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COST EVALUATION OF WATER TREATMENT PLANTS IN KENYA

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THESIS

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TO DAD AND MUM

MY SISTERS, AND BROTHER

[redacted]

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SUMMARY

The thesis deals with costs of different production methods of potable water in Kenya. Water supplies in this country involves construction of treatment plants for surface water and groundwater sources, and also the running of these facilities.

Plant construction and running is expensive and needs qualified people in all stages of planning, design, implementation and running. The funds used for a water supply scheme should yield the best possible output.
The treated water should be of high quality and enough in quantity to meet the demand.

In the planning of water treatment plants big savings are possible by selecting the most appropriate processes, materials and construction methods. Proper selection also has a great impact on running costs which must be taken into account already in the planning stage of a treatment plant.

A treatment plant could simply be defined as any construction that produces potable water.

The origin of the water is precipitation. Rainwater harvesting has been considered and is a good supplimentary source of water. Using local material any family can afford to store rainwater. Therefore the investment costs should range from zero upto Kshs. 1430 per capita depending on storage construction. Running costs are almost negligible. Shallow wells can speed up the provision of water program in rural areas. The investment costs are Kshs. 170 – 230 per capita and with a good maintenance program the running costs are also low

(Kshs. 10 per capita). This kind of program should run in hand with spring protection which requires little maintenance and the investment costs are lower (Ksh. 100 per capita).

The groundwater potential in this country as a whole is yet to be assessed. Boreholes have an investment costs of Kshs. 900 per capita on the basis that no treatment except chlorination is required. Running costs varies between Ksh. 1 - 25 per capita becuase of fuel and labour. Boreholes have an advantage over surface sources over greater simplicity of operation.

Surface water treatment plants are financially and managerially burdensome. The river appears to be the source because of its immediate availability, but because of the character of the water, complete treatment is required in most cases. Failures are inevitable in treatment plants because of spares, maintenance and water utility operator experience. However, gravity supplies cost much less. The investment costs in treatment plants range from Kshs. 13 to over 707 per capita. If the plant is well run over design life, the unit capital cost of treated water can be very low (Kshs. 0.10 to over 1.50 per cubic metre). Running costs are quite high (Ksh. 0.28 to over 30 per cubic metre). These costs vary so much because of the difficulties of assessing the data available. Recording is not consistent, especially on maintenance and expenditures on electricity bills in most plant operation charts.

Scale of economies exists; smaller plants ($< 100{,}000 m^3$/year) spend more per unit production of water than larger plants. Medium plants fall within 100,000 - 300,000 m^3/year of treated water produced. But proper capacity sizing of treatment plants should be done with due regard of

transmission (distribution) costs. Alternatively, use of package plants should be investigated.

The number of operating water supplies by MoWD is increasing, resulting in a growing burden of finance, administration, transport, procurement and staff management. There are advantages of centralized management e.g. cheaper bulk purchases, but services rendered will deteriorate as the number of schemes increase. Decentralization at certain levels (Provincial or District) should be considered.

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1. INTRODUCTION

The Government of Kenya perceives the urgency of the need of potable water in rural areas. The rural areas carries 85% of the population, and 8% only are served by a watersupply system. The remaining 77% of population is widely dispersed. Very large resources are allocated to provide water, but current financial difficulties may slow down the growth in resources available for rural water supplies development. The Government is committed in its aspirations.

It would be good practice to evaluate the extent to which the projects are designed and operated to cover the entire population of the area supplied. The MoWD attempts to spread the available rural water supply resources according to the remaining unserved population. Past experience is valuable. The present water supplies need to be appraised in terms of modifying the processes and costs. Costs are important tools in planning, especially if they can be stored, retrieved, updated and analysed. This goes along with proper qualitative and quantitative assessment of sources.

Running of these facilities are just as important and requires an efficient organization.

The Government believes in increasing the coverage of the water supply system in both urban and rural areas important and therefore it is necessary to improve the financial condition of the water supply sector. The improvement of the financial condition can be achieved through full assessment of our resources, evaluation of already existing projects in terms of costs, efficiency of different processes and setting up efficient managerial system, and implementation of the modifications. These will also facilitate proper decision making.

In this report an attempt has been made to assess the costs of construction and running i.e. operation and maintenance of water treatment plants of various types of sources. The data is available at the MoWD Headquarters in the form of bill of quantities in the tender documents and variation orders, and water supply operation charts. A few tender documents from which costs of construction of surface treatment plants were derived, were made available. The variation orders are too general to be of use in this case. So the cost estimates are lower than the actual. The water supply charts were also made available. The operation and maintenance costs of 36 water treatment plants were derived from these charts of the Financial Year 1981/82, because these had been fully checked. However, it is difficult to tell how complete the charts because of erroneous rates or missing expenditures like electricity and maintenance. It is not known how frequent the master meters at various plants are checked. Also the operator skills were not assessed. But the charts are the best estimates available. Detailed monitoring of raw and treated water quality was not examined. Comparison is more meaningful if most of plants meet the required standards of water quality.

Costs on borehole construction are available, but these are more difficult to analyse because of different phases of construction. The costs are greatly influenced by the haulage distance of the drilling rig.

The information on shallow wells was mostly derived from the reports on ongoing projects in Western Kenya.

Generally, costs are not so accurate as to justify a full analysis.

2. NATURAL WATER RESOURCES

2.1 General

Kenya is a country covering 583,000 square kilometres that lies across the equator in eastern Africa, 34°E and 42°E, and 4°N and 4°S. It has a 400 kilometre eastern border with the Indian Ocean and western boundary with Lake Victoria. Approximately 80 per cent of the land area may be classed arid or semi-arid desert (I.D. Carruthers, 1973).

2.2 Climate

Kenya experiences a wide range of climatic conditions influenced by the equatorial location and the monsoonal systems of the Indian Ocean. The climatic factor of greatest water resource significance is precipitation. Precipitation usually occur in the form of drizzle, showers, and thunderstorms.

The distribution of mean annual rainfall is governed by elevation. The annual rainfall normally follows a seasonal pattern, the length of rainy seasons varying with geographic regions. Generally, rainfall is poorly distributed over the year. In well watered parts of the country annual rainfall range from 630 mm upto more than 2030 mm (I.D. Carruthers, 1973).

The highest temperatures in Kenya have been recorded in the arid regions near Lake Turkana, around Lake Magadi, and along the Somalia border. The coldest are found on the tops of mountains where night frost occurs above 3,000 meters and permanent snow or ice above 5,000 meters.

Sunshine is generally high throughout the country, except that the eastern, central and southern areas experience prolonged cloudiness during the period of June through to September.

In arid areas the monthly values of maximum relative humidity reaches between 60 per cent and 70 per cent; in areas with vegetation it normally exceeds 90 per cent. The minimum varies significantly with elevation and time of year. Typical values of the minimum are 70 per cent for all the coast during all seasons, 60 per cent for the highlands during the rainy seasons, and 40 per cent during the dry season (National Master Water Plan Vol.I, 1979).

The mean annual free - water evaporation in Kenya ranges from 1250 to 3120 millimetres, and the mean monthly rates ranges from 85 to 260 millimetres. In general, the months with the highest rate of free-water evaporation are the months with least precipitation. The monthly estimates at various stations are generally above 100 millimetres. Thus, with the exception of the mountain peaks, areas depicted as experiencing less than 125 millimetres potential evaporation per month may be considered to have a monthly value between 100 and 125 millimetres (National Master Water Plan Vol.I, 1979).

2.3 Surface Runoff

Surface runoff is that part of precipitation which travels over the ground and through channels to reach the watershed outlet (National Master Water Plan Vol.I, 1979). The River drainage system in Kenya is determined by the Rift Valley which bisects the highland Zone from North to South. Within the rift, drainage is into a number of lakes which have no surface outlet. West of the rift, rivers drain into Lake Victoria. To the east, rivers follow a south-easterly course into the Indian Ocean.

Kenya is divided into five main catchment areas as delineated on Figure 1.

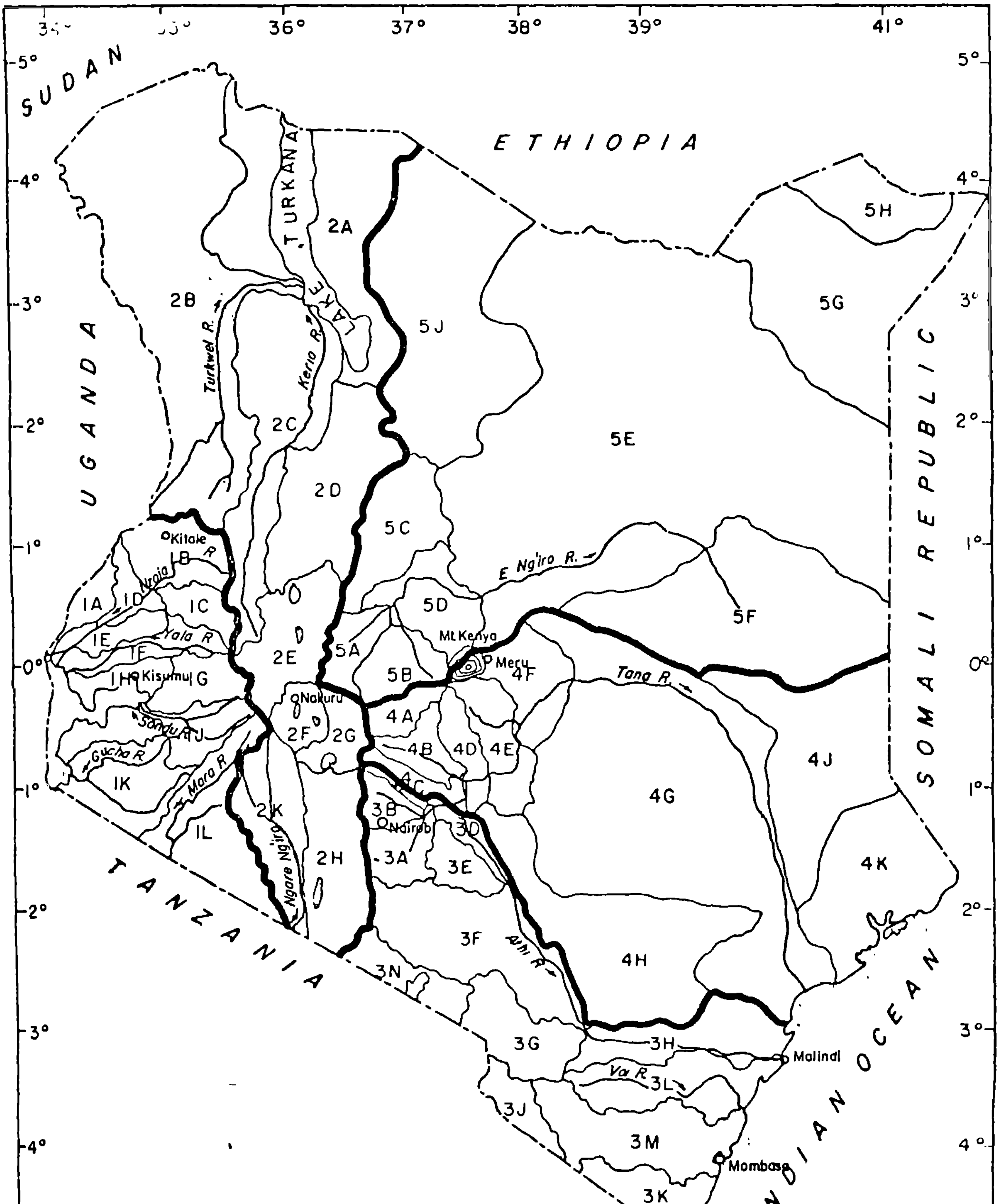


FIG. I MAIN CATCHMENTS AND RIVER BASINS

1. Lake Victoria
2. Rift Valley
3. Athi River
4. Tana River
5. Ewaso Ng'iro River

Table 1 shows the main statistical information on the five drainage areas and major rivers. The total annual flow of nearly 15 billion cubic metres might appear to be immense and quite sufficient for Kenya. However, it is necessary to examine the distribution of the population in relation to water availability.

Table 1 Drainage Areas and Main River Runoff

Drainage Area	Area (sq. km.)	Percentage of total	River	Mean annual runoff (million) cubic m.)	
1. Lake Victoria (Discharge into Nile system)	49,000	8.4	Nzoia	1,920	
			Yala	966	
			Nyando	500	
			Sondu	1,236	
			Gucha-Migori	870	
			Others	1,800	
			Sub-total		7,292
2. Rift Valley (Internal discharge to Lake Turkana Lake Natron & other lakes)	127,000	21.8	Melawa	185	
			Gilgil	28	
			Molo	39	
			Perkerra	126	
			Others	432	
			Sub-total		810
3. Athi River (Eventual discharge into Indian Ocean)	70,000	12.0	Athi	749	
			Tsavo	28	
			Njoro-Lumi	293	
			Others	115	
			Sub-total		1,295
4. Tana (Discharge into Indian Ocean)	132,000	22.7	Tana-Garissa		4,700
5. Ewaso Ng'iro (Discharge into Lorian Swamp and in exceptional wet years to Somalia)	205,000	35.1	At Archers Post		739
Total	583,000	100			14,836

Source: Water Department, Nairobi.

Kenya's main surface waters commence their flows at moderate to high elevations in the highlands. Headwater streams descend steeply for 30 to 80 kilometres from their sources before they flatten their slopes at confluences or at regional toporaphic breaks. Overland plus tributary channel flow travel times consequently range from about 3 to 12 hours. Relatively small amounts of channel storage exist in these steep streams so river rise and recession rates are high. These features coupled with river gauge readings usually taken twice daily at fixed times tends to create systematically biased records from staff gauge stream flow stations. This error can be magnified during periods having regular daily rainfall patterns. Only the largest rivers, such as the Nzoia and Tana, do not have this hydrometric difficulty (National Master Water Plan Vol.I, 1979).

2.4 Groundwater

The development of goundwater in Kenya dates back to 1927 and is receiving considerable attention, primarily because of the relative low cost of groundwater in some areas, the short and inadequate supply of surface water resources, as well as the inherent advantage of subsurface resources over surface waters. Good sources of subsurface water are unpolluted and requires little treatment. Groundwater reservoirs have been significant because of their ability to store usable water, especially during the dry years, in the perennially water deficient areas of eastern, southwestern and northern Kenya.

Natural sources of groundwater discharge are springs, seepage areas, lakes and base flow of perennial streams. Groundwater from hand-dug wells have been used mainly for domestic and stock use at Kenya's Coast, northern and northeastern areas for many centuries. Available records on boreholes sunk indicate that groundwater is widely used though not uniformly distributed in the republic.

