania's' Water Sources has been included and the Hydrologic cycle introduced. Issues pertaining to Legislation and Water Rights have been updated and on raw water quality and human health and wetlands added. A river basin map, a geological map and a map showing the major wetlands have also been included. In addition, the likely effect of climate change on the use of historic data to predict future events is also included.

2.1.2 The Water Sources of the Tanzania Mainland

Source water is potential raw water for use in the supply of water, i.e. it is natural fresh water that could be abstracted and processed for drinking purposes.

The chemical composition of natural fresh water is the end result of rainwater that has fallen on to the land and interacted with the soil and rocks as it moves down rivers, or into lakes, or percolates underground. Its overall quality is further modified by run-off from various land uses (non-point or diffuse sources) and by discharges (point source). The quality is modified further by biological activity.

One of the recent estimates of the availability of water resources in Tanzania [< >] suggests that the total renewable water resources amount to 93 km^3/yr of which 84 km^3/yr is internally produced and 9 km^3/yr is accounted for by the Ruvuma River, which flows on the border between Tanzania and Mozambique. Renewable groundwater resources are estimated at 30 km^3/yr, of which all but 4 km^3/yr is considered to be a surface and groundwater overlap.

TABLE 2.1: WATER SOURCES AND USE

Item	Year	Amount	Unit
Renewable water resources			
Average precipitation		1,071 1,012 10^9	mm/yr m^3/yr
Internal renewable water resources		84×10^9	m^3/yr
Total actual renewable water resources		93×10^9	m^3/yr
Dependency ratio		9.7	%
Total actual renewable water resources / inhabitant	2004	2,469	m^3/yr
Total dam capacity	2002	$4{,}196 \times 10^6$	m^3
Water withdrawal			
Total water withdrawal	2002	$5{,}184 \times 10^6$	m^3/yr
- irrigation	2002	$4{,}425 \times 10^6$	m^3/yr
- livestock	2002	207×10^6	m^3/yr
- domestic	2002	527×10^6	m^3/yr
- industry	2002	25×10^6	m^3/yr
• per inhabitant	2002	143	m^3/yr
• as % of total actual renewable water resources	2002	5.6	%

< > AquaStat FAO's Information System on Water and Agriculture, Review of water resources statistics by country, United Republic of Tanzania, 2005.

About 5.7 percent of the total land area of the United Republic of Tanzania is covered by three lakes, which also form the border to neighbouring countries:

- Lake Victoria, which is part of the Nile River basin, is shared with Kenya and Uganda. Its total area is 68,800 km^2, of which 51 percent belong to the United Republic of Tanzania.
- Lake Tanganyika, which is part of the Congo River basin, is shared with Burundi, Democratic Republic of Congo and Zambia. Its total area is 32,900 km^2, of which 41 percent belong to the United Republic of Tanzania.
- Lake Nyasa or Lake Malawi, which is part of the Zambezi River basin, is shared with Malawi and Mozambique. Its total area is 30,800 km^2, of which the United Republic of Tanzania claims 5,569 km^2 or 18 percent.

Other lakes include Lake Rukwa, Lake Eyasi, Lake Manyara, Lake Natron, and Lake Balangida.

2.1.3 The Hydrologic Cycle

Fresh water is not a mineral such as coal and oil where on one hand consumption means destruction and on the other hand new supplies are not formed, so that these resources are ultimately depleted on earth. On the contrary when water is used whilst its quality may change, and its state may be converted into another state, it always remains water. The most important difference is that fresh water is constantly being formed afresh.

The driving forces are the same energy and the earth's gravity. Water from the atmosphere falls to the ground as rain and part of this evaporates and returns directly to the atmosphere. Another part is intercepted by the vegetation or retained on the ground, wetting the topsoil and part accumulates and adds to the surface or groundwater resource. Part of the water accumulated, flows as surface runoff towards streams, rivers, lakes and oceans, and another portion infiltrates into the ground. This water seeps to shallow depth or percolates further downwards to reach the underground strata. Some of this water flows in the direction of the downward slope and emerges again at the surface either in the form of a spring, or as contribution to a stream or river or into lakes and oceans. From streams, rivers, lakes and oceans, water return to the atmosphere through evaporation. The whole hydrologic cycle starts again as illustrated on the following page [< >].

This clearly illustrates that apart from palaeo groundwater, water is never at rest but in a state of continuous recycling movement

2.1.4 Water Policy on Water Sources

National water policy is to provide clean and safe water to all her citizens and as soon as is financially possible. This is implicit in the Millennium Development Goals (MDGs) of 2010 and 2015 and a fundamental corner stone of the 2025 Development Vision. In order to achieve these goals, Tanzanian water policy is to ensure there is an appropriate use of the water sources such as lakes, rivers, under groundwater, rainwater harvesting and dams. The policy provides also for preservation of the sources against pollution. Common water uses are: domestic, municipal, industrial, irrigation, and for hydroelectric power generation and as a means of transport.

[< >] Taken from UNEP/GRID-Arendal. World's water cycle: schematic and residence time. UNEP/GRID-Arendal Maps and Graphics Library. 2002. Full schematic available at: http://maps.grida.no/go/graphic/world_s_water_cycle_schematic

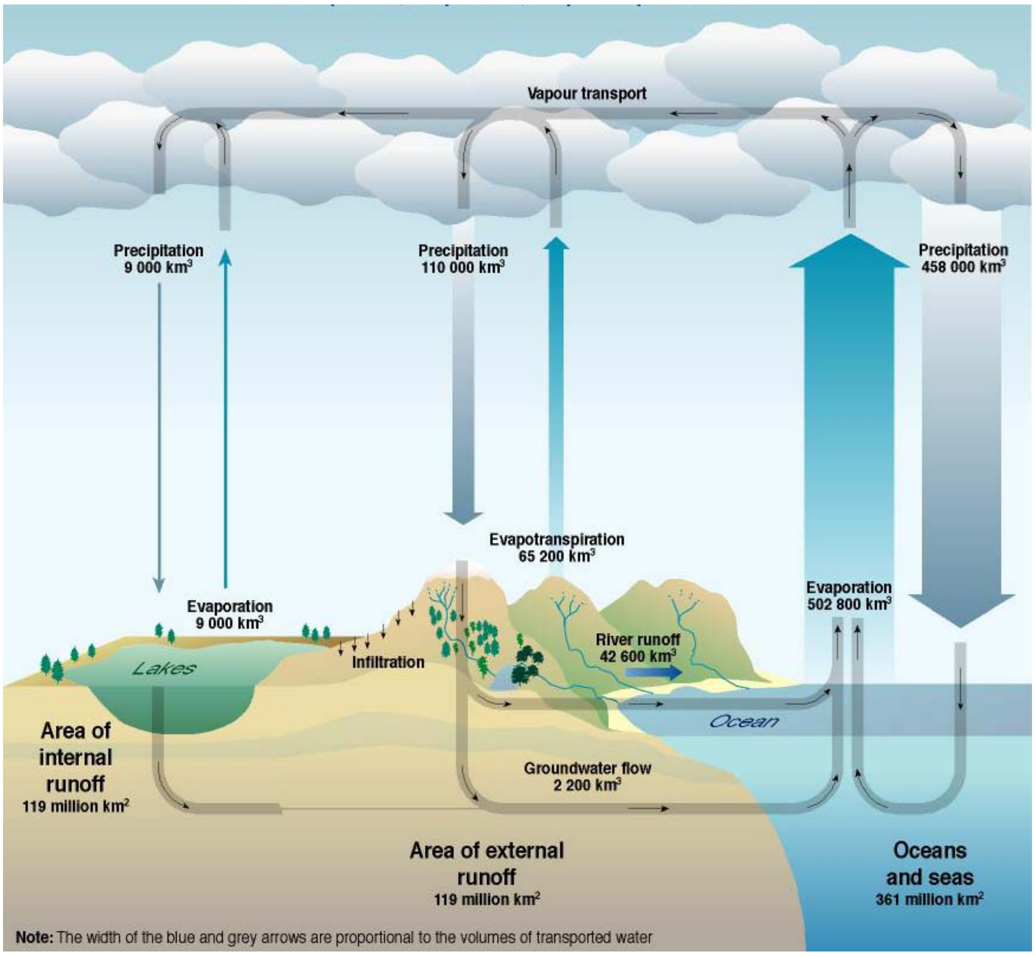


FIGURE 2.1: SUMMARY OF THE GLOBAL WATER CYCLE

2.1.5 Legislation of Water and Sources

The principle piece of legislation is the Water Utilization (Control and Regulation) Act No.42 of 1974 (WUCA) and its amendment No.10 of 1981 which established nine basin water offices (see section 2.2.1.2). Amongst other things the act states that all water in the Tanzania mainland is vested in the United Republic (part III sect. 8). Other pertinent legislation includes the Written Laws (Miscellaneous) Act. No. 17 of 1989 and the General (Regulations) Amendment.

Tanzania is well advanced in drafting a new legal framework for water resources management, aimed at attaining the objectives of the National Water Policy of 2002. Three separate pieces of legislation are expected to result from the proposed legal framework to cover water resources management, rural water supply and urban water supply and sewerage. Amongst other things this legislation is intended to formalise property and other informal arrangements related to the use of water resources whilst taking cognisance of customary laws and the interactions between traditional water management systems and modern, formal systems. The first of these new acts, the Water Resources Development Act (2004, draft) concedes to the administration both informal, local and customary water use permits (formerly water rights) and formal ones and, unlike earlier legislation, provides for an interface between the two systems of access to water.

Other acts relevant to the water sector are the Urban Water Supply Act and Waterworks Ordinance; Public Health Sewerage and Drainage Ordinance; and Tanzania Bureau of Standards Act.

In the case of water utilization and control of water pollution, some or all may have relevance. The framework is complex and designers and water users must pay attention to the extensive details in order to ensure compliance with the relevant laws.

Water in Tanzania is vested in the United Republic such that no person may "own" water, but may instead have the right to use water. Some rights to use water are automatic. For example, anyone with lawful access to water may use that water for "domestic purposes" (which are defined by the Water Utilization and Control Act to be for watering, dipping or spraying stock) and any owner/occupier of land may take limited quantities of water for non commercial purposes (as specified in WUCA) from a borehole or well without needing a special water right.

In addition, owners/occupiers may construct works on their land for conservation of rainfall and use the water as long as those works are not in a river or stream. Holders of mining licenses, prospecting licenses, mining claims and exclusive forestry licenses are each given implied water rights in their respective licenses, subject, however, to certain conditions.

In all other cases, where water is intended to be used, a Water Right (WR) must be acquired or use of the water is illegal as WUCA restricts pollution, abstraction etc. and it is important therefore that all water scheme abstractions are authorised by the water law authorities before they are abstracted. It is important for Designers to ensure that their Authority or Client has or is obtaining the necessary WR to enable the water supply scheme to legally abstract the water required.

2.1.6 Water Rights

Source water and in particular surface water is generally considered on a river basin by basin basis. The Tanzanian mainland consists of nine main river basins and Water Rights are issued by one of the nine Basin Water Boards.

A WR is defined as a "right to divert, dam, store, abstract and use water." No water may be used except in accordance with the grant of a water right or the legal requirements covering its use. It serves several purposes. First, it allows the authorities to be aware of the quantities of water being taken from and available from water sources. Second, it helps protect the holder from over-abstraction upstream rendering his investment unviable. Thirdly, it provides a framework for allowing authorities to control pollution discharges.

The process for acquiring a WR is as follows. First, an applicant for a water right must apply to the relevant River basin Water Officer for the right to take water using a standard application form.

WRs may be granted for the following purposes:

- Domestic
- Public Supply
- Industrial
- Stock watering
- Mechanical
- Irrigation
- Power
- Fish farming
- Mining

The application form requires applicants to explain to what extent agricultural businesses, domestic water use and supply of water will be affected. Applications are then published in the Government Gazette, in newspapers and posted at the District Office of the District concerned.

The public is given the opportunity to object to the application by filing objection at relevant water board. The process for objections is laid out in GN 233, 1975.

The District Agricultural Officer, District Executive Director and the District Water Engineer are then required to make a report regarding the application. The Water Officer must then consult with the Central Water Board (CWB) within the Ministry of Water which is the principal advisory body to the government on matters pertaining to the utilization of water nationally and to the allocation of water rights. It is also given executive power over pollution control.

For WRs sought from water bodies within urban areas which are under the control of an Urban Water Authority, the Water Officer must also seek the views of that Authority. Finally, the Water Officer determines, after considering all the advice obtained whether to grant a WR.

2.1.7 Raw Water Quality and Human Health

Generally, ground water is of better quality than surface water except when it comes to certain chemical concentrations i.e. fluoride.

For those constituents that impact most heavily on human health, groundwater is invariably superior to surface water unless locally polluted from human or animal waste. Examples of likely concentration ranges of enteric pathogens are shown in the following table.

TABLE 2.2: EXAMPLES OF HIGH DETECTABLE CONCENTRATIONS (PER LITRE) OF ENTERIC PATHOGENS AND FAECAL INDICATORS IN DIFFERENT TYPES OF SOURCE WATERS

PATHOGEN OR INDICATOR GROUP	LAKES AND RESERVOIRS	IMPACTED RIVERS AND STREAMS	REMOTE RIVERS AND STREAMS	GROUND-WATER
Campylobacter	20 - 500	90 - 2,500	0 - 1,100	0 – 10[a]
Salmonella	-	3 - 58,000 (3 - 1,000)[b]	1 - 4	-
E. coli (generic)	10,000 - 1,000,000	30,000 - 1,000,000	6,000 - 30,000	0 - 1,000
viruses	1 - 10	30 - 60	0 - 3	0 - 2
Cryptosporidium	4 - 290	2 - 480	2 - 240	0 - 1
Giardia	2 - 30	1 - 470	1 - 2	0 - 1
[a] *should be zero if secure* [b] *this range is the more likely*				

2.2 TYPES OF WATER SOURCES

2.2.1 Surface Water Sources

2.2.1.1 General

Surface freshwaters comprise those natural waters that are open to the atmosphere and contain only small quantities of dissolved materials, generally less than 1,000 mg/l, and includes rivers, streams, lakes and impoundments

The convenience of having readily available and accessible sources of water rapidly renewed by rainfall is offset somewhat by the susceptibility of surface waters to pollution from a variety of diffuse and point sources. Point sources are clearly identifiable, have specific locations, and are typically pipes and drains discharging wastes.