Groundwater investigations have been conducted in Kenya in a general appraisal of hydrogeology and groundwater potential. No sophisticated data or analysis have been produced (National Master Water Plan Vol.I - 1979) covering the whole country. Aquifer formation parameters, recharge, and effects of water production on well-field pressures have seldom been considered.

Borehole construction is monitored by the Ministry of Water Development (MoWD) who collect records on boreholes drilled by private individuals and companies by means of an application-permit process and is itself the largest driller in Kenya.

Rock type markedly influences groundwater occurrence in Kenya. The country consists of three major rock groups: Pre-Cambrian bedrock, volcanics and sediments. Typical mean values of boreholes parameters sorted by dominant rock types are given Table 2.

Table 2 Borehole Parameters

Parameters	Bedrock	Volcanic	Sediments
Total depth (metres)	97	128	89
Rest level (metres)	36	51	40
Artesian head (metres)	31	51	23
Initial yields (litres/minute)	73	126	129
Drawdown (metres)	42	41	15
Specific capacity (litres/minute/ metre)	20	47	60

Source: National Master Water Plan Vol.I - 1979

Therefore, the rock type affect total depth, artesian pressure, and the yield and drawdown of boreholes. Boreholes constructed in bedrock terrains depend more on water-filled faults, fissures and the degree of weathering than do wells in volcanic rocks. The failure rate in bedrock is 2.5, times higher than in volcanics. Failures amount to nearly one-quarter of all drilling attempts in bedrock. The high failure rate of boreholes in sediments is because of drilling in areas having unfavourable water chemistry chiefly in northern and eastern Kenya.

Studies for groundwater development are being carried out as an alternative source of water supply and to establish their potential, quality, quantity, and extent (D.M. Kirori, 1977). This will facilitate more careful siting of the boreholes. Attention is also being focused on the shallow wells development and spring protection as source of water supply in areas of high rainfall.

2.5 Non-Convectional Water Resources

A reliable provision of just a few cupfuls of water a day can contribute a lot to the life of an inhabitant of a dry area. There is a large reservoir of water in the form of water vapour. Dew, soil moisture, fog, mist and altmospheric vapour are considered as possible sources.

Taking recorded meteorological data (E. Afr. Met. Dept.), typical relative humidity at Wajir at 0900 East African time is 75% and the average dry bulb temperature at the same time is $25^{o}C$. Then at an atmospheric pressure of 990 millibars, the air over Wajir contains about 15g of water per kg of air, or nearly 18g per m^3. Assuming that the 1km, of air near the ground is well mixed and contains the same proportion of water throughout, it can be concluded that in $1km^3$ of air over Wajir there is about 16 million litres of water.

The assumptions are generous, but it gives an idea of the potential of such source. The yield is a fraction of 1 per cent of this water, something like 1000 litres per km^2 a day (P.E.J. Jones 1977). A plastic fertilizer bag and an empty tin may be the standard equipment needed.

The sun rays produce fresh water from salty sea water as a part of the natural hydrological cycle. The first experimental Kilifi solar still produced a maximum of about 5 l/m^2 per day on clear days (Paritosh C. Tyagi, 1977). Several inland lakes - Turkana, Baringo, Magadi, etc - have saline water. Conditions for use of solar stills is so favourable, especilly for small communities where brackish or saline water is locally available and good quality water from convectional sources is available at considerable distance, say in excess of 15 km., (Tyagi, 1977).

2.6 Water Quality

In general, the surface water is neutral or slightly alkaline. The dissolved substance concentrations are extremely low.

The turbidity of the waters varies widely seasonally. Generally the waters are fairly or, occasionally, very turbid. The colour changes with turbidity variation.

In some areas various reports cite widespread feacal and industrial pollution of surface waters. Hot temperatures are also favourable for bacteria growth. These waters ordinarily require treatment for public water supply use.

Groundwater is a complex chemical solution, owing its composition largely to the solution of soluble constituents in soils and rocks by percolating sub-surface waters, and the surrounding rock media. Therefore, the chemical quality is localized and is dependent more on hydrogeological factors.

Groundwater in the high rainfall areas of central and coastal Kenya are considered good and could be used for many purposes with few restrictions. In Western Province the Kefinco (1983) reports acidic groundwaters, otherwise there are no excessive levels of harmful substances.

In low rainfall area of northern and eastern Kenya the salinity content is high and about one borehole in seven produce "nonpotable water" (National Master Water Plan Vol. I, 1979). The fluoride concentrations in most volcanic areas generally exceed WHO permitted levels (1.5 mg/l).

Appearance of spring waters is turbid and coloured (Kefinco 1983) in western Kenya, but clear in most other places.

3. WATER TREATMENT METHODS

3.1 General

Man has shown desire to improve water quality. Three basic objectives of water treatment are :-

- Production of water safe for human consumption
- Production of water appealing to the consumer
- Production of water using facilities reasonable with respect to capital and especially operating costs.

In the design of water treatment plants, the provision of safe water is the prime goal. However, a properly designed plant is not a guarantee of safety. Skillful and alert plant operation and attention to the sanitary requirements of the source of supply and distribution system are equally important (American Society of Civil Engineers, 1971).

Water is the potential carrier of infectious disease. The types of infection are too numerous (A.S. of C E AWWA, 1971). Through measures that include protection of the source of supply, treatment, and sanitary control of the distribution system, public water supplies can be made safe from waterborne disease. As regards bacteriologic requirements, to ensure the absence of pathogenic bacteria and viruses the new WHO Guidelines recommend that for all types of water supplies, faecal coliform indicator organisms should be absent. With respect to total coliforms counts it is permitted to a limit of an occasional 10 organisms in unpiped supplies.

Physical characteristics: The levels for turbidity, colour, taste, and odour approached by well designed and operated systems should reflect a high degree of consumer acceptability.

Chemical characteristics: Appendix 1 gives recommended concentrations of various chemical substances for treated water quality.

Water quality criteria are to assist in the establishment of water system performance goals for any plant. Quality criteria change as new information on the nature and behaviour of water is revealed. The quality of raw-water sources is not expected to improve substantially, and indeed, may worsen in many places as greater use is made of streams for waste disposal. The water treatment plant, therefore, will have an increasingly important role in the production of water of high quality. No typical treatment plant design problem exists. Type of treatment depends on the quality of the source of supply and the quality desired in the finished product. Adequate information on the source is a prerequisite for design. This includes analysis of the water and, where the supply is nonuniform, the ranges of the various characteristics. Treated water quality goals are given in the Appendix 1.

Types of sources fall into two major categories:

1) Surface water sources such as rivers, lakes and impoundments on rivers and streams; and
2) Ground water sources.

3.2 Surface Water Treatment Methods

3.2.1 General

Surface waters tend to be variable in quality, to contain lower concentrations of minerals, to be more highly coloured, to be turbid at times, and to contain taste and odour-producing susbtances. Surface water supplies receive greater exposure to wastes, including accidental spills of a variety of substances. High temperatures throughout the whole year in Kenya favour the growth and blooming of bacteria in surface water sources.

The quality of the source, giving due consideration to variations and possible future changes, and the quality goals for the treated water, recognizing the growing desire of the public for better water, form the basis for selecting a treatment process. The MoWD requirements, experience and skill of operating personnel, and cost influence selection of the treatment facilities.

Various types and combinations of treatment units are used to achieve the performance desired. Determination of the most suitable plan may be on a comparative cost study which includes an evaluation of the merits and liabilities of each proposal (American Society of Civil Engineers, 1971).

Some sources of public water supply on high mountain slopes yield water of excellent quality, requiring little in the way of treatment. Good practice for such supplies calls for continuous disinfection as a safe-guard, chemical treatment as necessary for corrosion control, and close supervision over the source to maintain the excellent natural quality of the water.

3.2.2 Increased Storage

Sedimentation of particles, reduction of the live bacteria content, and reduction of the number of schistosomic cercariae occur when water is stored in a covered tank. Generally, the effects increase with longer storage period (Brokonsult, 1977).

Increased storage is the additional volume required over the storage volume for balancing supply and demand according to the existing design criteria, if the retention period is increased by, lets say, 48 hours. Note that the required storage volume for balancing purposes is different between "pumped supply" and "gravity supply".

3.2.3 Chlorination

Treatment of water with chlorine is used mainly for disinfection of water or as a safeguard against possible intermittent bacterial pollution in a normally "clean" water.

Chlorine also has an effect of diminishing organic content of raw water. It can be used as a pretreatment of water with high organic content in order to increase the effect of the following treatment process, e.g. slow sand filtration. Disinfection by chlorine will not take place until the organic content is low enough. Therefore, the amount of chlorine required for treatment will vary with the quality of the raw water (Brokonsult, 1977).

Many different chemicals can serve as satisfactory sources for the required chlorine to be used in treatment. The alternatives considered for use in rural areas in Kenya are:-

(1) Chlorine gas;
(2) Calcium hypochlorite (30%) (Tropical Chlorine Lime); and
(3) Sodium hypochlorite (10%).

Tropical chlorine lime is widely used in rural water supplies and most urban supplies. Chlorine gas is a highly toxic irritant and needs great handling care and adequate safeguards. Liquid chlorine is cheapest for large uses (G.M. Fair et el, 1981). It is reported that the Ministry has tendered for the supply of High Test Hypochlorite (H.T.H.) as a substitute for the tropical chloride of lime. H.T.H. is more expensive per kilo basis, but it is approximately twice the strength, (65% Vs 35%) and is inherently more stable chemically, and more sturdily packaged (Task 3 Report, 1980).

3.2.4 Coagulation, Flocculation, Settling and Filtration

Slow sand filter clogs rapidly with more polluted and turbid raw water. Chemical treatment consisting of addition of alum and soda ash (for pH-adjustment) is required. After coagulation and flocculation takes place, the flocs will form and settle in a sedimentation tank and then filtered through a rapid sand filter before chlorination and storage in a tank.

A minimum of two sedimentation tanks are needed in order to facilitate cleaning. Although each unit may have its own filter, flexibility should be allowed so that any sedimentation tank pairs with any filter.

3.2.5 Slow Sand Filtration

The biological purification process that takes place in a slow sand filter is an appropriate treatment method for surface water not containing a high turbidity. The acceptable limit for turbidity for water to be heated by slow sand filters has been set at 30 F.T.U. At higher turbidity levels clogging will occur too frequently (Brokonsult, 1977).

The filter unit containing the sand filter and gravel bed can be made of reinforced concrete or masonry.

3.3 Groundwater

3.3.1 Boreholes

The chemical quality of subsurface water depends very much upon the geochemical character of containing rocks. The two main critiria for quality description of the groundwater resources are the total dissolved solids (WHO new guidelines recommend 1000 mg/l) and fluoride content (1.5 mg/l). Presently water with high fluoride concentration is not treated, but blending of the groundwater with the purified surface water is a possibility in major cities. Fluoride can be removed by means of the iron exchange methods using either activated alumina, bonechar or "Defluoron2". This form of process treatment is too complicated for rural water supply schemes.

Good quality groundwater is usually pumped up and chlorinated as a standard safeguard procedure before distribution. Sometimes, groundwater contains excessive amounts of iron, The type of treatment depends on:-

a) the quality level required of the treated water
b) the quality of the raw water

The water sources can be divided in four classes depending on the raw water quality:-

1) Groundwater from deep boreholes, i.e. a raw water of good quality;

2) Water from large lakes, springs and protected shallow wells, i.e. raw water of a fairly good quality with low level of pollution and low turbidity (<30 F.T.U.);

3) Surface water and shallow groundwater from less protected wells, i.e. slightly polluted water with a turbidity of about 30-100 F.T.U.; and

4) Surface water e.g. from reservoirs which are moderately polluted and having a turbidity > 100 F.T.U.

An appropriate treatment is assumed for each of the twelve combinations of raw water quality/output water quality given in Table 3. Treatment includes operation of the plant and the staff.

manganese and other impurities. Such water can be treated by aeration and if necessary filtered.

In wet areas water quality in shallow wells differs only slightly from the quality of deep groundwater. Shallow wells water is withdrawn in small quantities at a time and therefore it is important that this kind of water requires no treatment to make it potable.

3.3.2 Springs

The appearance of spring water can be turbid and coloured. The turbidity and the colour are likely caused by silt coming up with water.

Some spring water sources employ full convectional treatment to remove turbidity and colour, but most supplies only chlorinate before distribution.

3.4 Rainwater Harvesting

Surface and groundwater originates from rainwater. In this case emphasis is laid on the rainwater that falls on a roof and is collected by means of gutters and stored. Water quality of rainwater is affected by the type of roof and storage. For iron roof and galvanised iron storage tank the water quality is sufficiently good although in the beginning the zinc content might be noticeable. The only form of treatment that might be required is protection from any source of pollution.

3.5 Engineering For Different Levels of Water Quality

Water treatment include one or several treatment processes such as storage, chlorination, filtration etc. Each treatment process requires its own equipment and structures for which the engineering design can be done in several different ways.

Table 3 Levels of Water Quality

Quality Level	Water Source			
	(1)	(2)	(3)	(4)
	Groundwater	Turbidity 30 low Pollution	Turbidity 30-100 slight Pollution	Turbidity 100 Moderate Pollution
Low	No Treatment	No Treatment	Storage	Storage
Medium	To Treatment	Storage	Chlorination	Flocculation, Settling and Filteration, Chlorine
High	Chlorination	Slow Sand Filtration, Chlorination	Flocculation, Settling and Filtration Chlorination	Source Recommended to be Rejected

(Source: Brokonsult - 1977)

4. EXISTING ORGANIZATION

4.1 General

The Ministry of Water Development (MoWD) has the primary responsibility for planning, development, operation and maintenance of public water supplies throughout Kenya. There are other Ministries and agencies that plan, finances, construct or operate water supply schemes and use the facilities, but MoWD has the key responsibilities. The MoWD organization charts are as shown in Figures 2a,b and c.

4.2 Project Construction Procedures

The District Development Committees (D.D.C.) initially identify rural water schemes and refers them to the MoWD for design and implimentation. The MoWD carries out the initial planning step conducting a feasibility study to identify source, to estimate the water demand, and to prepare a cost estimate. On the basis of this initial study the project moves into the design - construction cycle.

Urban water supply projects are identified through review of the existing situation in the towns, comparing projected demand and capacity of the existing supply.

The small, low technology projects are usually selected locally within the District controlling the construction facility (e.g. Water Conservation Unit or Shallow Well Construction Units)

The Engineering Department of MoWD consists of planning and Design Branch, an Implementation (construction) Branch, and Electrical and Mechanical Division, and sewerage Division dealing with engineering activities. The Department also contains an Operation and Maintenance Branch for water supply systems as a management function.