In most catchments used for water supply, pollution will be from diffuse sources, arising from land-use activities (urban and rural) that are dispersed across a catchment. Diffuse sources include surface runoff, as well as subsurface drainage, from activities on land. The main categories of diffuse pollutants are sediment, nutrients and pathogenic micro-organisms as can be noted from the above table. Other categories of diffuse pollutants are heavy metals (principally from urban land) and pesticides (mainly from agriculture and horticulture).

A summary of human activities that impinge on the suitability of freshwaters for potable water is given in Table 2.1. To be noted is that birds may be a significant source of faecal pollution in surface waters as indicated by standard faecal indicators (e.g. *E. coli*), and shed pathogens (e.g. *Giardia cysts, Salmonellae and Campylobacter*).

Surface water sources are sources where the abstraction of water is done on the surface. The rivers / streams, lakes, dams and rain water harvesting are examples of surface water sources. However, in most cases such sources need treatment because of the exposure to pollution. Surface water sources are either fed directly by surface runoff or from groundwater outflow.

The Hydrology Section of the Ministry of Water in Ubungo, Dar es Salaam in collaboration with the respective Basin Water Office is responsible .for collection and recording of stream / river flow data. In addition to a number of hydrometric stations, there are also a smaller number of climatic stations which measure evaporation, rainfall, wind, humidity, temperature, sunshine and radiation.

There are additional places with similar climatic information which are maintained by the Agriculture Department and the Meteorological Agency. It should therefore be possible to obtain most of the data related to water resources from one of these sources.

Whenever possible, projects that involve water resources data should be observed and analysed for at least three years before approval of a source for water supply.

TABLE 2.3: HUMAN ACTIVITIES AND ASSOCIATED INPUTS INTO FRESHWATER ECOSYSTEMS WITH HUMAN HEALTH RISKS

<table>
<tr><th>ACTIVITY</th><th>CONTAMINANTS</th><th>HEALTH RISKS INCLUDE</th></tr>
<tr><td>agriculture and horticulture</td><td>• sediments
• nutrients
• pesticides and other toxic chemicals and metals
• faecal microbial contaminants</td><td rowspan="4">immune and endocrine disruption

retarded physical and cognitive development, blue baby syndrome

foetal malformation and death

nervous system and reproductive dysfunction

behavioural changes

cancers

waterborne disease</td></tr>
<tr><td>industry</td><td>• nutrients
• toxic chemicals and metals
• oils</td></tr>
<tr><td>mining</td><td>• sediments
• toxic chemicals and metals</td></tr>
<tr><td>urbanisation, infrastructure and development</td><td>• sediment
• pesticides and other toxic chemicals and metals
• oils
• faecal microbial contaminants</td></tr>
<tr><td>recreation</td><td>• oils and fuel
• toxic chemicals</td><td></td></tr>
</table>

2.2.1.2 Drainage Basins in Tanzania

Tanzania is divided into 5 drainage systems

(i) The Indian Ocean drainage system and Bubu depression
(ii) The internal drainage system to Lake Eyasi, Natron and Bubu depression
(iii) The internal drainage systems to Lake Rukwa
(iv) The Atlantic ocean drainage system through Lake Tanganyika, and
(v) The Mediterranean Sea drainage system through Lake Victoria.

The drainage systems consist of nine river basins; others bear names resembling the drainage system. These nine basins are indicated below and on the following figure:

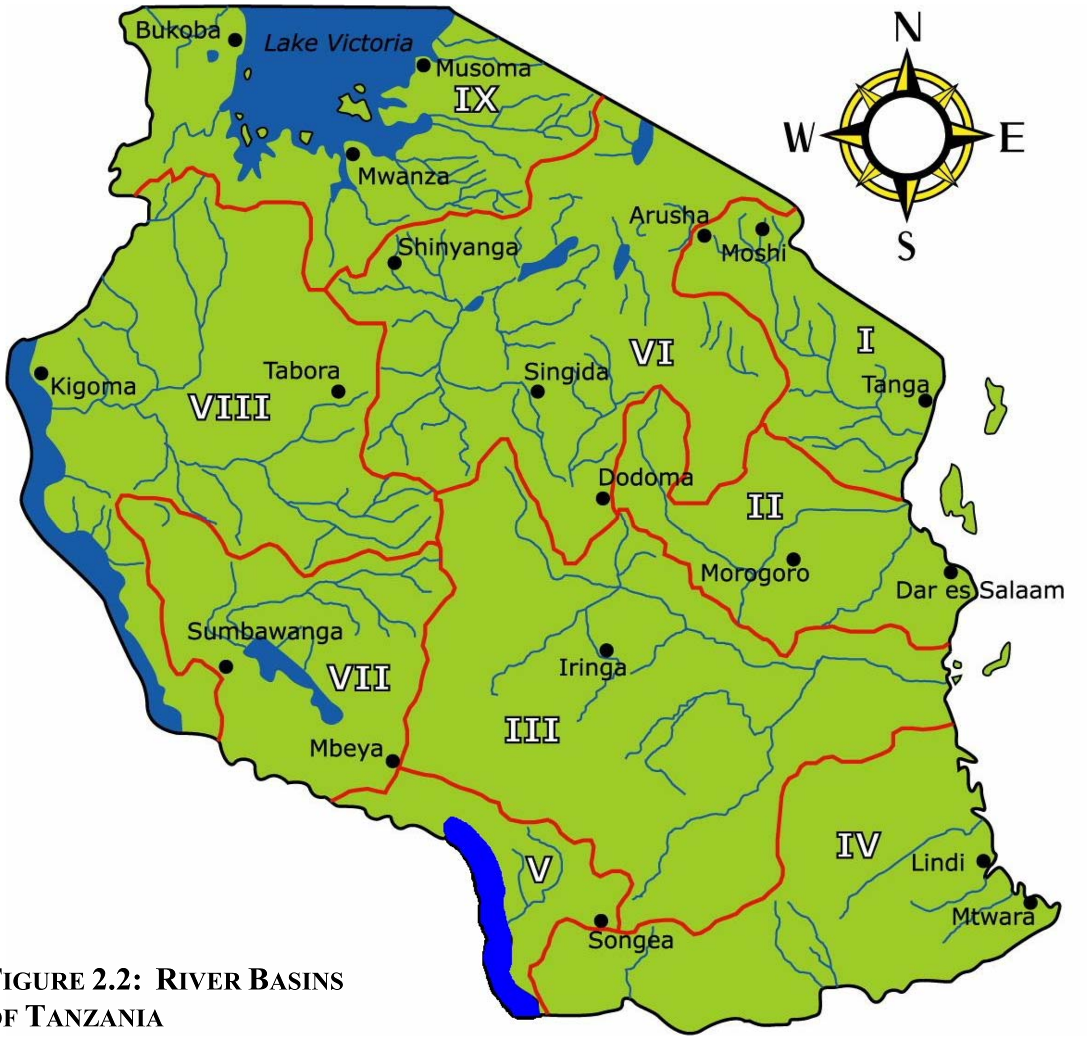


FIGURE 2.2: RIVER BASINS OF TANZANIA

(I)	Pangani River Basin	(V)	Lakes Nyasa Basin
(II)	Wami/Ruvu River Basin	(VI)	Internal Drainage Basin
(III)	Rufiji River Basin	(VII)	Lake Rukwa Basin
(IV)	Ruvuma and South Coastal River Basin	(VIII)	Lake Tanganyika Basin
		(IX)	Lake Victoria Basin

Each drainage system has its individual flow characteristics and each a Basin Water Office. Each Board should be contacted for flow characteristic in its basin.

In July 2002, the Government published a revised National Water Policy (NAWAPO), which sets out the future direction for the water sector in achieving sustainable development and utilisation of the Nation's water resources and the increase in the availability of water supply and sanitation services. The policy emphasizes integrated water resource planning based on River Basins as the planning unit. Also a mechanism for inter-sectoral planning at Basin level has been formulated. Water resource accounts of both surface water and groundwater have been set up. These are both quantitative and qualitative and are fundamental element of the water resources planning process.

However, initially these accounts are weak or non-existent for most the basins but will become important tools for:

- water resources planning (to show who is using water, how much water is used the socio-economic value of water used by each sector).
- water allocations at river basin level even if it is not for economic reasons.
- national level planning, useful for evaluation and prioritisation of water infrastructure investments, by showing demands and the socio-economic benefits.

The objective of water resources accounts is to have appropriate and sustainable data for management and preparation of water use plans the data to be used for decision making, giving water its real economic value.

Initially water accounts for two river basins, Pangani and Wami /Ruvu are to be established comprising tables as follows:

1. Rainfall and runoff for Pangani and Wami/Ruvu basins,
2. Water Balance for Pangani basin
3. Total water use within the Pangani Basin by major end users.
4. Total water use within the Pangani basin by the major end users but disaggregated by four sub-regions within the basin.
5. Total water use within the Pangani basin by for the four sub-regions and more detailed list of end users disaggregated depending on data availability.
6. A strategic planning and decision support tool for both river basin and at national level, (projection of future demand, water shortages, indication of users who are capable of paying for water services and who cannot).

2.2.1.3 Wetlands

Wetland are areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water, the depth of which does not exceed six metres.

Leaving aside coastal wetlands which are unsuited to human habitation or agriculture, Tanzania contains rift system wetlands and wetlands of the highlands drainage basins. Rift system wetlands are found in the rift depressions and characterized by salt lakes, playas, swamps and short streams with inland drainage. Soils are heavy and are affected by salinity and human habitation is very sparse.

Wetlands of the highlands drainage basins are often the source of long rivers originating in the highlands which meander through the plains forming lakes, swamps and flood plains before draining into the ocean or lake basins. They are characterized by fertile alluvial soils of varying textures.

Tanzanian wetlands are mostly utilized for seasonal crop production and grazing but in many areas there is potential for irrigation of an estimated 851,000 ha and the likelihood of increasing settled populations. As settled populations increase, the supply of safe water will become increasingly important and likely to be a special case for either surface water storage or the exploitation of shallow groundwater. However, given the fragility of many wetlands considerable environmental planning and care is needed and always involve NEMC.

The areas of major wetlands in Tanzania are shown on the following figure:

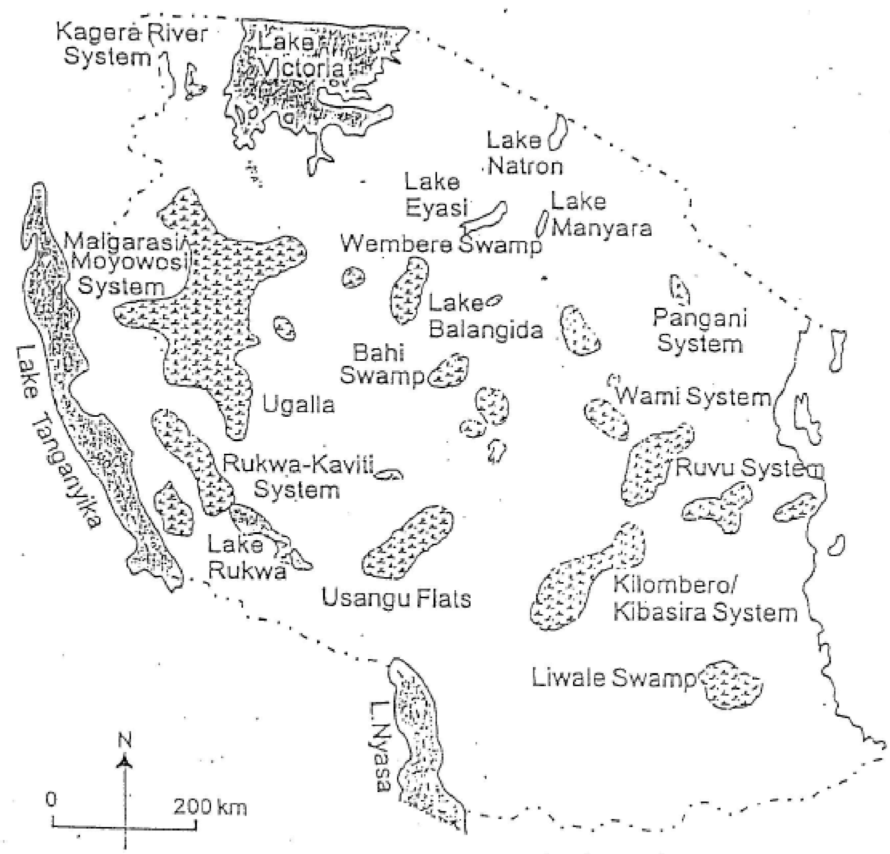


FIGURE 2.3: MAJOR WETLANDS OF TANZANIA

2.2.1.4 Rivers and Streams

Surface water is an important source of water in Tanzania. However, recently acquired data is limited although this problem is now being re-addressed. The problem is that as climate change accelerates, it is increasingly difficult to predict future dry season water availability, especially of smaller streams.

To check on the potential of a river as a water source one has to measure or calculate the minimum yield, preferably measured during the dry season. Historic information on many of the large rivers is available in the hydrological year-books or in water master plan reports. If no observations exist; flow records from adjacent rivers should be used to calculate the yield. Where possible, the minimum flow in the stream should be at least 10 times the calculated water demand.

One likely effect of climate change will be the need to rely less on run-of-the river schemes and more on those incorporating storage dams. Additionally, and as extreme flows are likely to become more pronounced, flood peaks are likely to increase and this must be allowed for in design and construction as must the likelihood of increased sediment load.

2.2.1.5 Lakes and Dams

Water from lakes, ponds and artificial or impounding reservoirs would be more uniform in quality than water from flowing streams.

Long storage in natural lakes permits sedimentation of suspended matter, bleach of colour and removal of bacteria while in impounding reservoirs the top layers of water are prone to algae and the turbidity, carbon dioxide iron, manganese, hydrogen sulphide of bottom layers may be high.

Water from other sources such as sea involves expensive extraction because of high concentration of salts (30,00036,000 mg/l) and also water reclaimed from sewage may only be used or non domestic purposes.

2.2.3 GROUND WATER

2.2.3.1 Introduction

Groundwater availability amounts to about 20-40 km^3 of 84 km^3 total annual renewable internal water resources equivalent to 11MCM groundwater per day. Aquifers comprise of unconsolidated sediments, volcanics, and weathered and fractured basement rocks whilst recharge is from direct rain infiltration and river influent.

The capital, Dodoma, and much of rural Tanzania is groundwater dependent. Borehole drilling commenced nearly a hundred years ago. Magnetic and electrical resistivity surveys for borehole siting were introduced from 1936. Formalised training of hydrogeologists led in the 1970s to an almost standard approach to hydrogeological investigation in the region and a period of stability followed, and some major investigations were carried out. Subsequently de-centralisation and fragmentation took place due to national funding limitations and groundwater monitoring and management is now limited and much useful data has not been disseminated.

Due to climate change and the intensive rural water programme, groundwater demand is increasing and there is need to promote the use of appropriate methodologies as an essential part of tackling the severe issues now facing the water sector in the country. Whilst so doing it is incumbent on project managers to ensure that copies of any information gathered are copied to the Geology Section in Dodoma to be added to the data base.

2.2.3.2 Springs

The best way to locate adequate springs and to get information about their reliability during dry spells is to interview people resident in the area. There are seldom records of the flow from springs. Simple overflow weirs, V-notches etc. should be installed for gauging the flow as early as possible in· the planning stage. The flow from an artesian spring often fluctuates less that of a gravity spring.

2.2.3.3 Boreholes and Wells

Wells and boreholes form an important source of, water in most parts of the country. The safe yield and cheap source should be determined by a hydrogeologist. Shallow wells have constituted an easy and cheap source of potable water for many areas in the country. However the likelihood of extended drought periods in the future means that the medium and long term success of such wells is likely to become increasingly limited and this must be recognised by planners.

2.2.3.4 Rainwater Harvesting

a) General

Rain water harvesting is a very traditional way of collecting water from surfaces that do not allow water to soak or penetrate e.g. rock outcrops, roofs of corrugated iron sheets, concrete etc. In seasonal rivers by construction of dams etc. Places where rain is sufficient the amount so stored could be quite substantial.

The Hydrology Section, Meteorology Agency, and Agriculture Departments should be contacted for rainfall data wherever rain harvesting technology is proposed. The amount collected depends on the surfaces where rain falls. The table below shows the run off coefficients for different materials.

Rain water is normally soft, saturated with oxygen and corrosive. Micro organisms and other suspended matter in the air are entrapped but ordinarily the impurities are not significant. However, collecting reservoirs, cisterns, can be contaminated and wherever possible after an extended dry period the first rain flush should be discarded.

b) Rainfall Data

This data is available from the Hydrological Section, Meteorology Agency and from water master plans. Practically the whole of the annual rainfall falls during the rainy seasons between November and May.

c) Roof Catchments

A first estimate of the average yield of a catchments area can be found using the following expression.

$$S = K \times I \times A \qquad 2.1$$

Where;

S = Yield in m^3 / annum
A = Area of catchments, m2
I = Average annual rainfall m/annum
K = runoff coefficient

The required capacity of the collection tanks should be calculated using available meteorological data showing the rainfall pattern of the area. However, for rough calculations the tanks, capacity may be calculated as follows:

$$C = D \times T \times 10^{-3} \qquad 2.2$$

Where

C = Capacity of tank in m^3
D = Total water demand in litres / day

T = Longest dry spell in days

d) Run-off Coefficients

The following run-off coefficients should be used for calculating the fraction of the rainfall which can be harvested.

TABLE 2.4: RUN-OFF COEFFICIENTS FOR DIFFERENT SURFACES.

SURFACE	RUN-OFF COEFFICIENT
1. Roof catchments	
– Roof tiles	0.8 to 0.9
Corrugated sheets	0.7 to 0.9
2. Ground surface covering	
– Concreted	0.6 to 0.8
Bitumen, plastic sheeting, butyl rubber	0.8 to 0.9
Brick pavement	0.5 to 0.6
3. Compacted and smoothened soil	0.3 to 0.5
4. Treated ground catchments	
– Clay / cow dung trashing floors	0.5 to 0.6
Silicone treated soil	0.5 to 0.8
Soil treated with sodium salts	0.4 to 0.7
Soil treated with paraffin wax	0.6 to 0.9
5. - Uncovered surface, flat terrain	0.3
– Uncovered surface, slope less than 10%	0.0 to 0.4
– Rocky natural catchments	0.2 to 0.5

2.2.4 Groundwater Quality

Groundwaters are generally of better microbiological quality than surface waters because of the range of mechanisms active under the ground that can attenuate microbial contaminants initially present in the water. Moreover, changes in microbiological quality that occur are not as large or as rapid as those in surface waters. Although some aspects of the chemical quality of groundwaters may be a concern, such as fluorides, iron and manganese, and salinity, characteristics of the microbiological quality of groundwater often mean they are preferable water sources to surface waters. However, once a groundwater becomes contaminated by chemicals, it takes a long time before the contamination is flushed out.

Groundwaters are not usually in direct contact with faecal material, as surface waters may be, but rainfall and irrigation provide means by which surface contamination can be carried into the groundwater. In some countries, groundwaters have been contaminated by the very bad practice of pumping wastes down disused boreholes and this is a practice that should be avoided. The vulnerability of aquifers to microbial contamination is however increased by:

- recharge water coming into contact with microbial contamination
- higher porosity aquifer media, which allow greater penetration and transport of microbes
- shallow aquifer depth

- absence of a confining layer
- light overlying soils and porous subsoil strata, which reduce the efficacy of processes removing microbes in these layers.

One potentially major pathway for contamination often overlooked is the conduit provided by a poorly sealed borehole, particularly during a flood or after heavy rain. Contaminants can enter directly down the borehole shaft or down the junction between the casing and the soil. To protect the groundwater against this source of contamination it is essential to design and construct the well head to protect against such contamination from the surface. Boreholes should always be secured against surface pollution regardless of the use made of the groundwater abstracted from them. Groundwater contamination can persist for a long time and affect a large area.

Groundwater in coastal areas is prone to salinity. This is likely to be caused by overpumping and seawater intrusion into the aquifer, salt drift, or possibly dissolution of salt deposits. The quality of groundwater supplies subject to seawater intrusion may change in association with pumping, water level variation and tidal cycles.

It is more difficult for contaminants to get into groundwater than into surface water. Once there, however, it is more difficult for the contaminant to be removed. The characteristics of the contaminants, the rate of groundwater flow through the aquifer, and the type of material the aquifer is composed of, will all influence whether the contaminants will attenuate through die-off, decay, adsorption or dispersion.

Once in the aquifer, the quality of the groundwater may change due to its interaction with the ground matrix. Sediments like sand may act as a filter and remove some types of contaminants from the groundwater as it flows through the aquifer. Fractured or karstic (limestone exhibiting dissolution features) aquifers offer little filtration or adsorption of contaminants. In the absence of recontamination, the bacterial quality of the water in an aquifer will usually improve during storage because of die-off due to unfavourable conditions. Passage through aquifer media will also reduce levels of viruses and protozoa, although the rate at which they are inactivated is much slower.

Simultaneously, the rocks may be releasing minerals into solution or exchanging ions with those in the water.

If iron and manganese are present the water may be clear initially while these are in a reduced state but, once dissolved oxygen is present in the water, they can oxidise to coloured forms (generally rusty or black), which may be insoluble and settle out.

Deeper aquifers are more likely to contain higher concentrations of minerals in solution because the water has had more time to dissolve the minerals from the surrounding rock material.

Groundwater may also contain significant concentrations of naturally occurring radiological determinands, notably radon.

Variability in the quality of groundwaters may arise for any of five reasons:

1. Seasonal recharge

   During the rainy season, high rainfall combined with lower evaporation rates causes greater leaching of chemicals, such as nitrate, stored in the soil. More new water enters the aquifer from the surface at this time and may therefore show high concentrations of these chemicals.

2. River recharge

   High river levels during flood may increase the amount of new water feeding into aquifers.

3. Intermittent discharge events

   Activities that contribute to variability in water quality in this category include septic tanks leaking or overflowing during high rainfall, fertilising of pastures, land application of sewage, or chemical spills. Where well heads are non-secure, floods may also cause spikes of contamination as the result of floodwaters running down the bore casing.

4. Groundwater abstraction

   Changes in pumping regime in the supply borehole or neighbouring boreholes can cause changes in groundwater flow directions or leakage rates. As a result, seawater (if near the coast), and water from nearby rivers, or overlying or underlying aquifers may be drawn into the vicinity of the supply borehole.

5. Changes in climate and land use

   Gradual, long-term changes in water quality may arise from changes in climate and land use. Although they may not affect the security of the groundwater, because changes may be slow enough to allow removal of micro-organisms, they may have important implications for the future water quality and quantity from the aquifer.

2.3 WATER SOURCE SELECTION CONSIDERATIONS

2.3.1 General Considerations

In selecting a source of drinking water, there are a number of factors that must be considered including:-

- Quantity: Is the quantity of water available at the source sufficient to meet future development?
- Quality: Is the raw water quality such that, with appropriate treatment water can be supplied that meets or exceeds the quality specified in the required standard?
- Protection: Can water, today and in the future, be protected from human excreta, from industrial discharges and from agricultural run-off? Can the catchments area, e.g. a forest, be protected efficiently to ensure sustained quantity and quality of the raw water?
- Feasibility: Is the source available at reasonable cost considering both capital and Operation and Maintenance costs? Can the source be exploited using simple and reliable treatment and transmission technology?

2.3.2 Specific Considerations

- Sources which require little or no treatment of the water should be chosen in first instance provided the required quantity of water can be obtained. Hence springs and ground water resources should always be exploited in the first hand.
- For household and small-scale community supplies, rainwater harvesting may serve well in most medium and high potential areas in Tanzania.

- Surface water from rivers, streams and lakes will almost always require some treatment to render it safe for human consumption. However, for large supplies surface water will often still be the most economical alternative. Rivers which have the bulk of their catchments in forest areas should be preferred.
- Sub-surface water drawn from a riverbed or river bank can sometimes be a viable alternative in dry areas with only seasonal flow in the river, or in rivers with a high silt load.
- It should be studied whether or not a combination of sources may give a more economical and reliable water supply than a system based on only one source. Mixing can also be used to reduce the content of certain constituents, e.g. fluoride, to acceptable levels.
- Sources from which water can be supplied by a gravitational system are particularly favourable as electricity costs are particularly significant in pumped water schemes.

2.3.3 Choice of sources

Before deciding on the selection of a water source a number of factors must be considered.

2.3.3.1 Quantity

The quantity of the water must suffice the future demand. If one source is not sufficient possibilities to include two or more sources to jointly meet the future demand should be investigated. Consideration' should also be given on the possibility to develop the source in phases i.e. initially as run-of-river and subsequently by providing storage.

2.3.3.2 Quality

The quality of the water should be such that, after appropriate treatment, it meets the specified standards.

2.3.3.3 Protection

Sources should be protected and conserved for both present and future use.

2.3.3.4 Feasibility

The source should be amenable to being exploited using appropriate technology and within reasonable costs (capital and operation and maintenance costs) and the exploitation be environmentally sound.

2.4 SAFE YIELD FLOW CONSIDERATIONS

2.4.1 Urban Centres with a Population over 10,000

The 96% - probability daily low flow shall be regarded as the yield of a river or stream. A flow - frequency analysis shall be made using the lowest recorded daily flow of each calendar year for which records are available for the dry season. Due cognisance shall be taken of the latest available information on the possible effects of climate change on worsening in the dry weather flow regime.

2.4.2 Urban and Other Centres with a Population under 10,000

The 96% probability monthly low flow shall be regarded as the safe yield of a river. The flow frequency analysis shall be by using the recorded lowest average flow during the month for each calendar year for which records are available for the dry season. Due cognisance shall be taken of the latest available information on the possible effects of climate change on worsening in the dry weather flow regime.

2.5 HYDROLOGY

Planners and designers are again warned to take due care in their analyses and because of climate change to take account of the most recent climate modelling information available. Where uncertainties exist then sensitivity analyses should also be carried out to assess risks involved over the period of both the project and with regard to permanent structures that could be adversely affected.

2.5.1 Precipitation Data

This data is necessary as it has to be used together with data in the foregoing section in computing maximum probable floods. Precipitation data corresponding to high runoff values are particularly useful.

If plans are made to install stream flow measuring facilities during the initial stages of a project, then rain gauges must also be set at salient points in the watershed.

2.5.2 Stream Flow Data

This data is still the most directly useful if it is continuous over a considerable length of time at the location of the site. However, such a coincidence is rare. With respect to the character of the stream flow data available, flood flows at the site may be determined under one of the following conditions

2.5.2.1 Stream flow record at or near the site

Such records, if available, and covering a period of at least two but preferably five years may be analysed to provide flood frequency values. Hydrographs of outstanding flood events can be analysed, to provide runoff factors for use in determining the maximum probable flood. Note however that climate change may impact on this also.
Shorter duration records may be used to obtain some of the run-off factors needed to compute the maximum probable flood. Values obtained from a short record should not be used without analysis of data from nearby watersheds of comparable runoff characteristics.

2.5.2.2 Stream flow records but at distance

Where stream flow records are available on the stream itself but at a considerable distance from the site, such a record may be analysed to provide unit hydrograph characteristics and frequency data which may be transferred to the site using appropriate area and basin characteristic coefficients.

The transfer can be made directly from one drainage area to another if the areas have comparable characteristics. Often sites are located within the transition zone from mountains to plains and stream gauging stations are located well out on the plains; in such instances special care must be taken when using records from gauging stations on the plains for determination of flood flows at a particular site especially for any dam site.