ORGANIZATION CHART OF THE MINISTRY
OF WATER DEVELOPMENT - 1982

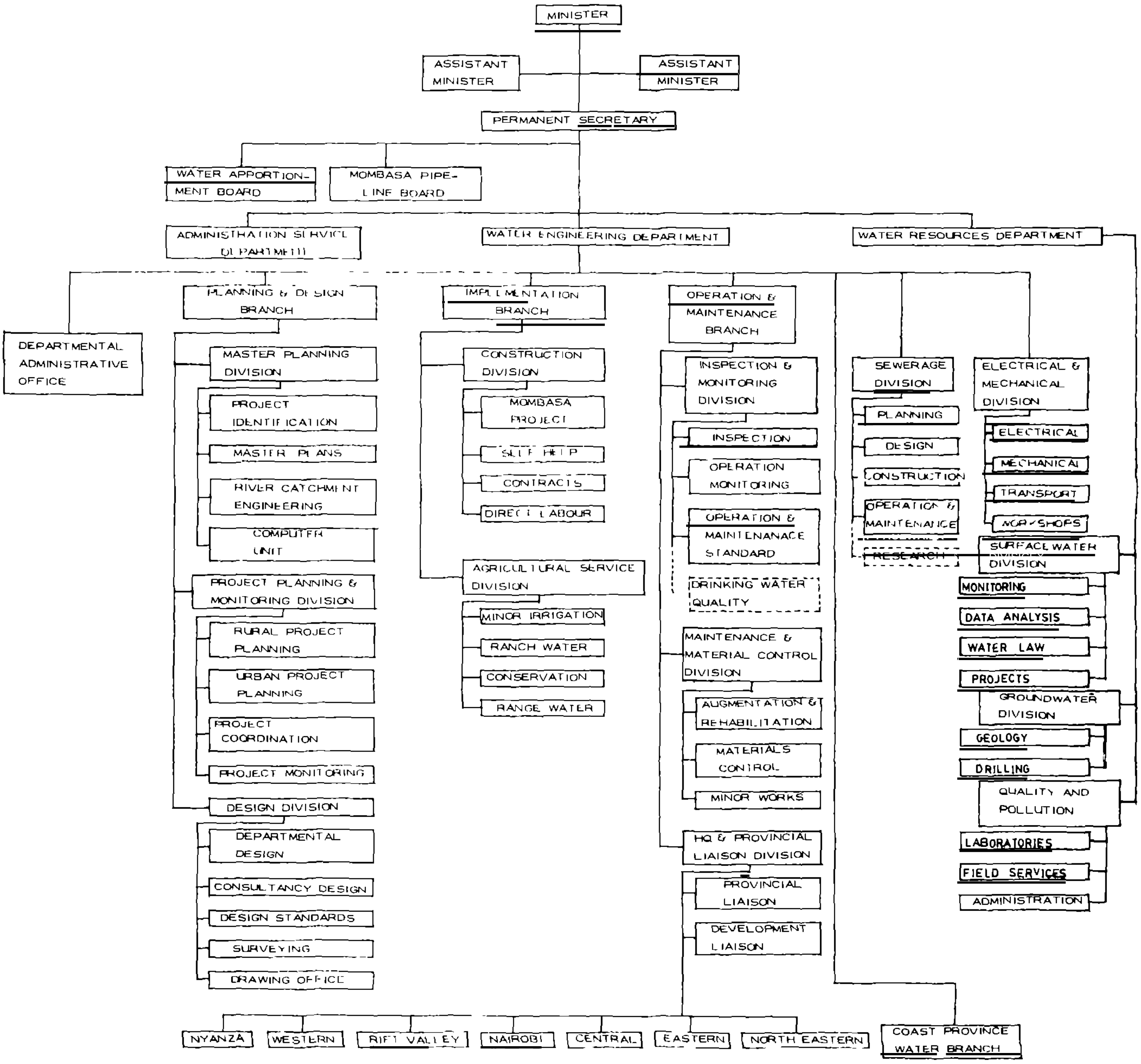


Figure 2 a.

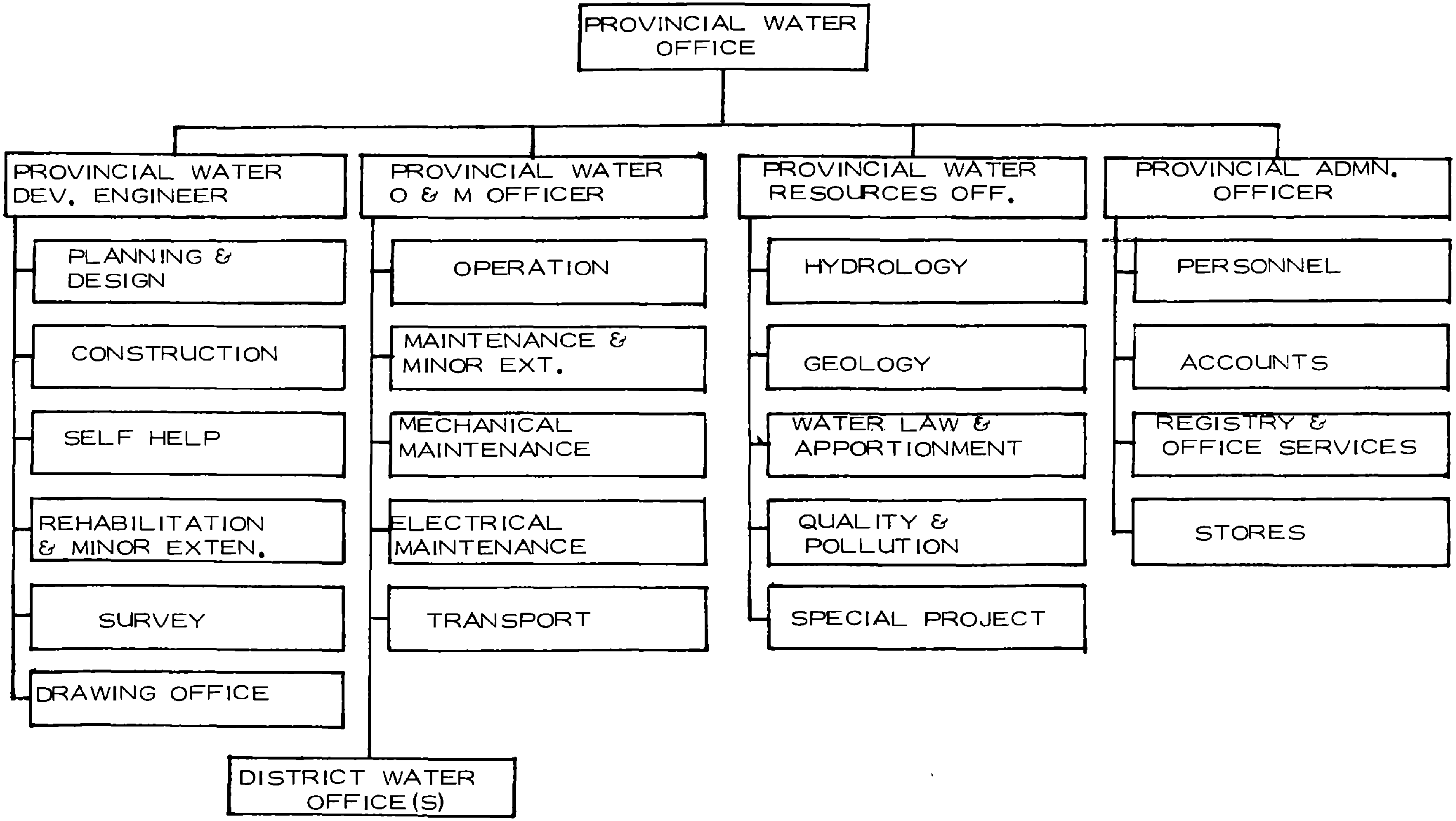


FIG. 2b BASIC PROVINCIAL WATER OFFICE ORGANIZATION CHART

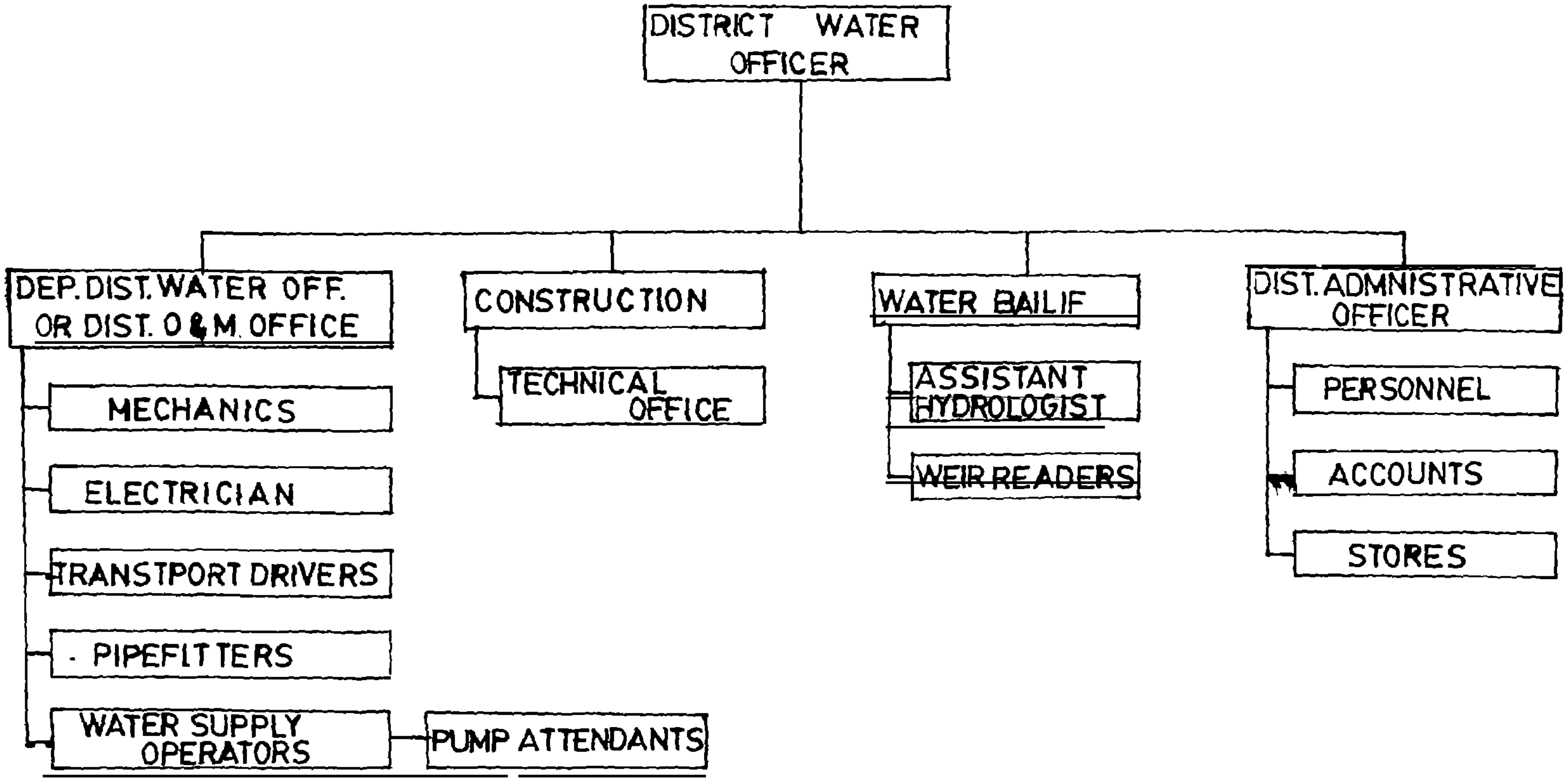


FIG. 2c TYPICAL DISTRICT WATER OFFICE ORGANIZATION CHART

The Design Division is almost dependent on consultant design for large schemes,but the design of small schemes is undertaken at provincial level by MoWD engineers. The The implementation branch uses project engineers to supervise construction projects. Construction periods typically extend over 18 to 24 months depending on size and funds availability. The construction of the projects is usually tendered and awarded to a contractor or otherwise the Director Labour Section is directly issued with funds to implement the project.

The Groundwater Division in the Water Resources Department provides hydrogeological services for borehole siting, issues borehole permits, and performs well drilling both by MoWD rigs and by contractor rigs.

4.3 Operation and Maintenance Organization

The operation and maintenance organization is also shown on the charts Figure 2 from Headquarters to the District Water Office level. Operation and Maintenance uses a province and district organization structure at present. This method is described as suitable for existing low level of activity and available infrastructure, but possesses geographic disadvantages and potentially cumbersome and diffusive political influences (National Master Plan Vol.IV, 1980).

At provincial level either a Provincial Water Engineer or a Provincial Water Officer heads the Provincial staff. The position is essentially an administrative one of managing the Provincial Organization, operating within specific budgets and allocating funds to the extent of his authorization. He is to some extent involved in the design of new projects in the province, and intimately involved in their implementation.

At district level the District Water Officer, heading the District staff, is directly responsible for the operation and maintenance of all water supply systems in the district. He is also responsible for warehousing all spare parts, stocking fuels and basic chemicals. Both these responsibilities point to a position which is a key one, in the operating and maintenance organization.

Each water supply is manned by trained staff (Task 3 Report, 1980). The operators are mostly technicians from MoWD training school. Apart from operating the plant they can also repair burst pipes. There are also pump attendants. The number of operators at each plant depends on size and duration of operation. An 8 hour operation needs at least 1 - 2 operators, while a plant operated for 24 hours may need at least 4 operators. The MoWD operates about 350 rural and 35 urban water supplies.

4.4 Existing Operations and Maintenance Procedures

4.4.1 Daily Maintenance

The procedures at the water treatment plant consist of checking engine lubricating oil levels, fuel oil levels and a general inspection of the plant. For the plants incorporating treatment facilities, the chemical solution levels are checked and replenished as necessary. Except for turbidity rod-test being done periodically to determine the dosage of coagulant, checks on raw water quality are non-existent. Some plants have jar-test equipment for determining optimum coagulant dose.

Residual chlorine and pH are determined in most treatment plants using lovibond comparator. Alkalinity and carbonate tests are performed using either T. tablets or titration.

They appear to follow slavishly, a procedure set forth as general policy regardless of consequences, rather than to fulfill a need. At the very least, the Provincial Water Engineer/Officer should be given authority to deviate from established procedures, as he sees fit, in the case of emergency reports (Task 3 Report, 1980).

Fuel Purchase

A request for fuel is sent by the operator to District Water Officer, who arranges transportation to pick up fuel in drums, (if available), from the MOW bulk storage depot. Transport usually consists of an open lorry and because there is no suitable equipment for drum handling, container life is very short; consequently there is a chronic shortage of serviceable drums.

In a great many cases lorries made deliveries of oil, only partially loaded because there are rarely enough serviceable drums to make a full load. The net result of the shortage of transport and of serviceable drums, is that many plants are frequently shut down because of lack of fuel (Task 3 Report, 1980).

Chemical Purchase

Chemicals are usually tendered for annually by MoWD Nairobi and shipped on demand more or less directly to the user. That is, shipment from the supplier is usually by rail to the nearest railway depot. The Ministry must then haul the shipment to the user. Supply of chemicals is sometimes delayed due to late payment of accounts by the Ministry.

In some cases shipments of chemicals are routed through Provincial Headquarters. This procedure results in needless extra handling and increases the strain on Ministry transport facilities (Task 3 Report, 1980).

Pumping units are provided with full time attendants to check and replenish the small individual fuel tanks. Most treatment plants are installing electrical motors to run the pumps.

Daily operations include the keeping of records relating to hours of operation, volume of water supplied and residual - chlorine tests.

General procedures for operation and maintenance are contained in the Water Operations handbook issued by the MoWD training school in Nairobi.

4.4.2 Emergency Repairs

Major breakdown of a water system invariably involves considerable downtime. Some newer systems, or systems close to urban centres, telephone communications can be made with the District Water Office without difficulty. In the majority of instances however, a breakdown is reported either by letter or by travelling to the District Water Office by public transport, bicycle or even foot (Task 3 Report, 1980).

When the message is received at the District Water Office appropriate artisans are sent out as soon as transport is available. However, there is a severe shortage of transport in every District. The inevitable delays are particularly serious when there is no standby unit at the site or when there is unserviceable standby unit (Task 3 Report, 1980).

4.4.3 Preventive Maintenance

Preventive maintenance other than day-to-day lubricating oil changes etc, is virtually unknown. There is no program established to replace and repair equipment after a stipulated operating period as recommended by most manufacturers.

Such a program would be advantageous and requires trained staff, funds, repair facilities and particularly vehicles (Task 3 Report, 1980).

4.4.4 Water Treatment Procedures

Recommended water treatment procedures are explained in the water supply handbook issued by the MoWD training school in Nairobi. The required procedures are basic.

Some of the treatment plants are provided with some basic equipment, e,g, burettes, jars, comparators etc. As can be noted from operation charts of treatment plants kept in the Operation and Maintenance Branch in Nairobi, these basic equipment is not fully utilized in most cases.

Improper dosing of coagulants can cause treatment plants to operate at rates substantially under design (Task 3 Report, 1980). Point of application of the chemicals is important too. However, significant improvements in both the quantity and quality of water produced could be achieved with appropriate training (Onsite for each operator) and improved basic testing facilities.

4.4.5 System Reliability

The overall reliability of the water systems varies considerably. The gravity systems are the most reliable due to their lack of mechanical equipment. Systems relying on diesel power are the most unreliable. The unreliability of the engines (largely due to lack of preventive maintenance programs) and the difficulty in maintaining an adequate fuel supply with the inadequate storage facilities installed are the two prime causes of the frequent failure of such systems.

Water treatment plants are usually affected by mechanical breakdown, fuel shortage, fitters, inadequate sources of water and intake pipe failures (blockage).

4.5 Transportation and Communication

Communications between the individual water system and divisional offices are largely inadequate in most cases, there are no telephone or radio facilities available. The operator must walk severally to the nearest telephone to report and to request maintenance assistance or supplies from district or divisional offices.

The lack of sufficient transport causes frequent shortages of fuel, chemicals and maintenance materials although lack of proper planning for the supplies is probaly another factor.

4.6 Fuel, Chemicals and Equipment Supplies

4.6.1 Existing Purchasing Procedures

Existing purchasing procedures are similar in both Provinces and generally consist of the following steps:-

(a) The Operator advises the District Water Officer of his requirements either verbally or in writing through the District Inspector.

(b) The District Water Officer raises a requisition which is submitted to the Provincial Water Engineer or Provincial Water Officer as applicable.

(c) The materials are then supplied from stock if available.

(d) If not available from stock, the Provincial Water Engineer (Provincial Water Officer) may raise a Local Purchase Order for goods to a value of Kshs. 1,000/-.

(e) If he suspects the value will exceed Kshs. 1,000/- he then calls tenders. A minimum of three tenders must be received or the procedure must be repeated. If the tenders come back with a value in excess of Kshs. 4,000/- they must be forwarded to the Central Tender Board for approval.

(f) Alternatively, if it is expected that the tendered value many exceed Kshs. 4,000/- the Provincial Water Engineer (Provincial Water Officer) refers the matter to the Central Purchasing Authority Nairobi.

Purchasing by tender is a sound economic practice, under normal circumstances. However, where there is insufficient lead time (as in the case of an emergency or breakdown) or where only one local supplier exists, the purchasing system must be sufficiently flexible to allow the Provincial Engineer/ Officer to deviate when necessary, from established purchasing procedures.

Certainly in the case of an emergency the Provincial Water Engineer/Officer should be empowered to place an order by telephone with a local supplier (with confirming Local Purchase Order to follow) for the equipment to be delivered immediately to the site. This arrangement could reduce down-time of equipment from say, a month, following existing procedures, to a matter of a few days.

It goes without saying however, that local suppliers must be paid promptly, otherwise they will not act upon verbal instructions.

Existing purchasing procedures, are in a few words, cumbersone, slow and inefficient.

Spares and Replacement Parts Purchase

Spares and replacements, such as pump and engine parts, drive belts, valves, etc., are handled through the District Water Officer who arranges their ordering and delivery.
The foregoing comments apply and amply illustrate the problems which result in needless delays in obtaining essential equipment at the water plants (Task 3 Report, 1980).

4.6.2 Existing Storage Facilities

At Provincial level, existing storage facilities appear to be adequate. In general, plant storage is also sufficient.
At the District level, the situation is more difficult to assess.

5. CONSTRUCTION COSTS OF WATER TREATMENT PLANTS

5.1 General

The sources of supply available in Kenya are groundwater, surface water and catchment of rain water. Considerations that govern the choice of source are availability, cost of development, and cost of operation. There is however, greater need to choose the type of source that, when developed, will afford the greatest simplicity of operation, but this is not always done (Floyd B. Taylor, 1967).

Once the source has been chosen, the next step is the design and construction of the facilities that will make the water available to the people for domestic use.

The objective of functional water system design should be to provide for most people at the lowest cost an adequate supply (amount) of safe water at convenient outlets and especially for piped systems, under pressure at all times.

Among the most critical needs for proper planning and management of water supply systems is the ability to prepare proper cost estimates. Although no two treatment plants are alike, comparisons are not meaningless. Two plants with similar water treatment goals can often be compared meaningfully to a common base (Clark and Dorsey, 1982). There is a general need for standard and consistent costing procedures to achieve the following objectives:-

(a) Rapid but approximate order-of-magnitude estimates, which are useful for rough estimate early in a study. Later they can provide a check on results obtained from a more detailed method.

(b) Evaluation of projects to characterize the costs to be incurred and to ascertain their economic feasibility; or

(c) Compare expected costs of alternative measures to identify preferred cost-control strategies.

Established methodology for costing could also improve the quality and usefulness of economic assessments to meet additional needs such as:-

- Providing information needed to ascertain the economic burden of an abatement process on a specific plant or industry;
- Predicting the costs of pollution control for industrial and government groups in the evaluation of ultimate costs to the consumer or taxpayer, and;
- Gauging the effect of pollution control on the economy and estimating its benefits to society.

(d) Definitive estimates, which require detailed information obtained from an engineering design. Because they are costly to prepare, definitive estimates should not be made unless construction is contemplated or detailed engineering information is available.

The availability of cost estimates depends on availability of basic data, the stage of design development, definition of the scope of the project, the time spent on analyses, and the experience of the analyst. Generally, understanding which design variables have the greatest impacts on cost is important.

Of the many problems in handling and using data facing MoWD the situation with respect to investment costs is one of the most critical. In an inflationary world projecting costs and comparing alternatives is extremely difficult. Nevertheless the losses from inadequate cost analysis are high: It is difficult to negotiate sensibly with contractors without an appreciation of the great risks one faces in constructions; identifying real costs provides a basic management tool to assess and guide the MoWD to move productive functioning. More systematic methods for preparing cost estimates based on analysis of existing data need be developed gradually within the administrative system (Brokonsult AB, 1981).

Any water supply project involves identification as regards the need of the people and potential land use, and then feasibility studies are carried out to find possible sources of supply. Preliminary design is then undertaken, usually by consultants, to assess water requirements and various alternatives of supply systems based on costs and availability of materials. Depending on the availability of funds the preliminary design report is used to prepare a final design report. The final design report includes drawn (plans) documents for the construction of the scheme. The implementation of the scheme is overseen by the MoWD engineers, but usually supervised by consultants when a contractor is awarded the job through tendering system. Small water supply schemes are done by the Direct Labour Section of the MoWD.

The construction costs of the distribution network for water has not been considered. It is true that distribution area and relief with proper planning will have an effect on the location and capacity of a water supply scheme. For piped systems most of the construction costs goes to the pipe network.

Raw water abstracted from Lake Victoria has low turbidity. Treatment is therefore by slow sand filters and chlorination as a safeguard. Water abstracted from high mountain slopes usually needs only a weir intake. Apart from the unit processes construction costs, in order to compare surface water and groundwater supplies consideration has been given to abstraction i.e. intake. Surface water intake may consist of the construction of a dam to store water for drought periods. The intake in some cases consists of pump arrangements.

The cost of construction of water treatment plant includes costs of:-

(1) Excavation and sitework,
(2) Manufactured equipment
(3) Unit process (concrete, steel, labour, piping and valves being considered in each unit process),
(4) Electrical and mechanical installation, and
(5) Housing.

This is for the purpose of comparison between different plants of different flow capacity. To compare between surface water, subsurface water and rainwater production, preliminary and general costs for mobilization and the cost of water intake, raw water main and pumping are considered.

The construction costs in Table 4 are not the final capital cost for the unit processes since general contractor overhead and profit, administration, engineering and legal fees, fiscal determinations, and interest during construction are not included. These items are directly related to the total cost of a project, not to the cost of the unit processes. The costs were obtained from the few tender documents that were available.

These costs are only estimates as they do not include variation orders. Construction costs data for all water schemes can be found at MoWD Headquarters. It is not clear whether this information is itemized for each unit process as would be in the bill of quantity found in tender document. Some water supply schemes are constructed by the Direct Labour Section of the MoWD and there seems not to be detailed cost estimates available for these.

Table 4 considers only the unit processes excluding the intake construction costs. For the unit process the unit cost of water per cubic metre is very low. The estimated construction costs are converted to year of commission price levels by using civil engineering cost index given in Appendix 3. The unit cost is an approximate estimate assuming the plant operates at design level always for a design life of 20 years. Inflation has been neglected for simplicity. However, the per capita investment costs varies greatly, more because of geographic region (design population) than the plant capacity. Population density has an impact on per capita costs.

Use of surface water in most cases involve construction of dams and intakes, which are very expensive. From Table 5 the construction costs consists of items listed in Appendix 2 with 10% contigencies as provided in the bill of quantities in the tender document. Dams are constructed to create reservoirs that will store water during droughts. The lifetime of the reservoir of 50 years has not been considered, but the costs have been spread over the treatment plant lifespan of 20 years. The main point here is to form a fair idea of treating surface water as opposed to other methods of supplies.

The construction costs of a surface water supply consisting of a reservoir is about the same cost for the distribution network. Therefore the figure given by Kefinco (1983) for investment cost of surface water supply of Kshs. 1200 per capita is about the average.

Distribution network for water supply scheme is also an important issue and should be considered separately, especially in "pumped supplies". Results from study analysis conducted in USA, show that the unit cost varies over the service area with respect to the distance the water must be transmitted (Clark, 1980). Transportation costs are significant and can negate potential economies of scale (Clark, 1979).

5.2 Surface Water Treatment Plants

The type of water treatment plant as stated in Section 3.5 depends on raw water quality from the source and the required treated water quality. These determines the treatment processes and therefore the construction costs. In Kenya surface water source are usually turbid and almost the same set of unit processes are used with variation in configuration. For example a few plants include a raw water tank, rapid mixing is either hydraulic or mechanical, there are also different ways of flocculation, either by use of sludge blanket in vertical flow basins or different designs of baffled walls. A few urban plants use mechanical paddles. The sedimentation basins varies too in design. The most common are rectangular horizontal flow tanks and vertical flow tanks, although circular horizontal flow tanks are usually found in older water works. Rapid sand filters are included in chemical treatment plants, the only difference is the backwashing. A few plants are provided with compressors for filter bed agitation during the backwashing with water. Finally there is one or two storage tanks for treated water. From the storage tank the water either flows by gravity to consumers or it is pumped to an elevated tank first, in piped systems.

Table 4 Treatment Plant Construction Costs

Water Supply	Cost Estimate Year	Commission Year	Treatment Plant Cost Estimates Kshs.	Adjusted Costs Kshs.	Design Flow M^3/Day	Design Population 1990	Unit Cost Kshs/M^3	Cost Per Capita Kshs.
Aguthi	1980	1983	5,363,036	8,296,515	2,650	36,500	0.45	147
Chesakaki	1978	1981	3,156,013	4,493,155	1,860	38,789	0.33	116
Chepkorio	1978	1982	1,731,711	3,083,212				
Isiolo I	1979	NA	9,752,895					
Kahuti IIA	1978	1981	3,205,744	4,563,956	5,381	82,500	0.12	55
Litein I	1980	NA	14,743,874					
Maralal I	1981	NA	10,633,844			6,881		(1545)
Mathioya I	1980	1983	9,969,152	15,422,089	3,400	56,511	0.62	273
Meru	1978	NA	851,270			136,000		(6)
Murang'a II	1975	NA	2,675,423		2,500	40,000	(0.15)	(67)
Ndarugu I	1974	1976	994,720	1,316,905	3,270	129,460	0.06	10
Othaya	1976	1983	259,602	586,067	11,000	76,000	0.01	8
Tigania I	1975	1977	432,878	504,304	800	32,735	0.09	15

NA - Information not available

Table 5 Construction Costs of Surface Water Intakes and Treatment Plants

Water Supply	Total Estimate Kshs.	Commission Year Price Level Kshs.	Unit Cost Kshs/M^3	Cost Per Capita Kshs.
Aguthi I	16,687,817	25,808,002	1.33	707
Chesakaki	14,488,733	20,627,325	1.52	532
Chepkorio	2,738.168	4,875,152	-	-
Isiolo I	17,208,183	-	-	-
Kahuti IIA	6,565,683	9,347,435	0.24	113
Litein I	29,524,681	-	-	-
Maralal I	31,072,458	-	-	(4516)
Mathioya I	21,035,658	32,541,764	1.31	576
Meru	2,798,937	-	-	(21)
Murang'a II	4,035,943	-	(0.22)	(101)
Ndarugu I	1,269,940	1,681,267	0.07	13
Othaya	2,616,253	5,906,349	0.07	78
Tigania I	2,018,213	2,351,224	0.40	72

5.3 Boreholes

According to Mini-Evaluation report (Brokonsult, 1981) water supplies based on groundwater (boreholes) are normally smaller than surface water based supplies.