2.5.2.3 Inadequate on stream but satisfactory records exist for stream with similar characteristics in the same region.

When no adequate stream flows data is available on the specific stream, but satisfactory records exist for a drainage basin of similar characteristics in the same region, analyse the records for unit-hydrograph characteristics and frequency data and transfer them to the site using appropriate area and basin characteristic coefficients.

2.5.2.4 Use of high water marks

These may be used, with care, in estimating flood magnitudes. However, where there are a number of high water marks in the vicinity of the project site and particularly if such marks are obtained from the records of public offices (such as Trunk Road Maintenance and Regional Engineer), they may be as basis for a separate supplemental study.

2.5.2.5 Ungauged streams and no suitable nearby data

For rivers with no or few observation records, extrapolation should be made of flow records from adjacent rivers and, of rainfall data to construct a probable flow-frequency curve.

Rivers and stream which lack installations to measure the flow but which have been identified as a potential source of water supply should be provided with permanent gauging stations as early as possible in the planning process.

The draw-off for other water supplies from the same river should be considered in the flow analysis when determining the available water.

2.5.3 Analysis of Stream Flow and Precipitation Records

The objective of analysing stream flow and precipitation records is to develop procedures where by a hydrograph (time versus distribution of runoff) that will result from a given amount of rainfall may be estimated. Another objective is to get the flood magnitude frequency relationship based on actual events.

Besides the already mentioned records, it is necessary to collect all relevant information concerning the particular watershed and particularly changes in catchment cover which could influence interpretation of the analytical results. In case of a dam design, maps of the area above the dam site should be prepared to a standard scale showing the drainage system, .contour lines if available, drainage boundaries, and location of any precipitation and stream flow measurement stations

Available data on soil types, cover and land use provides valuable guide to judgement.

2.5.4 Design Floods

One of the major problems in hydrologic design is the estimation of maximum floods. These estimations are used to assign hydrological and hydraulic dimensions to dams, spillways and other structures, protection embankments, etc. Whatever the method used, the design flood should be the maximum probable flood which is defined as the larges flood that can be reasonably expected to occur in a given stream at a selected point. In any design the inflow design flood as defined, must be adopted, wherever practicable unless any proposed dam is to create a major storage area in which case flood routing can be considered.

Stream flow data available are to be found in the published hydrological year books, from the hydrological office at Ubungo, Dar es Salaam and from Basin Water Board offices. Though the maximum probable flood is considered applicable for most design, it is often not possible, under prevailing conditions of many gaps in the data, to carry out an analysis for it. Moreover it is an involving and complex study and cannot be undertaken for all sites or dams sites. Whenever such a study is warranted it should be referred to the Hydrology Section for review and comment. For small projects or those in which a spillway capacity is obtainable at a relatively low cost, the approximation of the design flood can be determined by procedures described herein.

Determination of the maximum probable flood is based on rational consideration of the chances of simultaneous occurrence of the maximum of the several elements or conditions which contribute to the flood. For example the El Nino/Indian Ocean Anomaly events in the Rufiji catchment in 1997-98. A major consideration is the determination of .the runoff that would result from an occurrence of a probable maximum storm based on meteorological factors. In Tanzania, a hydro-meteorological approach is considered necessary because stream flow records are scanty with gaps and therefore may not provide reliable data for estimates of maximum probable flood flows.

Alternatively and where long periods of record are available for analysis, and once again bearing in mind the possible future effects of climate change on flood peaking in particular, flood study reports from other countries can act as a guide. For example, the 1996 Flood Estimation Handbook from the UK, suggested the following:

TABLE 2.5: FLOOD, WIND AND WAVE STANDARDS BY DAM CATEGORY

<table>
<tr><th rowspan="2">DAM CATE-GORY</th><th rowspan="2">POTENTIAL EFFECT OF A DAM BREACH</th><th rowspan="2">INITIAL RESERVOIR CONDITION STANDARD</th><th colspan="3">RESERVOIR DESIGN FLOOD INFLOW</th></tr>
<tr><th>GENERAL</th><th>MINIMUM IF OVER-TOPPING IS TOLERABLE</th><th>CONCURRENT WIND SPEED AND MINIMUM WAVE SURCHARGE ALLOWANCE</th></tr>
<tr><td>A</td><td>Where a breach could endanger lives in a community</td><td>Spilling long term average flow</td><td>Probable maximum flood</td><td>10,000-year flood</td><td rowspan="2">Mean annual maximum hourly wind speed. Wave surcharge allowance not less than 0.6 m.</td></tr>
<tr><td>B</td><td>Where a breach could (1) endanger lives not in a community or (2) result in extensive damage</td><td>Just full (i.e. no spill)</td><td>10,000-year flood</td><td>1,000-year flood</td></tr>
<tr><td>C</td><td>Where a breach would pose a negligible risk to life and cause limited damage</td><td>Just full (i.e. no spill)</td><td>1,000-year flood</td><td>150-year flood</td><td>Mean annual maximum hourly wind speed. Wave surcharge allowance not less than 0.6 m.</td></tr>
<tr><td>D</td><td>Special cases where no loss of life can be foreseen as a result of a breach and very limited additional flood damage would be caused</td><td>Spilling long term average flow</td><td>150-year flood</td><td>Not applicable</td><td>Mean annual maximum hourly wind speed. Wave surcharge allowance not less than 0.3 m.</td></tr>
<tr><td colspan="6">Note: Levels defined throughout the year, these specified levels: Where reservoir control procedures require, and discharge capacities permit operation at or below specified initial levels may be adopted providing they are stated in statutory certificates and reports for the dam.</td></tr>
</table>

2.5.5 Estimation Methods

The detail with which hydrological computations need be made in preparing a flood study depends on:

(i) Character and availability of precipitation record.
(ii) The character and applicability of the streamflow data available.
(iii) The relationship of spillway cost to overall cost of the project.

If a spring source is being contemplated, no attempts whatsoever should be made to increase artificially the flow of the spring by excavation or damming etc. because of the danger of losing it altogether.

2.5.5.1 Envelope Curves

Envelope curves can be prepared by drawing curves enveloping plotted points, representing maximum recorded values for various drainage basins. The values plotted should represent similar types of floods that have occurred within the broad geographical sub-division within which the watershed lies, and should not be limited to events of a single river system. A simple method of preparing envelope curves is also to tabulate maximum peak discharges and respective drainage areas prior to plotting points.

2.5.4.2 Estimating Runoff by Empirical formulae

The selection of an appropriate design flow is an essential part of the engineering studies for project. The material below is mainly concerned with projects from which little direct hydrological data is available. Various alternatives are suggested although designers must be aware that different empirical formula can give widely varying answers.

(i) Strange's tables

W.L. Strange evolved some relations between rainfall and run-off based on the study of certain tropical catchments. He accounted for the geological conditions of the catchments as good, average and bad; and surface conditions as dry, damp and wet prior to rain.

TABLE 2.6: YIELD AS RELATED TO RUNOFF AND DAILY RAINFALL

DAILY RAIN FALL IN mm	RUNOFF % & YIELD WHEN THE ORIGINAL GROUND IS:					
	DRY		DAMP		WET	
	%	YIELD IN mm	%	YIELD IN mm	%	YIELD IN mm
6.25	-	-	-	-	8	0.50
12.50	-	-	6	0.75	12	1.50
25.00	3	0.75	11	2.75	18	4.50
37.00	6	2.25	16	6.00	25	9.37
50.00	10	5.00	22	11.00	34	17.00
75.00	20	15.00	37	27.75	55	41.25
100.00	30	30.00	50	50.00	70	70.00
Note: for good or bad catchments add or deduct up to 25% of yield						

(ii) Inglis formula

Where,

R = runoff in cm

P = rainfall in cm

For hilly areas: $R = 0.85P - 30.5$ 2.3

For plains: $R = (P - 17.8) \times P / 254$ 2.4

For fan shaped catchments: $Q = 214 A / (A + 10.4)1/2$ 2.5

Where,

A = area of catchments in km^2

(iii) Lacey's formula

Probably one of the best known formulas is attributable to Lacey and is based both on empirical information and observation.

$R = P / [1 + (304.8 / P) \times (F / S)]$ 2.6

Where,

S = Catchment factor

F = Storm duration factor

TABLE 2.7: CATCHMENT FACTORS AGAINST STORM DURATION

STORM DURATION	CATCHMENTS CLASS				
	A	B	C	D	E
Very Short	2.00	0.83	0.50	0.23	0.14
Standard length	4.00	1.67	1.00	0.58	0.28
Very long	6.00	2.50	1.50	0.88	0.43

TABLE 2.8: PERCENT RUNOFF AS RELATED TO CATCHMENT CHARACTERISTICS

CLASS	DESCRIPTION OF CATCHMENTS	PERCENT RUNOFF
A	Flat, cultivated and black cotton soils	10
B	Flat, partly cultivated, various soils	15
C	Average	20
D	Hills and plains with little cultivation.	35
E	Very hilly and steep with hardly any cultivation	45

(iv) Estimating Floods from Rainfall Runoff Data

The hydrometeorological approach of analysing runoff and flood events requires a firm estimate of the difference between precipitation and resulting runoff. The standard procedures are the hydrograph and unit hydrograph principles. The method may not always be amenable to analysis in the case of ungauged watersheds

There are many standard works describing these principles but it is recommended to use the 1987 USBR treatise, 3rd edition, on "Design of Small Dams" Chapter 3 for reference available new in spiral bound form from Water Resource Publications. <http://wrpllc.com>

(v) Peak discharge empirical formulae which include

(a) Dicken's formula

$$Q = CIA \tag{2.7}$$

Where,

Q = Flood flow in cumecs

C = Catchment coefficient

I = Rainfall in cm per hour

A = Catchments area in sq. km

TABLE 2.9: RANGE OF C VALUES FOR DIFFERENT CATCHMENT CHARACTERISTICS

DESCRIPTION OF CATCHMENTS	VALUE OF C
For bare drainage basins	19.46 – 27.80
For basins with hills on the skirts with undulating country below and down to outfall	13.90 – 16.68
For undulated country with hard clay soil	12.20 – 13.90
For flat sandy cultivated plains	2.78 – 8.34

(b) Ryve's Formula

$$Q = CIA^{2/3} \tag{2.8}$$

Values for 'C' for different locations are given in the following Table.

TABLE 2.10: RANGE OF C VALUES FOR DIFFERENT LOCATIONS

DESCRIPTION OF CATCHMENTS	VALUE OF C
For up to 80km from sea coast	6.8
For between 80km and 2400km from coast except	8.3
For limited area near hills	10.0

2.5.5 Frequency Analysis

Accurate estimation of flood frequency discharge increases safety of the structures. In the case of small dam, diversion works and other hydraulic structures of medium and minor importance, where structural failure or overtopping will not involve loss of life, it would seldom be economical to design them to withstand the probable maximum flood. A calculated risk is therefore taken in designing such structures for a flood lesser than the maximum probable. The appropriate design return period is selected on the basis of economic analysis, policy decisions and the accepted risk.

Frequency studies interpret a past record of events to predict the future probabilities of occurrence. If stream flow records are of sufficient length and reliability they may yield satisfactory estimates. However, extrapolation of results should normally not exceed twice to four times the length of recorded data for reliability.

There are a number of probability distribution functions (PDF) that are used in flood calculations. The PDF are either two parameters , such as Lognormal or three parameters such as Gumbel max with a skewness coefficient of 1.14. The length of observation period is of great influence on the accuracy of the results of any flood frequency analysis.

- For example for estimation of parameters for lognormal requires at least 20 years of continuous data.
- For PDF of three parameters distribution that also include skewness, an observation period of 50-60 years is often required for determining it well.

Guidance should be sought from Hydrology Section of the Ministry of Water in Ubungo as to minimum periods of data that are considered sufficient for realistic analysis and as to which PDF is most suitable for Tanzanian conditions. It must also be noted that extreme care should be exercised if use of the Gumbel Max. PDF is contemplated.

Thus and whilst there are a number of methods of frequency analysis available, only a simple method, considered sufficient for small hydraulic structures is presented here. For more information, the Hydrology Section of the Ministry in Ubungo and hydrology books should be consulted.

Frequencies can be evaluated graphically by plotting magnitudes of a flood flow or minimum discharge, against the frequencies with which these are equalled or exceeded and considering a smooth curve suggested by the plot is representative of future possibilities. The method employs the general equation for hydrologic analysis which may be expressed as:

$$X = \overline{X} + k \times \sigma \qquad 2.9$$

Where,

X = magnitude of flood or low discharge of some given probability (P) or return period (T)

$\overline{X}$ = mean of flood or low discharge records

σ = standard deviation

k = frequency factor

There are a number of extremal frequency equations that can be used and the selection of which is the most appropriate is difficult to decide and becoming even more so due to climate change. They include: Generalized Extreme Value, Generalized Pareto, and Wakeby distributions; Lognormal and Gumbel (Type I Extreme Value distribution).

The estimated parameters of each distribution are shown in the following Table:

TABLE 2.11: PARAMETERS OF DIFFERENT EXTREMAL DISTRIBUTIONS

#	Distribution	Parameters
1	Gen. Extreme Value	$k=0.09507$ $\sigma=37.30332$ $\mu=44.82304$
2	Gen. Pareto	$k=-0.24544$ $\sigma=79.58058$ $\mu=6.30602$
3	Gumbel Max	$\sigma=40.56873$ $\mu=46.78648$
4	Lognormal	$\sigma=0.83375$ $\mu=3.9476$
5	Wakeby	$\xi=0$ $\alpha=197.97905$ $\beta=24.34139$ $\gamma=75.84217$ $\delta=-0.2156$

A frequency analysis for peak floods on the basis of Gumbel's distribution is illustrated in the following Tables where N is the number of occurrences (in this case 21) and M is the order no.

TABLE 2.12: FREQUENCY ANALYSIS BY PLOTTING POSITION AND FREQUENCY FACTORS

YEAR	ANNUAL PEAK DISCHARGE X IN CUMECS ARRANGED IN DESCENDING ORDER	ORDER NUMBER 'M'	RETURN PERIOD T=N+1 / M…	PLOTTING POSITIONS PROBABILITY OF EXCEEDENCE P= 1 IN % … T	X^2
1935	181.2	1	22	4.54	32,833.44
1946	179.5	2	11	9.09	32,220.25
1938	120.5	3	7.33	13.63	14,424.01
1951	110.2	4	5.50	18.18	12,144.04
1942	108.2	5	4.40	22.72	11.707,24
1950	95.7	6	3.66	27.27	9,153.49
1946	91.4	7	3.14	31.24	8,353.96
1940	87.8	8	2.75	36.36	7,708.84
1943	83.9	9	2.44	40.91	7,039.21
1947	82.4	10	2.20	45.45	6,769.76
1939	79.9	11	2.00	50.00	6,384.01
1949	77.0	12	1.83	54.54	5,929.00
1936	70.8	13	1.69	59.09	5,012.64
1948	65.0	14	1.57	63.63	4,225.00
1933	64.0	15	1.46	68.18	4,096.06
1944	59.1	16	1.37	72.72	3,492.81
1937	58.8	17	1.29	77.27	3,457.44
1952	51.2	18	1.22	81.81	2,621.44
1934	48.0	19	1.15	86.36	2,304.00
1945	45.2	20	1.10	90.91	2,043.04
1932	29.6	21	1.05	95.45	876.16
Summation	1789.0				182,820.84

N = 21; Mean, $\overline{X}$ = sum (X) / N =85.19; Squared mean, $(\overline{X})^2$ = 7257.4

Mean of squares = sum (X^2) / N = 8705.75, and

Standard deviation: $\sigma = [(\text{SUM}(X - \overline{X})^2)^{1/2}] / (N-1)$

TABLE 2.13: CONSTRUCTION OF FREQUENCY CURVE USING GUMBEL DISTRIBUTION

RETURN PERIOD T, in years 1	X 2	σ 3	k FROM TABLE 4	k.σ 5	FLOOD FLOW IN CUMECS X + k.σ 6
5	85.19	39.00	0.913	35.16	120.80
10	85.19	39.00	1.615	62.98	148.17
20	85.19	39.00	2.289	89.27	174.46
50	85.19	39.00	3.161	125.28	208.46
100	85.19	39.00	3.815	148.78	233.97

TABLE.2.14: FREQUENCY FACTORS GUMBEL RETURN PERIOD (YEARS)

N	5	10	15	20	25	30	50	60	75	100	1000
15	0.967	1.703	2.117	2.410	2.632	2.823	3.321	3.501	3.721	4.005	6.265
20	0.919	1.625	2.023	2.302	2.517	2.690	3.179	3.352	3.563	3.836	6.006
25	0.888	1.575	1.963	2.235	2.444	2.614	3.087	3.570	3.463	3.729	5.842
30	0.866	1.541	1.922	2.188	2.393	2.560	3.026	3.193	3.393	3.653	5.727
35	0.851	1.516	1.891	2.152	2.354	2.520	3.979	3.142	3.341	3.598	
40	0.838	1.495	1.866	2.126	2.489	2.493	3.104	3.301	3.301	3.554	5.576
45	0.829	1.478	1.847	2.104	2.303	2.464	2.913	3.078	3.268	3.520	
50	0.820	1.466	1.831	2.086	2.283	2.443	2.889	3.048	3.241	3.491	5.478
55	0.813	1.455	1.818	2.071	2.267	2.426	2.869	3.027	3.219	3.467	
60	0.807	1.446	1.806	2.059	2.253	2.411	2.852	3.008	3.200	3.446	
65	0.801	1.437	1.796	2.048	2.241	2.398	2.837	2.992	3.183	3.429	
70	0.797	1.43 0	1.788	2.038	2.230	2.387	2.824	2.979	3.169	3.413	5.359
75	0.792	1.423	1.780	2.029	2.220	2.377	2.812	2.967	3.155	3.400	
80	0.788	1.417	1.773	2.020	2.212	2.368	2.802	2.956	3.145	3.387	
85	0.785	1.413	1.767	2.013	2.205	2.361	2.793	2.946	3.135	3.376	
90	0.782	1.409	1..762	2.007	2.198	2.353	2.785	2.938	3.125	3.367	
95	0.780	1.405	1..757	2.002	2.193	2.347	2.777	2.930	3.116	3.357	
100	0.779	1.401	1..752	1.998	2.187	2.341	2.770	2.922	3.109	3.349	5.610

Flood Flow for Very Small Dams

Very small dams (in. this context taken as dams with a height less than 4m, . spillways and intake structures may be designed for the 100 year flood unless an economic-statistical analysis is used to determine the optimal design :flow.

2 6 INTAKES

2.6.1 Intake Design Flood·

For safe design of surface water intake arrangements, the 100 year flood shall form the basis for design. For large dam reservoirs, a much longer period shall be considered.

For rivers with continuous discharge observations, the 95% duration flow should be taken as the base flow.

For streams with no discharge records available, ascertain local information and guides, or a Thompson V-notch weir or similar should be installed at suitable section of the Stream and flow observations shall be carried out for at least three years before the stream can be considered as a possible source for water supply.

Maximum and minimum flow shall be recorded during the observation period and comparison with similar stream and/or rainfall data shall be carried out.

The silt load of the stream shall be determined. Information on this can often be obtained from the Hydrology Section. If such data is not available, facilities must be established to collect such data.

2.6.2 Intake Location

The following criteria shall apply for the location of an intake

(i) The character of the intake surroundings, depth of water, character of bottom navigation requirements, the effects of currents, floods, and storms upon the structure and scouring the bottom shall be established.

(ii) Whenever possible, it should be positioned on a level that allows the water to be gravitated to the consumers. The possibility of large fluctuations in water level shall also be considered.

(iii) If treatment is required, the intake and treatment sites should be so located, if possible, so that the water can flow by gravity through the treatment works.

(iv) It should be positioned away from sources of pollution and floating material such as logs, vegetation, etc. It should also be located upstream of densely population areas and where possible of farming areas.

(v) It should be positioned upstream of bridges, cattle watering places washing places and sewerage outlet points.

(vi) It should be at a location where the area immediately upstream the intake is not easily accessible to people and cattle. If not then protection should be provided.

(vii) It should be located where the flow is adequate to cater for the water demand.

(viii) On stable watercourses, it should be located on the outside (scouring) side of a bend and not on the inside (depositional) side as this significantly reduces the amount of sediment entering the intake. Otherwise inflow may be turbulent but not disruptive to the natural cross-stream scouring flow pattern of the watercourse.

It is however necessary to be extremely careful in migratory rivers to be sure that the intake is neither disruptive to the natural flow and that bank protection is adequate as swirl velocities can develop at high flows, even on gentle bends with localised velocities several times that of the forward flow velocity of the watercourse.

2.6.3 River Intakes

Small intakes are generally built as circular concrete or masonry towers, 3-6m in diameter, into the river bank where water is reasonably deep even in dry seasons. The lower portion of the tower serves as a sump-well and the upper one which is above the high flood water lever is used for installing pumping equipment. A number of openings are provided in the tower at different levels and penstocks with valves are fitted in these.

The penstocks are protected by means of screens which exclude coarse suspended matter. The valves are operated from the pump floor; in such a way that water near the surface which is low in turbidity and fresh (due to contact with air) is admitted to the sump-well below. The lowest opening is provided sufficiently below the low water level in the river so that the intake can draw enough water during the dry season.

If the river is shallow and wide and the water recedes too far in from the bank, an approach channel needs to be excavated to lead water to the intake. This channel will require maintenance, by way of silt clearance which can be done during low flow.

If the river is likely to go dry during the dry season and the flow is likely to become subterranean, an inlet pipe may be buried in the approach channel to collect water and act as an infiltration gallery.

If the river flow varies from high during rains to very low or nil during the dry season, a small weir be provided to provide enough pool of water around the intake during dry season. However before constructing any permanent structure across a river both the downstream scouring effects and the results of raising the natural backwater curve upstream need to be studied and where necessary protection measures taken. In alluvial material it must be remembered that during flood it is not unusual for the river bed to fluidise and in effect become part of the flow and creating a permanent barrier such as a weir can markedly affect the behaviour of the river.

In the case of a small river supplying water to a village or small town, the intake can be just a horizontal pipe laid over masonry supports across the river with a bellmouth and fixed below water level for taking in water. This end can be protected by means of a wooden crib and a strainer. The pipe will carry the water to a small storage reservoir on the bank from where it is abstracted further on.

A floating or pontoon intake may be a viable alternative in relatively large rivers with variable water levels. If the fluctuation is not too much, the connecting arms between pontoon and bank can also be the supply pipes using watertight swivel bends.

For larger intakes it may be worth considering a short bypass channel with linked stoplog gate at the entry and an undershot weir or radial gate at the downstream end. The linked stoplog gate is operated such that inflow is from just below the surface so as to keep out both floating matter and coarser bed load sediments and the downstream undershot weir or radial gate to allow the channel to be continuously flushed except at very low flows.

A side entrance intake, suitably screened, then draws water from the channel about two-thirds of the way along it.

2.6.4 Intakes in Lake and Dams

Reservoir intakes are usually circular or rectangular wells constructed in masonry or concrete. Suitably protected tubular steel structures are also possibly, especially when the intake is constructed subsequent to the construction and filling of the dam. All reservoir intakes are constructed in the deeper portions of the reservoir so that water can be drawn even when reservoir levels are low. In the case of earthen dams, the intake should be located beyond the embankment toe so as to have an independent foundation while in concrete or masonry dams the intake can be part of the dam structure itself.

Intakes in lakes should preferably be 3 - 4 m below the surface but at least 1 m above the lake bottom.

In lakes with bilharzia risk, the intake point should be a minimum of 80 m from the shoreline with a connecting underwater pipeline. Uplift of the underwater pipe when empty should be prevented by anchoring. The underwater pipeline should usually be flexible. Either the pipe material itself or the joints should give the required flexibility.

The method and ease of cleaning of the intake screen should be considered in the design. When feasible a connection should be made from the discharge pipe to the underwater pipe to make backwashing of the intake pipe possible.

2.6.5 Spring Intakes

The design of a spring intake will depend on the nature of the spring.

If a spring issues from rock, the exposed face should be cleaned off and a chamber built to collect the water. The water is then conveyed by means of pipe to a storage reservoir. The top of the chamber should be covered to prevent contamination and a roof provided to be carried inside the hill above to such an extent that the soil above is about 3 m deep. A pond to submerge the issuing point should never be created, but the spring allowed to discharge freely.

When a spring rises from the ground, a lake or pond is formed around it. Low walls should be constructed around where water is coming out so as to form a storage tank. The vegetation in the neighbourhood should be cleaned off and the area should be properly drained, to prevent surface runoff from flooding the area.

2.6.6 Bank or Riverbed Infiltration

Where bed and bank conditions are sufficiently permeable (sandy), the water should be infiltrated into a well, collection chamber, or infiltration trench, instead of direct abstraction from a river or lake. If the sand layers are thick enough, the water quality will be similar to groundwater. Even if all the harmful substances cannot be removed, the natural filtration will balance considerably the water quality during floods and other disturbances thus making the operation of any subsequent treatment plant easier.

To find out the possibilities for bank infiltration a soil survey at the proposed intake site is required. This means sounding the location, thickness and kind of water conducting soil layers as well as the depth to bedrock or impermeable soil.

If preliminary investigation shows that there are chances for the use of infiltration, a test pumping should be done from a test pit or tube well to find out the yield and quality of the water. The test pumping should last for several days or weeks so that the flow and water level will be in balance.

The abstraction may be done using wells, tubewells, borehole, drains with collection chambers etc.

2.6.7 Intake Pipelines

A gravity intake pipe should be designed for a flow equal to 120 per cent of the pump capacity. Gravity intake pipelines should have self cleaning velocity, which means at least 0.7 m/s. In exceptional circumstances, lower velocities may be accepted.

A suction intake pipe should be designed for pump capacity. Suction pipelines should be designed for a very low velocity in order to reduce the friction loss and the drawing in of sediments. The pipeline should be flushed regularly by backwashing. The velocity required for flushing is at least 0.8 m/s.

A gate or sluice valve is required on an intake suction pipe as well as a non-return valve. The non-return valve should preferably be installed immediately after the initial strainer.

Such suction pipeline can on occasions become partly filled with air. In order to prevent floatation, the pipeline has to be anchored or pre-loaded allowing for 50% air filling. The danger of floatation will be reduced with increased inclination, however any upper bend on the pipeline should be avoided as this may also cause an air lock and significantly reduce the capacity.

2.6.8 Intake Pipe Strainer

The strainer should prevent debris such as leaves; fish etc. from entering the intake pipeline. It should be mounted on the inlet and should be, if possible, be at least 1.0 m below water level and at least 1.0 m above the bottom.

In order to reduce the drawing in of solid matter, the velocity through the strainer should be less than 0.7 m/ s. The width of strainer slits should preferably be less than 5 mm and of strainer holes 5 to 10 mm. The design of the strainer should allow for 30% clogging

The total opening of the strainer should be 2 - 3 times the cross-area of the intake pipe. 'Johnson' type stainless steel wire-wound tee strainers with a reverse flow backwashing facility should also be considered for rivers.

In a stream or a river with turbulent flow, special precautions may be needed and the strainer protected by a removable screen. The space between the bars should be 30 to 50 mm in an initial coarse screen and.5 to 10 mm in a subsequent fine screen. The screen should .be designed for 30% clogging and a maximum velocity of 0.7 m/s. The screen should be raked regularly.

The total opening of the strainer should be 2 - 3 times the cross-sectional area of the intake pipe.

2.7 DESIRABLE PROTECTION OF WATER SOURCES

All intake works areas should have restricted access and be fenced wherever possible. The restricted area in the case of river intakes should be at least 100 m upstream and 50 m downstream

All abstraction points should be so designed that no damage and erosion occurs through flooding and excessive rains. No waste water from agricultural or industrial processes should enter the river upstream, unless treated to the required standards, which should be not less than the existing river water quality.