The number of boreholes to be drilled is calculated from the expression:-

$$N_1 = IP \left(\frac{Qo}{Q, x}\right)$$

where N_1 = number of boreholes to be drilled
IP = integer fact
Qo = the demand required, m^3/Day
Q, = the daily (safe) yield from one borehole
x = the probability of getting a successful bore (<1)

The above parameters are needed to determine the number of boreholes that are required as an alternative to a surface scheme when pending for the same demand.

The drilling cost of a borehole is influenced by the depth and diameter of the borehole, experience of the staff, and efficiency of the equipment used. A general formula for estimating the cost of borehole construction is given by the Mini-Evaluation report to be:-

C_B = 45000 + 1000.D
where C_B = Cost with 1981 year price level Kshs.
D = borehole depth in meters (within a range of about 60-110m)

In addition, the construction cost can be greatly influenced by the haulage distance of the drilling rig.

Borehole construction involves geophysical investigations (hydrogeological structure is studied using seismic soundings and geoelectrical soundings), drilling, casing, well screening, grout sealing, well development and capacity testing.
Suitable boreholes are usually equiped with electrically driven submersible pumps. The motors for the pumps are sometimes powered by diesel engines. In a few older supply schemes piston pumps powered by diesel engines are used. The actual construction costs of groundwater supply scheme depends on geographic regions and varies from case to case.

Groundwater Supply Scheme also include a storage tank and as a safeguard measure, a chlorinator unit (the only treatment required). Mini-Evaluation report gives storage costs as Kshs. 30,000 in 1981 price level. For chlorination treatment plant a general cost estimate is given as:-

$$C_T = 44\,00 + 15.Q_o.N$$

where C_T = Cost in 1981 year price level, Kshs.
Q_o = the total daily demand in m^3
N = the required number of boreholes

The construction costs of boreholes are difficult to analyse because of the different phases of construction. The data is available in different offices of the MoWD.

The utilization of groundwater resources economically will depend on proper scientific approach of the qualitative and quantitative evaluation of aquifer systems and dynamics and a better understanding of their role in the total hydrological environment (D.M. Kirori, 1977). The quantity and quality is localized and is dependent mostly on hydrogeological factors. More than 4600 boreholes with an average depth of about 110m have been drilled in the whole country. Research to assess groundwater in Nairobi has found out that in most areas the production costs of water is higher than that of surface water supply (Joseph Nguiguti, 1977). This cannot propably be generalized throughout the country because of fifferent hydrological and geological conditions.

5.4 Shallow Wells

Shallow wells are hand-dug or tractor excavated and usually lined with concrete rings or bricks, and equiped with handpumps. No treatment is needed nor pipelines and storage tanks. The consumers come and pump water from the well. Hand-dug wells have been used at Kenya's coast, northern and north eastern areas for many centuries, mainly for domestic use. See Appendix 4.

Kefinco is presently undertaking shallow wells project in Western Province to supply water.

The capacity of one well (7.2 m^3/day) is supposily to supply for 200 consumers at a consumption rate of 37 l/capita/day. At this rate the investment costs have been determined at 170 - 230 Kshs/capita (price level of November 1982). Cost estimate for a shallow well rehabilitation by Moerman (1982) works approximately to the same figure. Average cost of a hand-dug well is summaries as:-

a)	material	12,636
b)	labour	11,600
c)	Transportation	15,200
	Total	39,436
	Say	40,000

For 200 consumers the cost works out as Kshs. 200 per capita

5.5 Protected Springs

Natural sources of groundwater discharge are springs, seepage areas, lakes and base flow of perennial streams which have used by man since time immemorial.

The utilization of springs for water supply depends decisively on their yield druing the dry period of the year. In 1983 Kefinco carried out a spring protection pilot scheme. They tested different structures to find the most suitable for the project area in Western Province. The water naturally discharges from the ground where its flow is impeded by a less permeable strata. Careful control and protection should be maintained near the site of the spring in order to prevent pollution.

The spring protection can be done by digging a bit back into the hillside to the water bearing layer where the water is flowing through the "eye" if the spring, and either a collecting tank is build or the place packed with gravel with an outlet pipe. (See the Appendix 5 and 6). There are gravity and artesian kinds of springs.

Kefinco (1983) report gives an investment cost of Kshs. 100 per capita in Western Province. Estimates prepared by Moerman (1982) for the construction of spring protection box are:-

Material	14,568/=
Labour	2,550/=
Transport	6,600/=
Total	23,718/=

Say Kshs. 24,000 per spring.

On the basis of 200 consumers per spring the investment cost is about Kshs. 120 per capita.

5.6 Rainwater Harvesting

Rainwater is harvested as it runs off roofs, or over natural ground, roads, yards, or especially prepared, catchment areas. In many countries in Europe and Asia rainwater harvesting was used widely for the provision of drinking water, particularly in rural areas (IRC, Technical Paper, 1981).

Rainwater harvesting should be considered in areas where rainfall is heavy in storms of considerable intensity. It requires adequate provision for the interception, collection and storage of the water. Depending on the circumstances the catchment of the water is on the ground, or the runoff from roofs is collected and stored.

Reasonably pure rainwater can be collected from house roofs made of tiles, slates, corrugated galvanized iron, aluminium or asbestos cement sheeting. The rainwater may be stored in containers of simple medium size pots, tins, drums or small tanks.

A study carried out by Omwenga (1984) on rainwater harvesting gives estimates of the water collection facilities. The costs varies with the kind of materials used. It is mainly based on roof catchment. Partial costs of putting up the galvinized iron roof are included since water collection is a secondary function to shelter. Material costs will include gutters, storage and labour. Required storage capacity will vary depending on funds, consumption and area of catchment. Considering a family of 6 - 10 persons and their drinking water requirements, a 1500 litres granary basket tank would cost Kshs. 950 to install. The investment cost is Kshs. 160 per capita.

Construction of a concrete block tank costs Kshs. 8,600 for $5m^3$ capacity.

Material	2,800/=
Labour	1,500/=
Transport and contigencies	4,300/=
Kshs.	8,600

Investment cost is Kshs. 860 - 1430 per capita

A galvinized iron tank of capacity $2.5\,m^3$ would cost Kshs. 7,000 for complete installation, but is not as durable as a concrete or blockwork structure.

Generally the investment costs for storage facilities will vary greatly depending on the design and materials used, but the point here is that, some kind of storage is within the budgets of most families.

6. OPERATION AND MAINTENANCE COSTS

6.1 General

Operating costs are incurred to achieve certain immediate purposes, and the expenditure must be constantly renewed if it is desired to continue receiving the benefits. Water treatment plant operation costs include chemicals, direct labour involved in operations, fuel and miscellaneous items that are required for day to day operations. Maintenance costs include the replacement of parts; the share of labour costs that can be attributed to maintenance activities; the costs of labour services used for maintaining the treatment plant which are not directly employed on the scheme. In addition to these direct costs there are overhead costs associated with operations and maintenance including staff costs associated with the management and support of the schemes; vehicle costs associated with operations and maintenance; and workshop costs. The works and vehicles operated by the Ministry supply services to the construction programs as well as the operation and maintenanace activities and so the associated costs must be allocated. It is often difficult to determine overhead and some of the maintenance costs (Mini-Evaluation, 1981). This report deals with treatment plants mainly and not the entire scheme. In this research it was also difficult to separate the operation and maintenance costs for the treatment plant and for the distribution network. Engineering cost estimates take a certain percentage of the construction costs to estimate maintenance as recommendated in the MoWD Design Manual.

Operation and maintenance costs are lumped together and will be refered to as treatment costs. The analysis of the treatment costs is designed to indicate the extent to which treatment plant type and size may influence the unit cost of treating water.

At each water treatment plant "water supply operation charts" are kept. The plant operators are daily required to record dosage of chemicals used, fuel, some qualities of the water, miscellaneous items, amount of water flow and pump running hours. The information is then summarized on a monthly chart with also includes staff salaries. For the purpose of this research some of the Financial Year 1981/82 operation charts have been used. The information is at best an estimate. Most plants have their master flow meters blocked or broken down.

6.2 Surface Water Treatment Plants

Treatment plants range from a simple water intake with a chlorination for disinfection to a full chemical treatment plant. The surface water presently is of good quality chemically except for the turbidity and bacteriological characteristics. The turbidity varies and can be very high during rainy seasons because of the dissolved and suspended solids resulting from soil erosion. In the Rift Valley the lakes are salty and as a source of water they are not suitable for convectional water treatment.

Kenya relies heavily on surface water from rivers. Water tapped from high mountain slopes in few supplies requires virtually no treatment as the water is clear and unpolluted. In some cases chlorination is done as a safeguard against possible infection.

Surface water supplies are treated to meet water quality standards (see Appendix 1). Treatment is mainly to remove turbidity and to disinfect the water. In the process pH adjustments may be necessary.

It is not easy to separate acquisition and treatment operating costs. Therefore operating costs incurred in collecting water for delivery to the plant is lumped together with operating costs associated with the purification of source water. Distribution costs are not considered in this report, but support services related to the overall utility management function are considered especially with regard to water treatment.

From the operational chart records, most of the expenses at the treatment plant goes into fuel and chemicals. The fuel expenses which usually ran into thousands of shillings every year can be reduced effectively by regular servicing of the pumps and selection of properly sized pipes with smooth inner lining. The chemical expenses can be kept to a minimum. The initial introduction of coagulant chemicals is very often a key factor on the amount as well as the effectiveness of the chemicals. It is necessary to introduce the coagulant chemicals into a zone of high turbulance, such as a head of a venture flow meter or weir, to provide rapid and complete dispersion before aggregation of floc can occur (Robert A. Ryder, 1977). From the charts, it can be noted that Kenyan waters are usually neutral (pH of about 7). This requires high doses of alum for effective coagulation. Alum is more effective at lower pH (<6) and this may require incorporation of acid dosing unit at each plant.

Surface water supplies can be grouped into two types, gravity and pumped. The gravity fed water supply has by far the lowest unit operation cost. Operation cost varies between Ksh. 0.28 per m^3 for gravity fed to Ksh. 30 per m^3 for pumped supply depending on size. In general, the results indicate that scale of economies exist in operation and maintenance of treatment plants (see Table 6 a and b, and Figure 3).

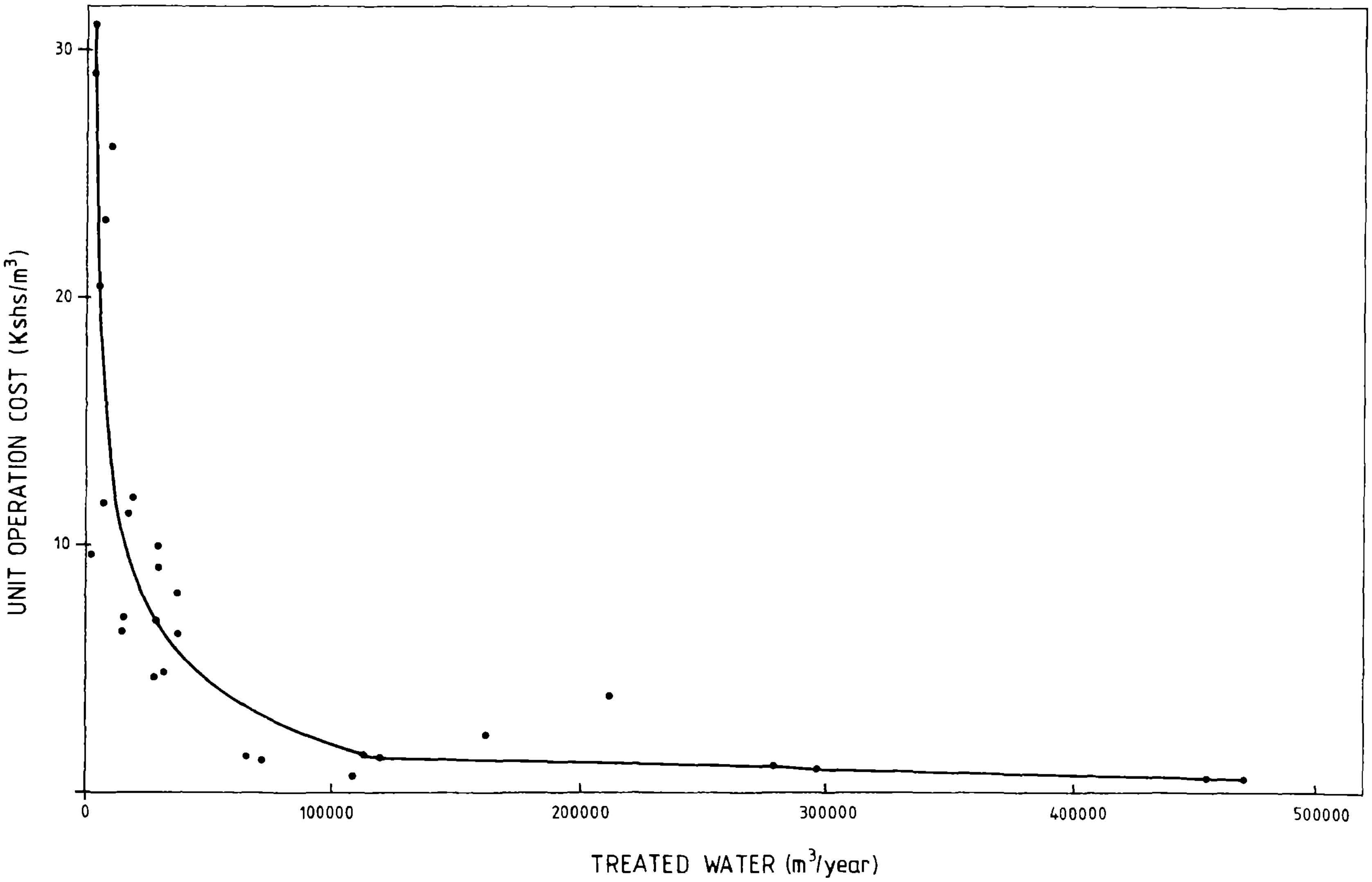
Table 6 a Operation and Maintenance Costs
Financial Year 1981/82