No cultivation should be allowed up to 25 m on either river or stream bank. No cattle watering in the river upstream of the abstraction point should be allowed. No pit latrines should be allowed within 100m from the river banks.

As far as is practicable, the headwaters and catchment areas should be protected by forest within which no cultivation and cattle grazing should be allowed. River and stream banks should be kept grassed and covered with bushes, trees etc. and protect against fire.

In addition to the above, springs should be afforded extra protection of the area immediately above and around its location. The immediate upstream area should be protected from surface rain water by .shallow catch water drains.

2.8 DESIGN CRITERIA

Proper selection: of the design flood ensures both .the safety and economy of any structure. Similarly, proper selection of the minimum discharge ensures the reliability of the purpose of the hydraulic structure. The following design criteria are recommended:

i. The yield resulting from the driest five or more consecutive years should be taken for assessing the storage capacity of the reservoir. The driest five years is computed by splitting the available record of rainfall or discharge for many years, into blocks of five years and determining the total rainfall or discharge in the particular block of 5 years. The lowest value in a series of block years will determine the driest five years.

Again however, the likelihood that the historic situation is no longer truly representative of the future due to climate change must be carefully considered.

ii. In the case of dam storage volumes exceeding 6,000 hectare metres of storage, the design flood for the spillway should be the probable maximum flood or a flood or not less than 1 in 1,000 years return period.

iii. In the case of weirs, small dams (less than 15m height or less than 6,000 hectare metre storage), and barrages, the design flood shall be not less than 1 in 100 years.

iv. For minor structures such as very small dams of height less than 4 m and small weirs, a design flood of 1 in 50 to 1 in 100 years will suffice.

v. For fixing the maximum water level of the reservoirs, the initial spillway crest reservoir level before the impact of the design flood and any flood routing techniques shall then be used to determine the maximum water level and the top of the bank determined accordingly with sufficient freeboard. Where wind caused waves are possible either additional freeboard height must be provided or a wave wall constructed on the inner top of the embankment.

vi. The capacity of the reservoir shall be determined on the basis of a mass curve analysis.

vii. In the absence of specific sediment load data, a sedimentation allowance of ½% of capacity for every year of the reservoir life should be provided with a minimum of 10% of the proposed live storage.

In the absence of any information suggesting the contrary, the above criteria should be regarded as mandatory and departure from these must be on the basis of a thorough study of individual projects and in coordination with Ministry of Water headquarters.

2.9 GROUND WATER AS A WATER SOURCE

2.9.1 General

Groundwater is an extremely important domestic water resource in much of the country, and one of the more dependable resource for human development activities. In semi-arid and the drier parts of the country groundwater has played and will continue to play a major role as the sole water source for various uses especially in the central and northern parts of the country and the drier regions of Dodoma, Singida, Shinyanga, Tabora, Mwanza, Mara, Arusha, Coast and Southern Kilimanjaro.

Groundwater as a source of water has some advantages above other water resources. It is mostly hygienically safe, and it does generally not contain pathogenic germs.

- Where present, its availability is practically constant through out the seasons and no storage facilities are needed.
- Quality is relatively constant. Also it has other favourable properties like absence of suspended material, of colour, of taste and odour.
- If present, it will be available near places of demand. No expensive conveyance will be needed.
- It is also important to note that, all the waters on earth, other than palaeo-groundwater, participate in a continuous movement, as mentioned in the hydrological cycle above. Groundwater is part of this cycle.

2.9.2 Properties of Groundwater

Groundwater exhibits two properties, that of ground and that of water:

(i) Dissolution Capacity:

Water is a very good solvent. The chemical compound H2O may contain a lot of other chemical constituents. The pure form of the H_2O does not occur in nature, it will always have other compounds in solution.

(ii) Density:

The density of water is related to temperature. Water has its greatest density, 1000 kg/m3 at 4 ^oC. At other temperatures water will be lighter, even after freezing.

Furthermore, density is affected by the quantity of dissolved components. Saline water is heavier than fresh water. In many situations a layer of fresh groundwater may float upon more saline water.

(iii) Viscosity

The fluid water has a certain viscosity. Viscosity is the parameter indicating the ease of flow of a fluid or a gas. The greater the viscosity the less fluid a fluid is.

(iv) Heat Retention Capacity:

Water has a great capacity to store heat. The reason is that specific heat retention is high but heat needed for melting and for evaporation is also high. The consequence for groundwater is that it will have a fairly constant temperature, which more or less will equal the annual average air temperature. More generally, the high heat retention capacity of water has a dampening effect on climatic changes on the earth.

2.9.3 Groundwater Exploitation and Use

It is estimated that in Tanzania there are now more than 10,000 deep wells and 100,000 shallow wells drilled in Tanzania with water use as follows.

TABLE 2.15: ESTIMATED GROUNDWATER USE IN TANZANIA

SECTOR	AMOUNT USED ($m^{3/}d$)	% OF TOTAL USE
Rural Water Supply	625,000	50
Livestock & Dry land fishing	350,000	28
Urban Water Supply	130,000	10
Agriculture * (see note below)	130,000	10
Industrial + Mining	30,000	2
TOTAL	**1,265,000**	**100**
Note: * It should be noted that there is a growing demand on groundwater resources for irrigation		

2.9.4 Geology

Geological information is of great value to the hydrogeologist, as it indicates the extent of water bearing layers and less pervious layers, both in a horizontal and in a vertical direction.

A simplified geological map of Tanzania is shown on the next page, together with its key:

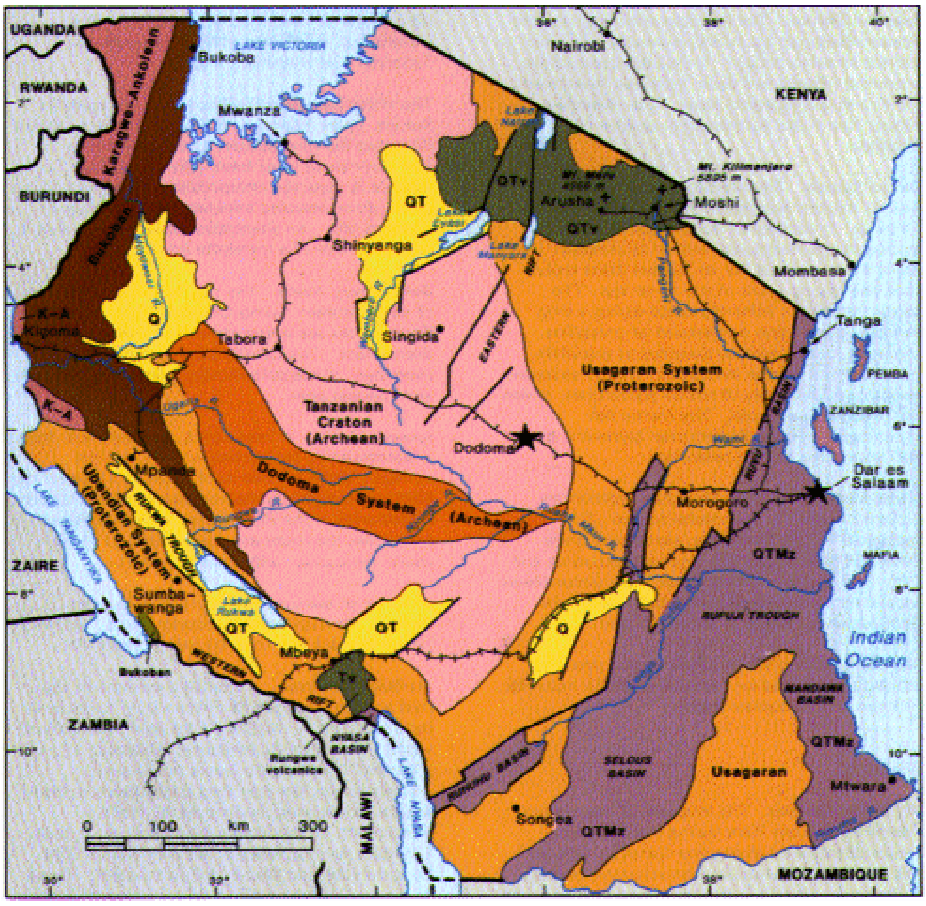
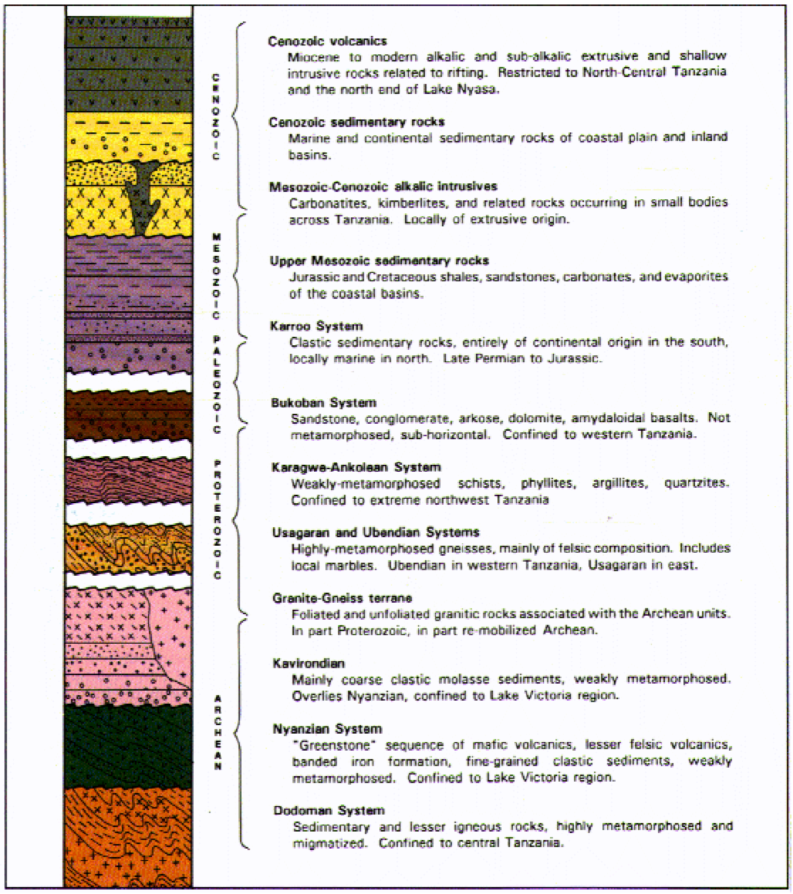


FIGURE 2.4: GEOLOGICAL MAP OF TANZANIA



KEY TO GEOLOGIC MAP

Hydrogeologically, rocks may be considered as falling in to one of two groups as follows:

1. **Sedimentary Rocks:**

   These rocks are the result of eroded sediments from source rocks. Sedimentary rocks are composed of silicate, carbonate and clay minerals. The rocks rarely occur as single units and younger beds are usually laid down upon older ones. However, the sequence may be disturbed or extensively folded and faulted.

   The occurrence of groundwater in sedimentary formations is generally found in sandstones, carbonates and unconsolidated materials. The sandstone formations are rated as highly productive aquifers due to both their primary and secondary porosity and permeability. The Calcareous formations are also good aquifers due to solution process taking place at later stages (karstification). Unconsolidated formations are termed as good aquifers due to both weathering and depositional processes resulting to the formation of sand dunes, alluvial fans, floodplains, buried river channels etc.

2. **Igneous and metamorphic:**

   Igneous rocks may be classified into two types; extrusive and intrusive. In extrusive rocks (volcanic) such as tuff, andesite, basalt, etc., water occurs in fractures and pyroclastic materials. The intrusive and metamorphic rocks termed as hard rocks are mainly granites and gneisses respectively. They are solid and non-porous which but can hold water in networks of cracks, joints, fractures or faults or along contacts between rocks of various types, as in the case of dikes and sills.

   Fine grained igneous rocks, e.g. aplites can be good aquifers because they have short and narrowly spaced fractures. While coarse grained rocks like granites, have long and widely spaced fractures forming a mosaic of splinths. The storativity is reasonably good between the splinths. Basic intrusive rocks, e.g. diorites and gabbros have low storativity and tend to be poor aquifers.

   Metamorphic rocks generally have low storativity in comparison with intrusive rocks. As a general rule, for randomly sited wells in crystalline rock, if sufficient water is not encountered in the first 100 metres, then the well should be abandoned.

2.9.4 Hydrogeology

Hydrogeology is the science dealing with groundwater occurrence associated with particular geologic formations. The nature and distribution of aquifers and aquitards in geologic systems are controlled by the lithology, stratigraphy, and structure of the geologic deposits and formations.

Four major types of hydrogeologic ground layers can be distinguished as follows:

1. An aquifer, or a water bearing layer is, a layer, able to allow transport of appreciable quantities of water under field conditions. Sand layers mostly are good aquifers.
2. An aquiclude is a non–permeable layer which may contain water but is incapable of transmitting significant quantities of it.
3. An aquitard is a less permeable layer again not capable of transmitting water in a horizontal direction, but allowing considerable vertical flow. Clay layers are examples.
4. An aquifuge, is an impermeable ground layer or body neither containing nor transmitting water. Granite layers may act as an aquifuge.

A description can also be made as to the pressure conditions of the groundwater concerned as:

1. Soil moisture, is one of the indicative factors very useful to tell the hydrogeologist of the area and relative groundwater pressure. At the phreatic level, the groundwater pressure just equals barometric pressure. Groundwater above the phreatic level will have a lower pressure than air pressure. Equilibrium between gravitational and capillary forces holds that water in its place. It may be subdivided into capillary water, present in a zone where water in the ground pores is interconnected and into pendular water present in separated smaller pores.

2. Saturated groundwater is one termed as a reliable economic formation for abstraction. It can be summarize further as follow:

   - It occurs below the water table
   - The soil pores are filled with water, and the moisture content. equals the porosity, n.
   - The fluid pressure, p, is greater than atmospheric, so the pressure head (measured as gauge pressure) is greater than zero.
   - The hydraulic head, h, must be measured with a piezometer.
   - The hydraulic conductivity, k, is constant; it is not a function of the pressure head.

   The fully saturated water zone can be divided into two main types of aquifers;

   - Unconfined aquifer (a water table aquifer), defined as an aquifer in which the water table is free near the ground surface
   - Confined aquifer, defined as an aquifer that is confined between two aquitards. They normally occur at depth.

3. Unsaturated zone, which can be summarized as follows

   - It occurs above the water table and above the capillary fringe
   - The soil pores are only partially filled with water; the moisture content is less than the porosity, n.
   - The fluid pressure, p, is less than atmospheric; the pressure head is less than zero.
   - The hydraulic head, h, must be measured with a tensiometer
   - The hydraulic conductivity, k, and the moisture content are both functions of the pressure head.

4. Coastal Plain Aquifers

   (a) At or near surface: Often these coastal plain aquifers dip towards the sea. Generally the area is dominated by sediments of sedimentary rocks formed either as terrestrial or marine deposits. The terrestrial deposits tend to be landward and the marine deposits seaward, although fluctuating sea levels have resulted in alternating continental and marine strata, sometimes giving rise to interfingering. Water table aquifers are common in a coastal plains location. They are typically continental sands, gravels and sandstones, or marine sands or limestones, whereas confining beds consist of marine and continental silts and clays. These aquifers are most vulnerable to sea water intrusion and over-exploitation must be avoided.

   (b) Deep or regional aquifers: It is becoming clear that where sedimentary deposits at or near the coast are deep, these may form very large regional aquifers occupying 10s or even 100s of cubic kilometres. Water may be struck at depths of 900 metres or more but can be semi-artesian rising to 50 m or less from the surface. The economic viability of such aquifers is yet to be proven

2.9.5 Types of Groundwater

2.9.5.1 Definition

Groundwater can be considered as either spring water or well (and borehole) water.

1. Springs, offer excellent water supply opportunities, but are generally found in hilly or mountainous areas only. They may require long pipelines in order to bring the water to the demand area. This is a feasible source for larger and concentrated settlements but rarely for dispersed populations.
2. Wells, based on depth wells can be classified into three main categories, namely as
   Shallow wells
   Medium wells, or
   Deep wells

(a) **Shallow wells:** Can be defined as wells of shallow depth, generally not beyond 20 m deep and are often hand dug. Many shallow wells are not perennial for they dry up during extended drought periods.

(b) **Medium wells:** They range between 20-35m deep and they are a reliable source of water for use. In most parts of the country they are perennial.

(c) **Deep wells:** These are wells with depth greater than 35m. Deep groundwater often has an excellent quality of water and is perennial.

2.9.5.2 General Requirements for Wells

A suitable well site has to meet the following criteria:

1. It should be within walking distance from the users (200-400 m).
2. The site should be accessible by trucks during the drilling, construction, and maintenance phases, and accessible for the users throughout the year.
3. It should not be within 100m of cattle watering pools, latrines and other health hazards, and preferably be upstream of those. Any pit-waste (solid waste) should be placed downstream of the well to avoid the water well being contamination by leachate.
4. It should be safeguarded against flooding. Especially near rivers the location has to be chosen so that the well is not threatened by any meandering action of the river. Furthermore, the danger of flooding of low lying areas should be taken into account
5. The subsoil should not render the construction of a well impossible. It is not feasible to make a hand dug wells in rocky materials, etc.
6. If one or more of these conditions are not fulfilled, the site should be rejected, even if sufficient water is available.

2.9.6 Determination of Groundwater Flow Patterns

In general, groundwater flow obeys two basic physical laws, which can be expressed in mathematical formulas. These laws are Darcy's law and principle of continuity.

Three important· factors in groundwater flow are:

- Differences in energy conditions
- Permeability of the underground
- Density of the groundwater

Darcy's law:

The friction exerted by a ground volume to flow of groundwater may be expressed in terms of resistance to flow or its reciprocal value, permeability. The French engineer, Henri Darcy, was the first who did experiments to investigate the permeability of the ground. He. discovered that for one particular type of sand the rate of flow was always linearly related to the gradient in groundwater head~

Darcy's law states that $v = -k \times I$ 2.10

Where:

v = rate of flow (flow density) in $m.s^{-1}$
I = Gradient in head in the direction of flow (dimensionless)
k = The permeability, a constant, in $m.\ s^{-1}$

The minus sign in the formula indicates that water flows in the direction of decreasing head; the gradient is negative

2.9.7 Groundwater Quality:

There is a clear relationship between quality and use. Groundwater quality may be expressed in terms of the physical, chemical and biological properties of water. The quality of water depends on the type and amount of substances dissolved in the water. The composition of the aqueous solution is a function of number of things which include:

- initial composition of the water,
- the partial pressure of gas phase,
- the type of mineral matter the water comes into contact with,
- the pH and oxidation potential (Eh) of the solution,
- the organic matter content,
- relative mobility of the water, and
- time of residence.

The general properties that are especially useful in revealing the character of water are:

- hardness
- specific electrical conductance hydrogen ion concentration
- free carbon dioxide
- total dissolved solids

a) Major dissolved constituents:

The major constituents which are used to characterize water are given in the following Table:

TABLE 2.16: MAJOR CONSTITUENTS USED TO CHARACTERIZE WATER

CATIONS	ANIONS
Ca^{2+}	CI^{-}
mg^{2+}	$S0_4^{2-}$
$Na^{+} + K^{+}$	$C0_3^{2-} + HC0_{3-}$
Fe (total)	F^{-}
Si	$N0_3^{2-}$

b) Minor constituents

Other mineral constituents which are determined in a water analysis include:

As, Ba, Cd, Cr, Cu, Cn, Pb, Mn, Hg, Ni, Se, and Zn.

c) Pollution

Since water is essential for life, pollution can have serious health consequences if maximum care is not be taken against it.

i) Types of water pollutants

The most significant problems with water pollutants are with systems which are not compatible with it, i.e. oil spills and/or organochlorine compounds, etc.

a) Toxic metals are shown in the following Table:

TABLE 2.17: TOXIC METALS FOUND IN WATER

Galena Pbs	Pb – neurotoxic metal
Associated with Zn	Cd – deleterious effects on Bone structure and kidneys
Cinnabar damage	Hg – serious irreversible Neurologic Hgs
Realgar Ar	Ar – toxic

Also found is Cr - Cr^{+6} but this is short lived as chromite as it is reduced to Cr^{-3} $FeCr_2O_4$

2.9.8 Behaviour of Groundwater in Varying Densities

There is a clear interface between fresh and brackish water of constant density. Under such cases the transition zone between the two is thin; the brackish groundwater will have a salinity of nearly sea water. The fresh groundwater may be considered as a lens floating upon static saline water with a sharp interface in between.

Flow of groundwater in varying densities

When groundwater flows in varying underground densities, the direction of flow can no longer be predicted from different heads, observed in observation wells. Hence the potential energy conditions of the groundwater are expressed by the, pressure equivalent of the potential. In formula:

$$P = d \times g \times z + p \qquad 2.11$$

Where,

P= Pressure equivalent of potential in a certain point ($Pa = N.m^{-2}$)

d= Density of groundwater at the point ($kg\ m^{-3}$)

g= Acceleration of gravity ($m.\ ^{-2}$)

z= Elevation of the point above reference level (m)

p= Pressure at the point ($Pa = N.\ m^{-2}$)

The flow of water will be from points of high pressure to points of low pressure and flow will occur along planes where the pressure equivalent of the potential is constant. Values of p can be easily calculated if head, density and elevation above reference level are known.

2.9.9 Groundwater Surveys

2.9.9.1 The need for Investigation:

Field and laboratory investigation have to be planned (type, extent etc.) with the following considerations in mind:

- What are the objectives of the considered project (what do you want to know = problem identification and how do you want to realize them (strategy)?
- What are available data (inventory), implying both quantity and quality of the data, how can they be used and is that information sufficient. Based on existing data, a preliminary insight has to be obtained into the (geo) hydrological situation of the region or the site (underground, characteristics, etc.)
- Other key information of great help are:
  - rainfall temporal and spatial distribution
  - geomorphology
  - vegetation
  - drainage pattern
  - soil characteristics, etc

With regard to the type of project, three categories may be distinguished', implying three different types of investigations:

- Regional - scale investigations, considering water resources in view of a future development, be it for irrigation, for public water supply or some other use.
- More or less local scale investigations, directed to the realisation on a particular groundwater withdrawal (optimal design in view of yield, quality, drawdown and its consequences)
- General geohydrological investigations, on different scales, on behalf of different objectives (i.e. the cutting of a canal, draining a building site, etc

Use and interpretation of available data

Available data can be present in the following form:

Maps, aerial photographs and satellite imagery.

<u>a.1 Topographical maps</u>

Topographical maps are used to show the physical features of the land.

a.2 Geological maps

This is an important tool normally used to give in some representative vertical sections an indication about the lithology of the layers present. It is of great help for the hydrogeological investigation.

a.3 Hydrogeological maps

These maps should show all the hydrogeological features of the area concerned.

a.4 Archived Satellite Imagery

Archived satellite imagery, much of which is increasingly available at little or no cost is another important source of useful information.

There are other maps such as Soil Maps, Aerial Photographs as well as some others with special features which may give valuable hydrogeological information.

Other data:

Water quality data:

Information regarding the quality of the groundwater should be collected.

Data on different hydrological parameters:

Records on discharges of rivers and streams, others on meteorological data such as rainfall, evaporation, etc., as far as they could be of help for the hydrogeological investigations envisaged, should be collected.

Information on wells and springs:

Information about any previous drilled boreholes is of great help in knowing groundwater potential areas. Also springs in the area should measured and the records be kept in an archive.

Data on borings:

Information about the composition of the ground and water obtained from samples taken from a borehole should be collected.

2.9.9.2 Geophysical Surveys at Land surface

Geophysical surveys are a relatively cheaper and faster way in groundwater investigation as compared to drilling of exploratory wells. This is the reason why geophysical surveys are applied in the preliminary stages of investigations. However, geophysical surveys require specialized professionals to execute the surveys and to interpret the results. Several methods are used in hydrogeology as described below:

a.1 Geo-Electrical Resistivity Soundings:

With the resistivity method normally an electrical current, generated by an artificial source, is sent through the ground by means of two current electrodes at the land surface. The resulting electrical potentials are measured with two other electrodes, also at the land surface. Since rock types have different electrical properties depending on their density, pore fluids, porosity etc, the strength of the current applied gives a measure of the apparent resistivity of the rock.

By varying the distances between either the current electrodes (Schlumberger arrangement,), or both types of electrodes (Wenner arrangement) apparent resistivities at different depths and layer thicknesses are obtained. The wider the spacing distance, the deeper the layers involved in transmitting the electrical current.

Parameters derived from resistivity studies:

The major advantage with the resistivity method as far as ground water investigations are concerned is that it gives direct indications of presence of water as resistivity is a function of water content of the rocks. Other geophysical methods tend to provide indirect indications.

The main reasons for incorporating the resistivity method in groundwater investigations are that:

a) depth of water can be determined,

b) aquifer thickness can be measured,

c) water quality can be estimated,

d) horizontal layering can be determined.

Limitations of the resistivity method

a) It is ineffective in areas with very conductive clay layers as these will concentrate the current at the expense of other layers.

b) A very resistive surface layer such as dry. sand acts as an insulator making it difficult to drive the current into the ground. In such cases one has to consider alternative methods

c) Faults and other forms of lateral discontinuities seriously distort the resulting field as the theory assumes horizontal layering.

d) Some highly resistive layers in the subsurface may seriously limit the penetration depth of the current. In such cases, working with power boosters may help improve' the penetration.

a.2 <u>Electromagnetic (EM) Methods</u>

This method is cheap and fast, as it does not involve extended walking with electrodes as for the case of resistivity. The methods rely on the measurement of secondary magnetic fields generated by conducting bodies in the ground when subjected to primary signal. The principle is that a time varying low frequency electromagnetic field is generated by a transmitter at the land surface, which later is transformed by an electrical conductor under ground. A combination of primary (in-phase) and secondary (phase shifted) signals are then detected by the receiver. Interpretation of the results will give a clue as to the structure of the underground. The method is useful in detecting buried conducting bodies such as fractured fault zones, dikes etc. This method may also be used in detecting polluted groundwater or, fresh water/brackish water interface.

a.3 <u>Seismic methods:</u>

The method has limited direct use in groundwater exploration; however it is useful in determining the depth to the bed rock. The methods make use of the elastic property of rocks.

The seismic waves are generated on the ground by explosion or any other instantaneous release of energy into the earth. The arrival of waves is recorded by a number of geophones set at different distances from the shot point. Interpretation of the results will yield the depth and thickness of layers with different elastic properties underground.

2.9.10 Drilling

After survey the drilling work in areas that look promising follows. It is the duty of the hydrogeologist to supervise all drilling activities and provide technical advice in the course of drilling. Another responsibility is the analysis of rock cuttings, identification of the productive zones and recommending for on borehole depth.

Logging of samples from the borehole as it is drilled is mandatory.

2.9.10.1 Borehole Logging

Rock sampling

Rock cuttings are collected, normally at a 2 metre interval while drilling is in progress and a proper borehole log is kept.

The samples are analysed to identify the water bearing zones, and the driller keeps a record of penetration rate to assist in identifying the hard formations and their thickness as well as recording the water struck levels.

Down-hole logging

For accurate description of the penetrated strata, application of geophysical logging methods assist in the determination of thickness of formations, the zones of highest porosity and water quality. The methods used are:

- Resistivity logging. This is the most commonly used method.
- Spontaneous Potential Logging.
- Natural gamma-Ray Logging.
- Calliper Logging.
- Temperature logging.

2.9.10.2 Drilling Methods

There are several different types of rig available for drilling water boreholes. They vary in size, capacity and capability depending on the type of formation expected and the depth required. There are rigs which do not perform well in hard rock formations and there are those that are multipurpose.