Water Supply	Source	Type of Supply	Acquisition And Treatment (Kshs)	Support Services (Kshs)	Total Operation Costs (Kshs)	Water Treated M^3/Year	Unit Operation Cost (Kshs/M^3)
Bathi	River/dam	Gravity	234,054	44,801	278,854	455,240	0.61
Busia Hills	River	Pumping	174,408	126,013	300,421	37,490	8.01
Busia -Mundika	River	Pumping	598,862	212,410	811,272	210,872	3.85
Chesakaki	River	Pumping	266,775	56,500	323,275	278,959	1.16
Hamisi	River	Pumping	64,830	43,404	108,234	3,487	31.04
Kabete	River/borehole	Pumping	263,264	+	263,264	635,097	(0.41)
Keroka	River	Pumping	154,682	+	154,682	31,930	(4.84)
Kibichori	River	Gravity	43,689	35,950	79,639	109,500	0.73
Kibichori-Bokoli	River	Gravity	226,091	58,200	284,291	296,865	0.96
Little Nzoia	River	Pumping	327,056	46,680	373,736	1,344,053	0.28
Lumakanda	River	Pumping	95,338	45,204	140,542	5,011	28.05
Malava	River	Pumping	89,346	37,670	127,016	18,335	6.93
Malindi-Sabaki	River	Pumping	959,691	425,271	1,384,962	839,195	1.65
Mawego	River	Pumping	71,441	17,316	88,757	7,566	11.73
Mbumbuni	River	Pumping	76,197	40,710	116,907	9,842	11.88
Msambweni	River	Pumping	122,386	-	122,386	71,926	(1.70)
Muana Dam	River/dam	Pumping	80,385	24,189	104,574	14,658	7.13
Munana	Small River	Pumping	82,779	42,476	125,255	27,153	4.61
Ndarugu	River	Pumping	197,447	32,196	229,643	470,598	0.49

\+ Data not available

Table 6 b Operation and Maintenance Costs
Financial Year 1981/82

Water Supply	Source	Type of Supply	Acquisition and Treatment (Kshs)	Support Services (Kshs)	Total Operation Costs (Kshs)	Water Treated M^3/Year	Unit Operation Cost (Kshs/M^3)
Ndivisi-Makuselwa	River	Pumping/ Gravity	314,159	72,750	386,909	674,754	0.57
Shikusa	River	Pumping	209,563	63,437	273,000	29,815	9.16
Wundanyi	River	Pumping	174,113	540	174,653	112,814	1.55
Port Victoria	Lake	Pumping	163,054	124,629	287,683	28,911	9.95
Sio Port	Lake	Pumping	71,479	42,476	113,955	17,626	6.47
West-Karachuonyo	Lake	Pumping	148,835	90,660	239,495	37,400	6.40
Bujumba	Borehole	Pumping	71,607	42,476	114,084	5,099	22.37
Gatundu	Borehole	Pumping	60,437	33,219	93,656	71,930	1.30
Githunguri	Borehole	Pumping	58,472	34,287	92,759	65,083	1.43
Hola (Galole)	Borehole	Pumping	342,944	35,678	378,622	162,297	2.33
Funyula Mangira	Borehole	Pumping	115,019	84,009	199,028	17,677	11.26
Nambale	Borehole	Pumping	82,420	86,369	168,789	6,720	25.12
Amagoro	Spring	Gravity	18,729	9,700	28,428	2,952	9.63
Chebilibai	Spring		5,629	18,725	24,353	1,885	12.92
Marsabit	Spring		327,646	168,615	496,261	67,752	7.32
Morijo Loita	Spring		3,730	7,305	11,035	820	13.46
Vihiga	Spring	Pumping	122,143	69,204	191,347	27,600	6.93



30
20
10
0
100000
200000
300000
400000
500000
UNIT OPERATION COST (Kshs/m³)
TREATED WATER (m³/year)

In some cases it could be noticed that all operation and maintenance costs are not properly recorded. For instance if electricity is used that is missing and it can have much influence on total operation and maintenance costs. Unrecorded cost may explain some very low operation and maintenance cost figures. On the other hand very high figures may be partly explained by extra costs recorded as operation and maintenance costs.

6.3 Borehole

The chemical quality of subsurface waters depends very much upon the geochemical character of containing rocks in Kenya. Groundwater from deep boreholes (deeper than 40m), need fuel and a limited treatment; probably only chlorination and pH - adjustment as far as treatment operation costs are concerned.

According to the assessment of groundwater in the Nairobi area executed during the UNDP/WHO/NCC-SF Sewerage and Groundwater Survey carried between 1972 and May 1975 it was found out that the production cost of water from boreholes in the area was higher than the cost of water from Chania II project, a surface water source (Nguigutu, 1977). Anyhow when Chania II was constructed its cost was much higher than anticipated during the planning stage. Whether borehole construction costs were also too low during the comparison cannot be known.

Usually groundwater is not treated but in some cases chlorinated. And so the operation cost is mainly for fuel, salaries of staff and maintenance. Unit production seems to be quite high (Ksh. 1 - 25 see Table 6).

According to Kefinco report (1983), the annual operation costs per capita for groundwater source in Western Province is Ksh. 32/cap in 1982. At overall consumption rate of 40 l/cap/day, the total unit operation cost is Ksh. 2.19/m^3 as compared to Ksh. 2.88/m^3 for large surface water source scheme (Kefinco, 1983).

6.4 Shallow Wells

Groundwater from shallow wells need handpumps and no treatment. The consumers pump water from the well manually. The operational costs incurred are for the maintenance services. Annual operational costs is calculated at Ksh. 10 per capita an equivalent of Ksh. 0.74 per m^3 (Kefinco, 1983).

Comparably as a source of water shallow wells if properly constructed is bacteriologically safer, contains no sediment loads, requires no treatment and is less liable to evaporation. Costs of energy and chemicals do not occur (see Appendix 5).

Due to insufficient maintenance, many shallow wells in Kenya turn out to be out of order after a short period. This is mainly caused by the question of ownership. It has been suggested that suitable organization (schools, markets, missions, church organizations, local representatives, hospitals and private enterprices) be allocated the responsibilities of owning the wells.

6.5 Protected Springs

The consumer fetches water from the protected spring. The maintenance cost is negligible, The utilization of springs for water supply depends decisively on their yield during the dry period of the year. Springs with high yield can be converted into pumped schemes. Real spring water is pure and usually used without treatment, if properly maintained, protected and pit privies and soakpits are contructed at a sufficient distance.

6.6 Rainwater Harvesting

Rainwater harvesting comprises of a tank to store water. Such tanks may require periodic disinfection, but still the maintenance costs is very low.

A galvanized tank has a lifetime of about seven years, but a concrete (masonary) tanks would last over fifteen years.

7. COSTS COMPARISON

7.1 Data

The MoWD has a vast record of data kept in different offices. Design documents are kept in different offices depending on the project implementation stages. Cost estimates of projects are either contained in the preliminary design reports or the tender documents. The costs in the preliminary reports are engineers estimates and the rates used are subject to changes before and during the actual construction of the project.

The tender document contains a more precise bill of quantities with rates depending on the contractor bidding for the job. The rates by different contractors are supposed to be competative, and so they are controlled these way. Each contractor's rates will depend on their source of material supply and bulk purchases. These rates are also subject to changes for varies reasons. These may not be avoided and so variation orders are often prepared. The rates of material and labour affect construction costs.

It would be a good idea to prepare a new bill of quantities with current rates as the construction of the project progresses to take care of variation orders, and so proper construction costs analysis for each unit processes can be done fairly accurately. This will facilitate a better estimate of maintenance costs and annual investment costs of a project. The construction costs used in this report are at best estimates and not the actual construction costs, and therefore not useful for full cost analysis. The construction cost distribution factors based on the following components: excavation, manufactured equipment, concrete, steel, labour, piping and valves, electrical construction and perhaps instrumentation, and housing can also be calculated.

These factors are useful for updating costs when factors escalate at different rates and for comparing cost estimates from different sources.

The MoWD "Water Supply Operation Charts" are quite detailed and adequate as far as operation is concerned. Expenditure on maintenance is not as detailed. Frequent shortages of chemicals and fuel make treated water quality vary so much, and most entries in the charts are estimates, making analysis difficult. The MoWD is mainly interested in using these charts to make financial forecasing estimates. Operation and maintenance requirements should be developed for building - related energy, process energy, maintenance material, chemicals and labour.

Development of construction and operation and maintenance cost curves will enable regression estimates to be calculated based on a general equation.

7.2 Supply Comparison

The cost per capita of certain surface water schemes and Kefinco's test shallow well programme are given in Table 7, November 1982 price level.

Table 7 Kefinco's Costs Estimates per capita

Alternative	Investment Costs Per Capita Kshs/cap	Annual Operational Costs Kshs/cap
Surface water, full chemical treatment, etc (large schemes)	1200	42
Boreholes water, diesel or electric motors etc.	900	32
Handpump wells	170 - 230	10
Protected springs	100	-

It is very clear that surface water supplies involves large investment expenditure per capita. For the intake and treatment plant the investment per capita is between Kshs. 13 - 707 per capita. For the whole scheme the figure would double. The unit capital costs of treated water production at design flow of the treatment plant is about Kshs. 0.1 - 1.60 per cubic metre, but large capital required for the construction is prohibitive and slows down the programme of supplying water to every household. The operation and maintenance costs are also high because of the chemicals, fuel and labour. The unit treated water cost is about Kshs. 0.28 - 30 per cubic metre.

The unit production of borehole water is about Kshs. 1 - 25 per cubic metre and Kshs. 0.74 for shallow wells. Annual maintenance of protected springs and rainwater harvesting facilities is almost negligible for simple structures. These has been summarized in Table 8.

Table 8 Water Production Cost Estimates

Alternative	Investment Costs Per Capita Kshs/cap	Unit Production Cost Kshs/M^3
Surface Water, full treatment (excluding distribution)	13 - 707	0.28 - 30
Boreholes (excluding distribution)	NA	1 - 25
Shallow Wells	200	0.74
Springs (some treatment)	NA	7 - 13
Protected springs	120	-
Rainwater Harvesting	160	-

NA - Data not available

8. SERVICE LEVEL

8.1 Walking Distance

According to MoWD Design Manual the maximum walking distance to the kiosk in a piped scheme should be 1 km in high potential areas. In the shallow wells and protected springs in Western Kenya the spacing is one unit per 0.44 km^2, a walking distance of about 0.66 km. Rainwater harvesting is as convenient as a plot connection.

8.2 Ease of Operation

People with individual connections (i.e.) in piped schemes get a more convenient service, as water comes under pressure. In the handpump alternative consumers exert muscle energy to draw water from the well. Kiosks offer water under pressure. A pressured supply is not considered decisive over handpump wells because only a small part of energy is needed for walking to the well and back. Rainwater storage can be equiped with a tap, but underground storage may need a handpump.

8.3 Quantity of Water

The overall consumption rate is bigger in the piped alternative, approximately 40 litres per capita per day (1982) in rural areas. For shallowwells the consumption is 37 litres per capita per day (Kefinco, 1983). It is not yet known whether extra water is worth the substantial increase in investment and operational costs. The wastage of water through open taps and leaking pipelines increase the consumption of water without any rise in service level. Rainwater harvesting will depend on storage capacity and rainfall intensity, but it is very convenient as a supplimentary source.

8.4 Quality of Water

Treated water quality in most surface water treatment plants varies widely depending on availability of chemicals. In some water supplies chlorination is not performed inspite of the dosing apparatus. This poses an apparent health risk for the consumers of water.

Proper operation and maintenance of sand filters is important for good quality water production. Quality of treated surface water is also a function of plant efficiency, operator experience and distribution system.

8.5 Reliability of Operation

In large schemes certain failures in the treatment plant or in the pumping units not to mention bursts in major transmission lines can stop the delivery of water for tens of thousands of people at a time. Diesel powered facilities are affected by lack of preventive maintenance programs and fuel, interrupting operation quite frequently (Kefinco, 1983).

Field study carried out in Nyanza Province (DHV Consulting Engineers, 1982) revealed that about 80% of the existing rural piped water supply systems were out of order. This can be noticed also in the "water supply operation charts" for the plants in other areas.

Spring protection and rainwater harvesting can only be affected by droughts which might also affect surface water sources.

With handpump wells mechanical failures are probable with certain frequency but in each case the repair can be made within one day with proper maintenance arrangement and not more than approximately 200 people are affected. Additionally, the nearest functioning handpump well will not probably be situated out of reach of the consumers because the water is produced quite evenly over the consumption area. Diesel and chemicals are not needed in the daily operation of handpumps.

8.6 Flexibility of Water Supply

The operation of each handpump well can be started immediately after it has been finished and if the water demand of certain areas turns out to be bigger than forecast, the situation can be solved by simply constructing the additional wells needed. Normally a piped scheme starts to function not earlier than two to three years after the construction has been commenced. The situation is more complicated and expensive if a piped scheme becomes underdimensioned on certain service areas.

8.7 Community Participation

The consumers are more responsible if they can accept water supplies as their "own". This will depend on how much they are involved in the programme of water supply.

It is easier to involve the community in the implementation and maintenance of handpump wells, spring protection and rainwater harvesting. At the same time local material can be fully utilized.

Although the consumers can participate in pipe laying, it is more difficult to integrate them in the construction, operation and maintenance of surface water and groundwater intake and treatment plants.

9. CONCLUSIONS

The MoWD has increased substantially the rate of design and construction of rural water supplies. An emphasis is given on construction of gravity, surface water schemes of large size with treatment works. A number of operational problems have resulted; underestimation of demand, shortage of manpower, and cumbersome procurement systems. Rivers remain the most reliable overall source of water in most scheme areas. This could be due to readily available data on river flows than other sources. An extensive programme on river pollution monitoring will have to be required. Although there is scale of economies in larger schemes, a failure will affect a wide area. Either supplimentary sources e.g. rainwater harvesting and shallow wells should be encouraged where possible or smaller schemes put up. The use of package plants should be investigated to reduce investment costs.

Considerations that govern the choice of source are availability, cost of development, and cost of operation. There is, however, greater need to choose the type of source that, when developed, will afford the greatest simplicity of operation.

The present system of operating water supplies through MoWD results in a growing burden of finance, administration, transport, procurement and staff management. Providing good quality water service is a critical element in establishing a comprehensive water supply management program.

The running costs of chemical treatment plants are very high especially "pumped supply". A good management program of a water system should revolve around the following topics:-

a) Operations - establishing staffing requirements, duties, and scheduling for office and field employees;

b) Maintenance - developing maintenance schedules and methods of control to provide for day-to-day preventive maintenanace;

c) Financial planning - the use of internal funds and capital improvement investments;

d) Planning - day to day operations and two-to-five years operations;

e) Design - reviewing and upgrading system design; (with regard to reducing chemical costs)

f) Employee relations - developing employee policies, labour relations, and job review procedures; and as far as the whole system is concerned; and

g) Consumer relations through communications.

To increase supply reliability management alternatives should be reviewed. For example:-

1) Decentralization to District or Province level

2) Parastatal organizations for District or Province to control the water scheme.

Shallow wells and spring protection programmes will speed up provision of water to rural population and are more likely to increase the awareness of the consumers.

The unit capital cost of surface water treatment is not so high (Kshs. 0.1 to over 1.5 per cubic metre), but the investment cost per capita are highest (Kshs. 13 to over 707). If other costs e.g. administrative, consultant fee, contractor charges, etc are included then the actual investment costs for treatment plants are higher. The investment costs per capita is a function of population density, and intake and treatment process structures. The operation and maintenance costs of the surface treatment are again the highest, except in a few gravity supplies with intake high up the mountain slopes (Kshs. 0.28 to over 30 per cubic metre).

A small borehole water supply with a network is estimated at Kshs 900 per capita in investment costs. This figure will vary from area to area depending on the drilling rig haulage distance and depth of borehole.

Shallow wells equiped with handpumps and spring protection are usually refered to as low technology alternative, investment cost is lowest (Kshs. 100 - 230 per capita). Also maintenance costs are low (Kshs. 10 per capita annually). Rainwater harvesting should be encouraged. Investment costs depends on the collecting and storage structure.

If the cost of network would be added to the investment it would raise these figures considerably.

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APPENDICES

APPENDIX 1

WHO GUIDELINES FOR DRINKING WATER QUALITY

H. Galal-Gorcher and G. Ozolins
Division of Environmental Health
World Health Organization

Sept. 1982.

Safeguarding drinking-water supplies is a major public health responsibility. The new guidelines provide a sound scientific basis for establishing standards with respect to health protection.

Values recommended in these guidelines are for total concentrations (i.e. all forms of substances present).

I. BACTERIOLOGICAL QUALITY

Piped Supplies	Number per 100 ml
(i) Treated water entering the distribution system	Faecal coliforms 0 Coliform organisms 0
(ii) Untreated water entering the distribution system	Faecal coliforms 0; 3 coliform organisms in any one sample, 0 in any two consecutive samples, 0 in 98% of yearly samples.
(iii) Water in the distribution system	Faecal coliforms 0; 3 coliform organisms in any one sample, 0 in any two consecutive samples, 0 in 95% of yearly samples.

Unpiped Supplies	Faecal coliforms 0 Coliform organisms 10
Bottled drinking water	Faecal coliforms 0 Coliform organisms 0
Emergency supplies of drinking water	Faecal cliforms 0 Coliform organisms 0

II. INORGANIC CONSTITUENTS OF HEALTH SIGNIFICANCE

	mg/l
Arsenic	0.05
Cadmium	0.005
Chromium	0.05
Cyanide	0.1
Fluoride	1.5
Lead	0.05
Mercury	0.001
Nitrate (as N)	10
Selenium	0.01

III. ORGANIC CONSITUENTS OF HEALTH SIGNIFICANCE

	μg/l
Benzene	10
Chlorinated Alkanes and Alkenes	
Carbon tetrachloride	3 (T $^+$)
1,2-Dichloroethane	10
1,1-Dichloroethylene	0.3
Tetrachloroethylene	10 (T+)
Trichloroethylene	30 (T+)
Chlorophenols	
Pentachlorophenol	10
2,4,6-Trichlorophenol	10 (Odour Threshold Conc 0.1 μg/l

Polynuclear Aromatic Hydrocarbons	µg/l
Benzo (a) pyrene	0.01

Trihalomethanes	
Chloroform	30

Pesticides	
Aldrin/Dieldrin	0.03
Chlordane	0.3
2,4 D	100
DDT	1
Heptachlor and Heptachlor Epoxide	0.1
Hexachlorobenzene	0.01
Lindane	3
Methoxychlor	30

$^{+}$T = Tentative Guideline Value

IV. RADIOACTIVE MATERIALS

Gross alpha activity	0.1 Bq/l
Gross beta activity	1 Bq/l

V. AESTHETIC QUALITY

	mg/l
Aluminium	0.2
Chloride	250
Copper	1.0
Hardness (as $CaCO_3$)	500
Iron	0.3
Manganese	0.1

	mg/l
Sodium	200
Sulphate	400
Total Dissolved Solids	1000
Zinc	5.0
Colour	15 True Colour Units (TCU)
Taste and Odour	Not offensive for most of the consumers
Turbidity	5 Nephelometric Turbidity Units. Preferably ≤1 for disinfection efficiency.
pH	6.5 - 8.5

APPENDIX 2

CONSTRUCTION COSTS OF SURFACE WATER INTAKE AND TREATMENT PLANT

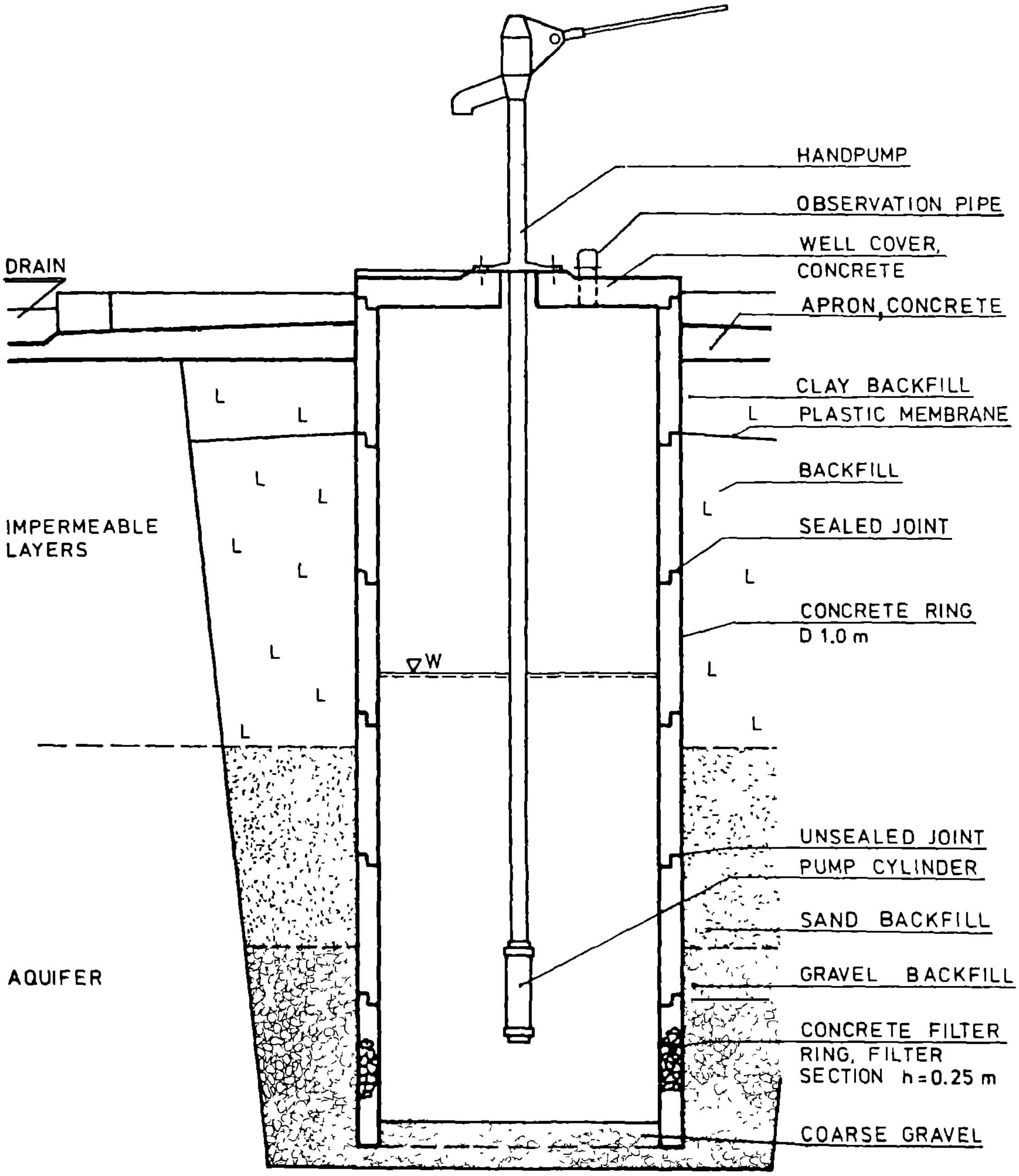
Water Supply	Price Estimate Date	Preliminary And General (Kshs)	Intake/ Raw water main (Kshs)	Treatment Plant Cost (Kshs)	Staff Houses (Kshs)
Aguthi Ph. 1	April 1980	5,386,767	4,903,943	4,335,600	539,887
Maralal I	Feb. 1981	7,923,200	1,472,962 DAM 9,184,396	8,529,904	1,137,227
Litein I	Mar. 1980	13,093,900	343,197	13,403,522	-
Chesakaki	May 1978	3,332,589	6,969,883	2,869,103	-
Murang'a II	Jan. 1978	1,164,729	72,107	2,131,909	300,294
Meru	Sept. 1975	1,462,912	307,694	773,882	-
Ndarugu I	Mar. 1974	250,200	-	874,601	29,690
Kahuti IIA	Jan. 1978	2,765,000	289,490	2,914,313	-
Isiolo I	July 1979	5,185,400	1,592,135	8,457,745	408,523
Othaya	Nov. 1976	908,500	1,233,910	236,002	-
Tigania I	April 1975	1,348,328	92,886	393,525	-
Chepkorio	July 1978	654,000	260,961	1,409,768	164,315
Mathioya I	Oct. 1980	9,065,750	994,710	7,848,675	1,214,190

APPENDIX 3

CIVIL ENGINEERING COST INDEX

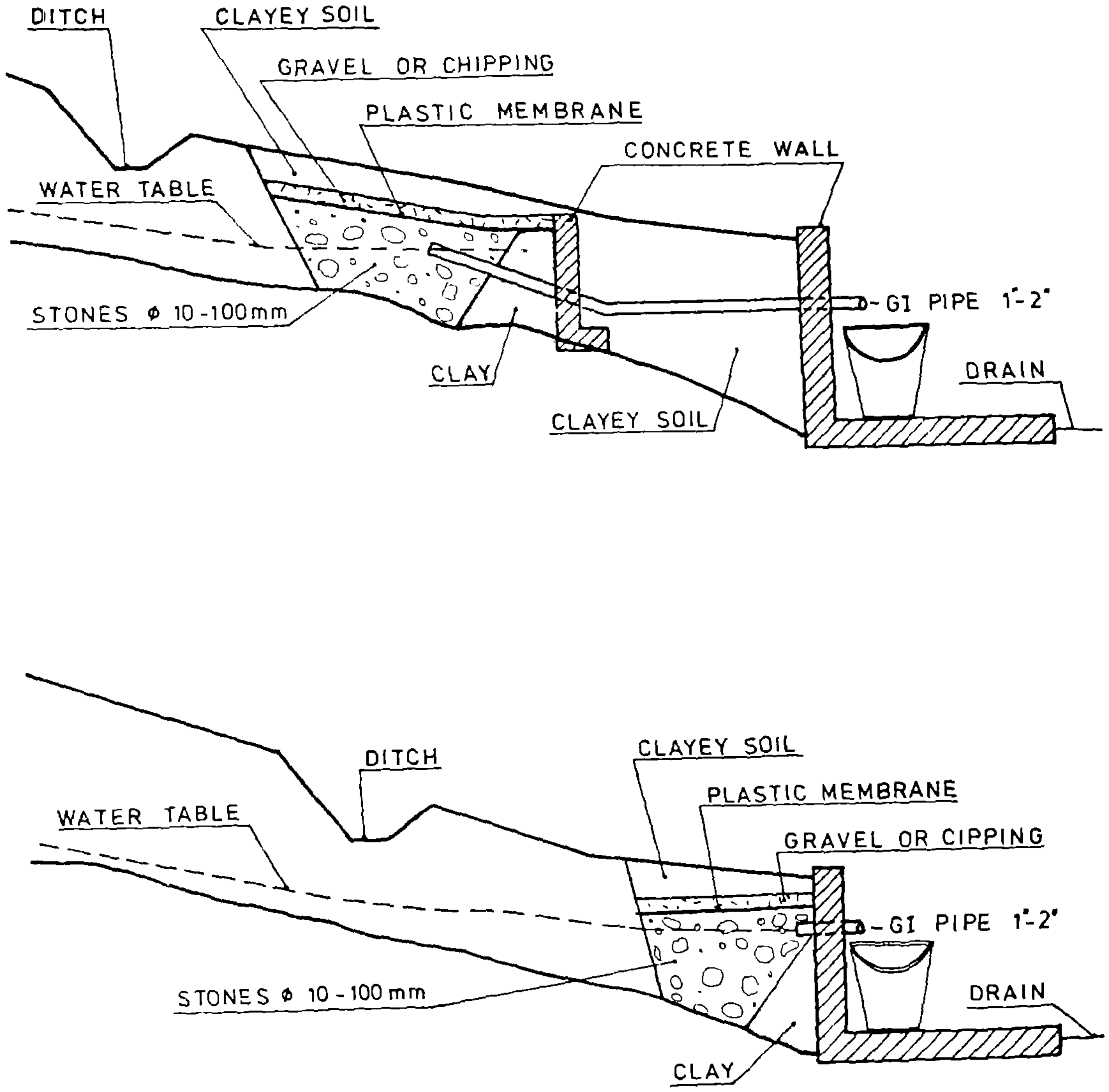
Year	Statistical Abstract	Mini-Evaluation Report, 1981
1970	-	94.5
1971	-	96.9
1972	100	100
1973	112	119
1974	144.8	157.4
1975	170.3	177.8
1976	191.7	191.8
1977	198.4	204.5
1978	210.3	216.8
1979	235.5	224.7
1980	271.5	279.9
1981	299.4	335
1982	-	386
1983	-	433
1984	-	476