Percussion and rotary-percussion drilling methods are generally the most applicable techniques for drilling in igneous and metamorphic rocks. If a significant thickness of granular or other overburden materials is present, a combination of methods can be effective, although not very practical. Cable-tool, hydraulic-rotary percussion and air-rotary percussion (down-the-hole air hammer) and foam drilling modifications are the most common types of equipment in use today for such rock types.

The cable tool rig drills by lifting and dropping a string of tools suspended on a cable. The major advantages of this method over other systems drilling in similar rock types areas are as follows:

- low initial equipment cost
- low daily operating cost
- low transportation cost
- low rig set-up time
- drilling rates comparable to standard rotary in hard rock at shallow depths
- very good samples are recovered
- very effective identification of water-bearing zones
- no circulation system required
- minimum contamination of water bearing zones

The major disadvantages of the cable-tool methods are:

- limited penetration rate (labour intensive)
- limited depth capability
- lack of control over fluid flow from penetrated formations
- lack of control over borehole stability
- frequent drill-line failures
- need for experienced drilling personnel

In rotary-percussion drilling, developed as variation of the standard mud rotary method, the main source of energy for breaking hard rock is obtained from a percussion machine connected either directly to the bit or to long drill rods with carbide tips. The major advantages of the rotary-percussion methods are as follows:

- high penetration rate
- excellent depth capability
- good control of fluid flows
- good control of borehole stability
- combination drilling capability (unconsolidated and consolidated formation)
- no special circulation monitor required unless special additives are required
- minimum damage to water bearing zones
- low rig set-up time
- good samples recovered
- effective identification of water bearing zones

The major disadvantages are;

- medium to high equipment costs
- medium to high operating costs
- medium transportation costs - heavy duty truck mounted rig
- need for experienced drilling personnel

2.9.11 Pump Tests

A pump test is one of the most effective devices of determining the hydraulic characteristics of water bearing layers. The basic procedure of performing a pump test is relatively simple; from a well, having a screen in the water bearing layer to be tested, water is pumped during a certain time and within a certain rate. The effect of this pumping on the water table is regularly measured both in the pumped well and in a number of observation wells nearby. The principle of a pump test is that a well is pumped and the effect of this pumping on the aquifers hydraulic· head is measured.

Parameters to be considered while performing a pump test should include:

- drawdown.
- discharge
- water level
- hydraulic conductivity
- aquifer thickness
- transmissivity
- storativity
- specific yield
- recovery

Duration of a pump test

The duration of pump test depends on the type of aquifer and the degree of accuracy desired in establishing its hydraulic characteristics. It is recommended. that a pump test continues until the cone of depression has stabilised (a steady state has been reached).

Evaluating pump tests

Methods used in evaluating pumping tests conducted in various aquifers are as follows:

	Unsteady state	Steady state
(a) Confined aquifer	Theis Jacob	 Thiem
(b) Leaky aquifer	Walton	De Glee Hantush
(c) Unconfined	Neuman Theis Jacob	 Thiem

The general assumptions:-and' conditions underlying these methods are:

- The aquifer systems have seemingly infinite areal extent
- The aquifer system is homogeneous, isotropic and of uniform thickness over the area influenced by the test.
- Prior to pumping, the hydraulic head is (nearly) horizontal over the area influenced by the test.
- The aquifer is pumped at a constant discharge rate.

- The well penetrates the entire thickness of the aquifer and thus receives water by horizontal flow

Timing of Pump Test etc.

Any borehole or well should be pump-tested, screened and developed before making decisions about any water treatment requirements. Samples need to be collected without any aeration, filling the sample bottle carefully to the top, and allowing several bottle volumes to run through so all air is displaced; a BOD bottle with its tapered lid is ideal. Measure the pH as soon as possible. Faulty sampling can cause a groundwater with a pH of 6.5 with 40 mg/l of carbon dioxide to lose all its carbon dioxide and end up with a pH of about 7.4. This will result in the selection of an unsuitable treatment process.

Secure and deep groundwaters usually have a fairly consistent chemical composition; shallow and non-secure groundwaters can vary markedly throughout a year

2.9.12 Groundwater Development

There are a number of important factors to be considered in developing a well (borehole).

These are as follows:

- well design
- well development
- well completion
- well maintenance

2.9.12.1 Well design

Factors for consideration:

(i) Diameter
(ii) Well casings
(iii) Well depth
(iv) Well screens
(v) Aggregates
(vi) The highest yield with minimum drawdown consistent with the aquifer capability
(vii) Good quality water with proper protection from contamination
(viii) The water remains sand free
(ix) A borehole that has long life
(x) Reasonable short-term and long-term costs
(xi) Stratigraphic information concerning aquifers, their depths and thickness
(xii) Transmissivity of the aquifer
(xiii) Grain size analyses of unconsolidated aquifer materials and identification of rock materials

In addition to the above, the costs related to the type and borehole construction materials, operation and maintenance should be looked into.

a) Borehole Diameter

A borehole should be drilled to a diameter sufficient to allow for easy installation of casings, screens and gravel pack (where necessary). The casings and screens so installed should be large enough to accommodate the pump with sufficient clearance for installation operation.

b) Well Casing

i) Casing Installation

- to be placed such that it finishes about 50 cm above the ground surface
- to be placed at all non-water bearing zones
- to be placed about 1½ or 2 m from well bottom.

ii) Casing Materials

The selection of casing materials is based on water quality, well depth, cost, borehole diameter, required yield and drilling procedure. The common types of casings used in borehole construction are steel, thermoplastic, fibre glass and concrete.

Steel is the most commonly used casing material, although thermoplastic materials are gaining a bigger share now because of cost and where the groundwater is highly corrosive

ii) Stainless Steel Casing

Such casing is usually coated with chromium to make it capable of resisting corrosion. Also during the manufacturing process nickel and molybdenum are added. It is most preferred as it increases the life span of the borehole.

iv) Thermoplastic

Commonly used when steel casings have failed due to corrosive waters. They include ABS (acrylonitrile butadiene styrene), polyethylene and PVC. (polyvinyl chloride) although the latter has some environmental features that need consideration.

They have the following advantages

- Corrosive resistance
- Light weight
- Relatively low cost
- Easy installation

v) Fibre Glass - Reinforced Plastic Casings

This type is corrosive resistant and suitable for highly corrosive waters.

vi) Method of Joining Casings

Steel casings are joined either by threading or welding, while the plastic casings are joined by threading.

c) Well Depth:

The depth of the borehole is normally determined from the lithological log. In drilling, a borehole should be completed to just below the bottom of the lowest aquifer to be exploited for the following reasons:

- More of the aquifer can be utilized as the intake portion of the well, resulting in higher specific capacity.

- Sufficient water is available to maintain the yield even during periods of severe drought or re-pumping
- To provide room at the borehole bottom for casing to keep away any loose materials between the casing and the borehole wall.

d) Well Screens

The optimum length of a .well screen is based on the thickness of the aquifer, or aquifers, available drawdown and nature of the stratification of the aquifer. In nearly every aquifer, certain zones will transmit more water than others. Thus the intake part of the borehole must be placed in those zones having the highest hydraulic conductivity which can be deduced· from the comparison of grain size curves

i) Borehole Screen Slot Openings

The screen slot openings can differ depending on whether the borehole is naturally developed on gravel packed. The choice of the screen slot size therefore depends on the grain size distribution curve for the materials. Coarse grained non homogeneous material can be naturally developed whereas fine-grained homogeneous materials are best developed by using a gravel pack.

ii) Need for Gravel Pack

Where gravel packs are considered necessary the D_{60}/D_{10} particle size (size passing sieve 60% and 10% respectively) is a guide to selection.

Sieve sizes referred to tend to vary but the following are common (European Standard):

0.7 – 1.2 mm, 1.5 – 2.0 mm, 2.0 – 3.0 mm, 3.5 – 5.0 mm, and 5.0 -7.5 mm.

If in doubt, the inclusion of a properly sized gravel pack should be included as this is likely to prolong the useful life of the borehole, too many boreholes having failed or suffered reducing yield due to omission of a gravel pack.

Gravel packs should consist of siliceous material, with well rounded, smooth and uniform particles. They must be well sorted and clean free from clay and silt. Unstable minerals such as calcrete and feldspar which easily decompose and change the properties of the gravel pack must be avoided as must flaky particles such as schist and mica as these tend to clog the screen.

The screen slot opening is selected from a study of sieve analyses data for samples representing the water bearing formation. In a naturally developed borehole, the slot size is selected so that most of finer formation materials near the borehole are brought into the screen and pumped out during development.

Where a gravel pack is being considered the following acts as a guideline:

- thickness of gravel pack not less than 0.1 m
- uniformity coefficient (D_{60}/D_{10}) is ≤ 2 to 2.5
- diameter of formation particles (D_f) = $4.5 – 5.5 \times D_{60}$

i) Select a standard gravel pack with D_{50} smaller than but as close as possible to the calculated value of D_f.

ii) Select a standard slot size just smaller than the D_{10} size of the gravel pack.

For the slot size selected and knowing the percentage open area of the screen (p), the well radius (r_w), and the screen length (L), calculate the water velocity through the slot for the design discharge (Q_d). This should be less than 0.03 m/s for continuous slot screens and 0.1 m/s for slotted screens.

Then screen velocity, $V_t = Q_d / (2\Pi \times rw \times L \times p)$ 2.12

The percentage of opening in slotted thermoplastic screen is small when compared to stainless steel wire wound screen and hence unlikely to be suitable for high yield aquifers. Thus if the velocity exceeds the limit for slotted screen, wire wound screen will be necessary.

Another advantage of wire wound screen is that the wire used has a tapered cross-section such that the slot size increases towards the inner side and is less likely to become choked.

iii) Calculate the velocity through the gravel pack

Gravel pack velocity, $V_f = Q_d / (2\Pi \times rw \times L)$ 2.13

This should not exceed $0.013/D_{f10}$

Where, D_{f10} is the D_{10} of the gravel pack.

2.9.12.2 Pump House Location and Pump Installation

Although it is not the job of the hydro-geologist or driller to locate the pump house, the site situation and various results obtained should be considered and any specific limitations, requirements, or recommendations in this regard should be provided.

Pump installation should be based on the information gained from the results of the pump tests. As a general rule however, a pump may be installed at 2/3rds the depth of the water column or 1 m below the stabilised cone of depression.

2.9.12.3 Well Development

This activity is commonly done before the pumping test is carried out. Its main objective is to remove all finer particles which can block easy movement of water in the well so as to attain the maximum yield (it improves well efficiency).

2.9.12.4 Well Completion

Factors for considerations include:

- Concreting the area and capping the borehole
- Protecting the area against pollution, risk of flooding and other possible sources of contamination.
- Ensuring that the well head design will prevent the borehole from being flooded
- Filling the completion form explaining clearly the lithological column
- Commissioning of the borehole and labelling
- Handing over

2.9.12.5 Well Maintenance

While the expected service life of a well depends upon the design, construction, development and operation of the well, proper maintenance helps to improve the performance and increase the life of the well.

Proper records of power consumption, well discharge, drawdown, operating hours, periodic chemical analysis of water and other such observations will help in devising proper maintenance procedures.

Well yields can decrease due to clogging of screens by carbonate and iron deposits, incrustation of fine particles of silt and clay, algae or bacterial growths etc.

Sometimes a fault in well construction such as, poor casing connections, improper slot perforation or screens and absence or defective gravel packs can decrease the well performance.

Wells in sandy deposits in particular are prone to bio

Periodic cleaning of screens can be undertaken by adding hydrochloric, polyphosphates, specific proprietary chemicals or chlorine followed by agitation of the water in the well.

2.9.12.6 Yield Reduction due to Biofouling

Biofouling of borehole screens is particular prevalent in sandy aquifers and often leads to reduced yield and/or increased drawdown even when chemicals causing encrustation are low in concentration.

It most often occurs as the result of infection of the bore by iron bacteria. The organisms mainly responsible for biofouling catalyse the oxidation of soluble iron and manganese in the water, and as a by-product produce slimes containing large amounts of ferric hydroxide. As well as affecting bore yield, this phenomenon degrades water quality with respect to taste, odour and organic matter content (which increases the disinfectant demand of the water).

For biofouling to develop, the organisms need a borehole that is open to the atmosphere (for oxygen), sufficient concentrations of iron and/or manganese in the water (a level of iron of less than 0.1 mg/L is usually too low for iron bacteria to survive) as well as dissolved organic matter, and bicarbonate ions or carbon dioxide.

Steps to prevent or at least reduce problems with iron bacteria include:

- disinfection of drill rods, bits, and tools to avoid cross-contamination from previous drilling activities (50 – 200 mg/l FAC)
- preparation of drilling fluid with chlorinated water (initially 50 mg/l FAC, but a minimum of 10 mg/l FAC must be maintained)
- the borehole, once completed, should be sealed to prevent of the entry of airborne bacteria.

Should biofouling occur, it is necessary to chemically treat the borehole with a heavy dose of chlorine or more preferably using a proprietary chemical specifically developed for the purpose and in bad cases, to redevelop the borehole to drive the chemical into the gravel pack and surrounding aquifer.

Once such biofouling is known to occur, regular dosing with an appropriate proprietary chemical will usually control the problem without the need for periodic re-development.

2.9.13 Groundwater Management

Groundwater management is a broad subject that needs special attention as it involves many factors for consideration including such things as:

- formal registration of all boreholes
- optimal uses of groundwater resource
- thorough knowledge of the aquifer (all aquifer characteristics) .
- observation wells being introduced for recording the water level fluctuations, natural recharge and discharge.
- protection of groundwater recharge and discharge areas
- proper guidance on well pumping and contamination be followed.
- latrines be located downstream of the borehole
- legislation/by laws be enacted and complied with to control conflict that might arise due to boreholes drilled short distances apart, hence sharing the same aquifer, etc. It is therefore recommended that, distance from one borehole to another be at 300 m apart unless there is acceptable data indicating the contrary.
- conjunctive use of both groundwater and surface water.
- determination of the safe yield and strict adherence to this figure to avoid groundwater overdraft