APPENDIX 4



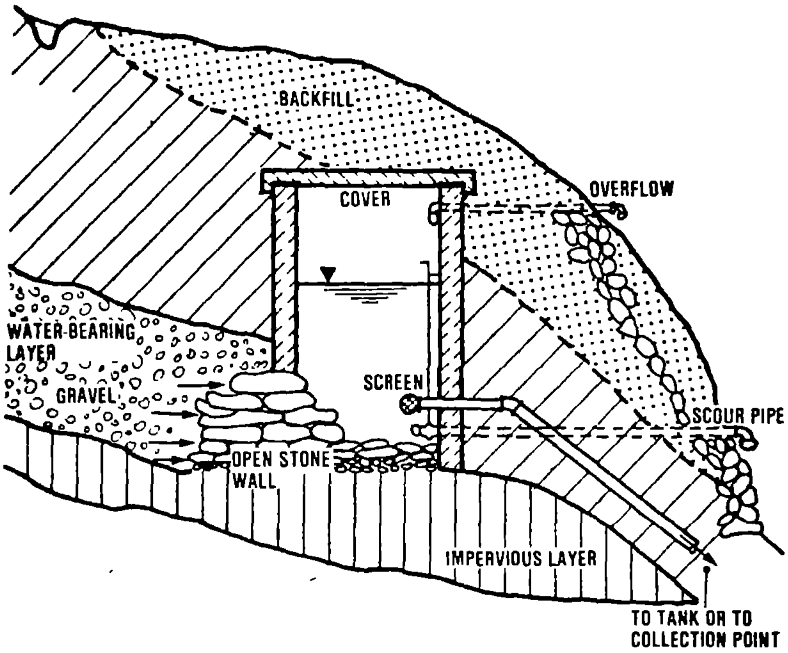
SHALLOW WELL LINED WITH CONCRETE RINGS

APPENDIX 5



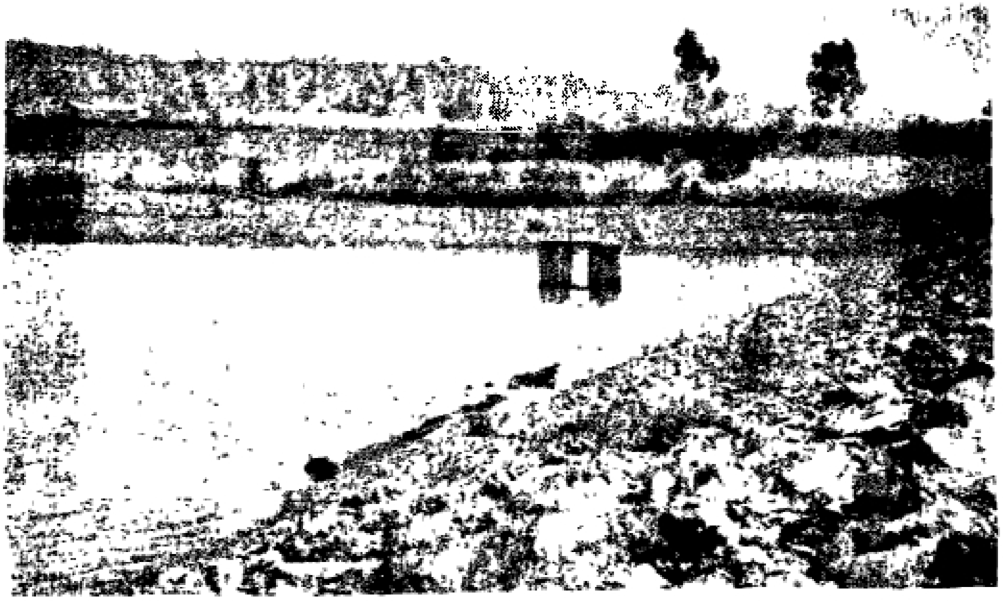
SPRING PROTECTION

APPENDIX 6

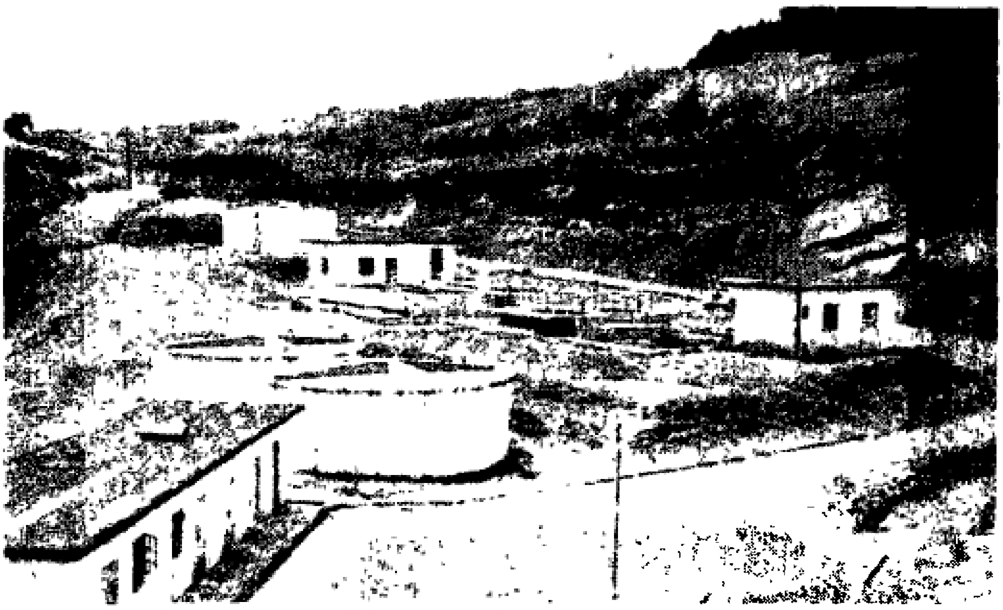


Spring Water Storage Chamber ('spring box')

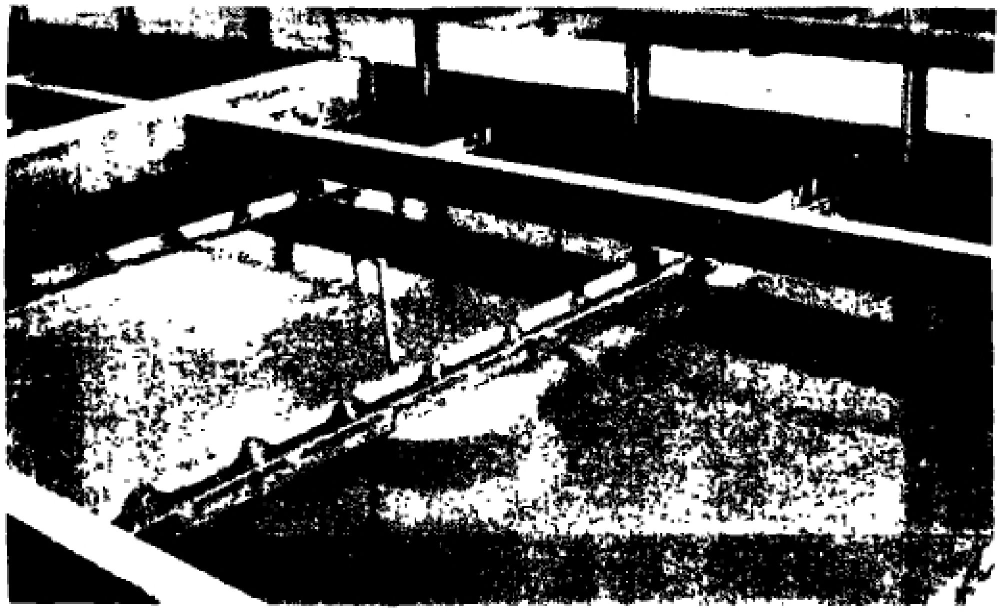
APPENDIX 7



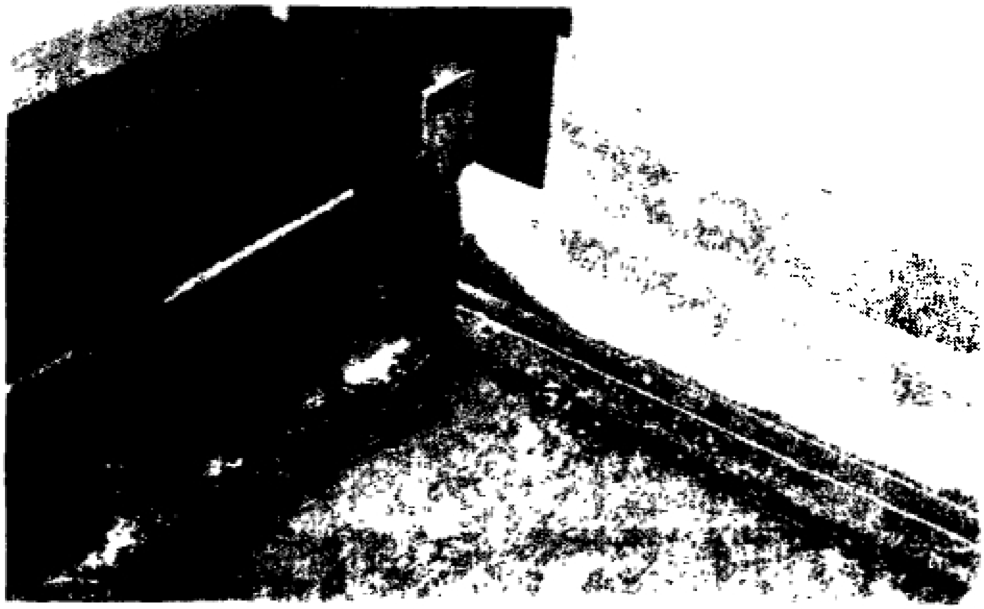
Bathi rural water supply reservoir with submerged intake. Dams are expensive.



Bathi rural water supply treatment works.
Raw water tanks in the background with the dosing house next to it. Vertical flow flocculation and sedimentation basin and rapid sand filter are in the middle. The office is on the right. In the foreground are two treated water tanks and raw water pumping unit in the lower left corner. Distribution is by gravity.

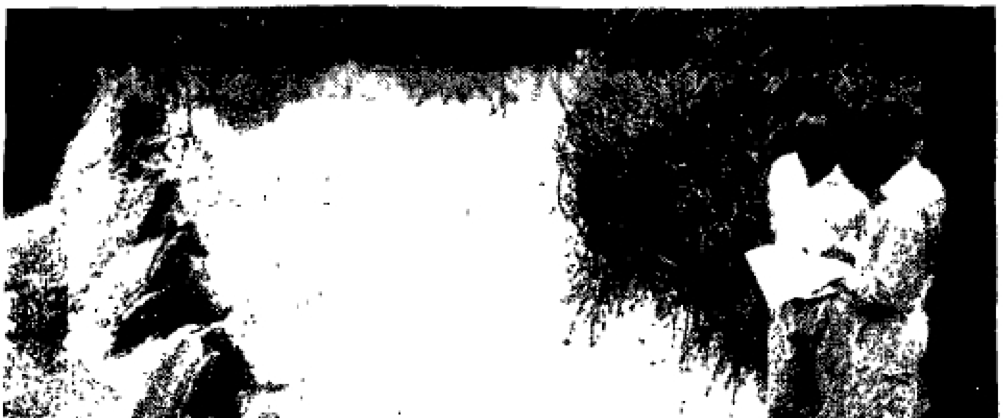


Bathi rural water supply.
Vertical flow sedimentation basins.

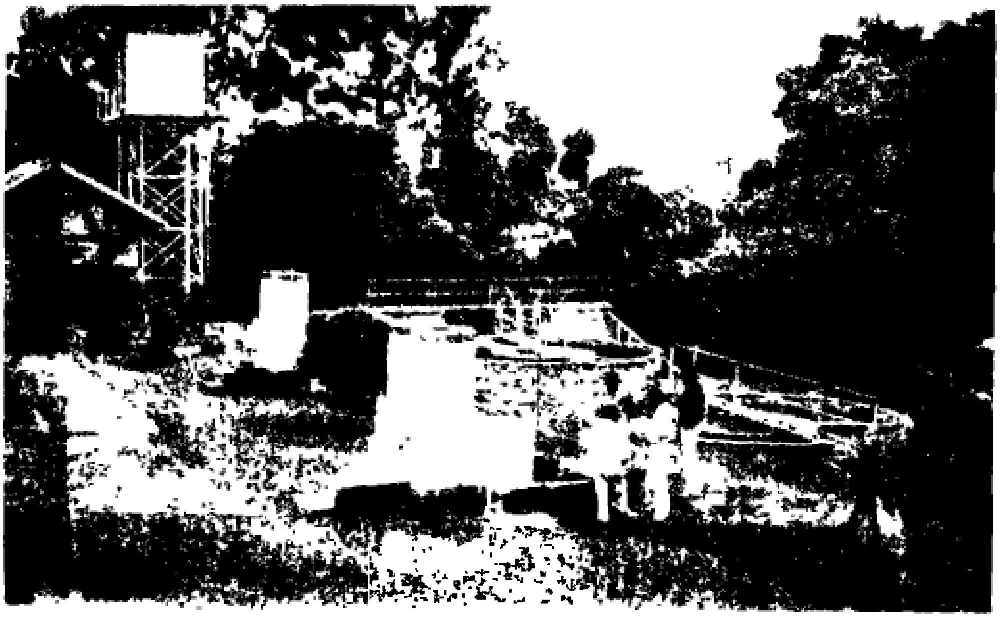


Bathi rural water supply.
Rapid sand filter unit.

Borehole water intake at Gatundu town. A pump house. Chlorination unit not in use. At this point. Borehole water is mixed with treated surface water.



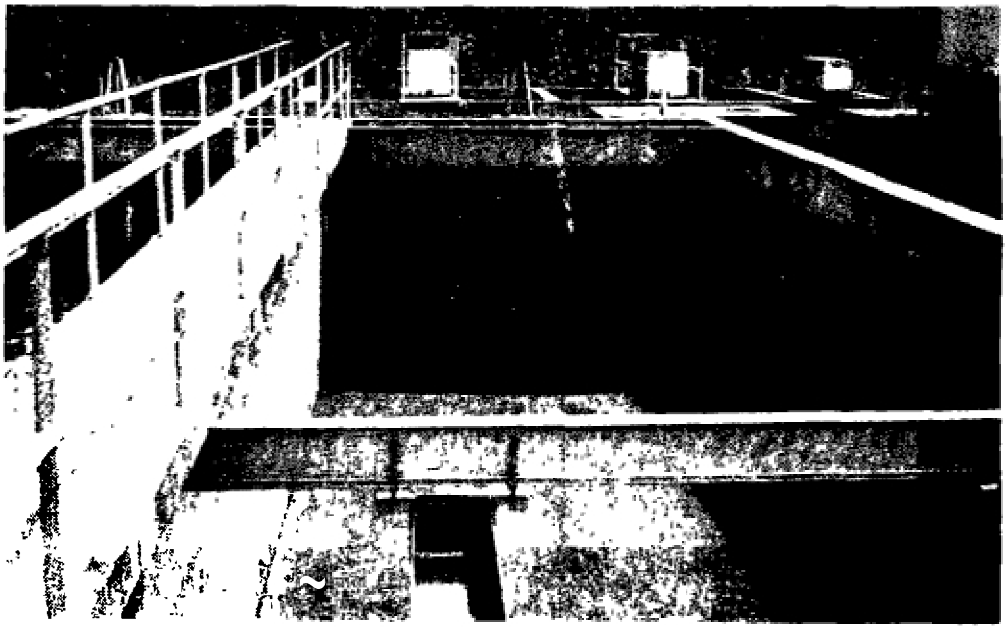
Ruiru town water supply.
A weir intake.



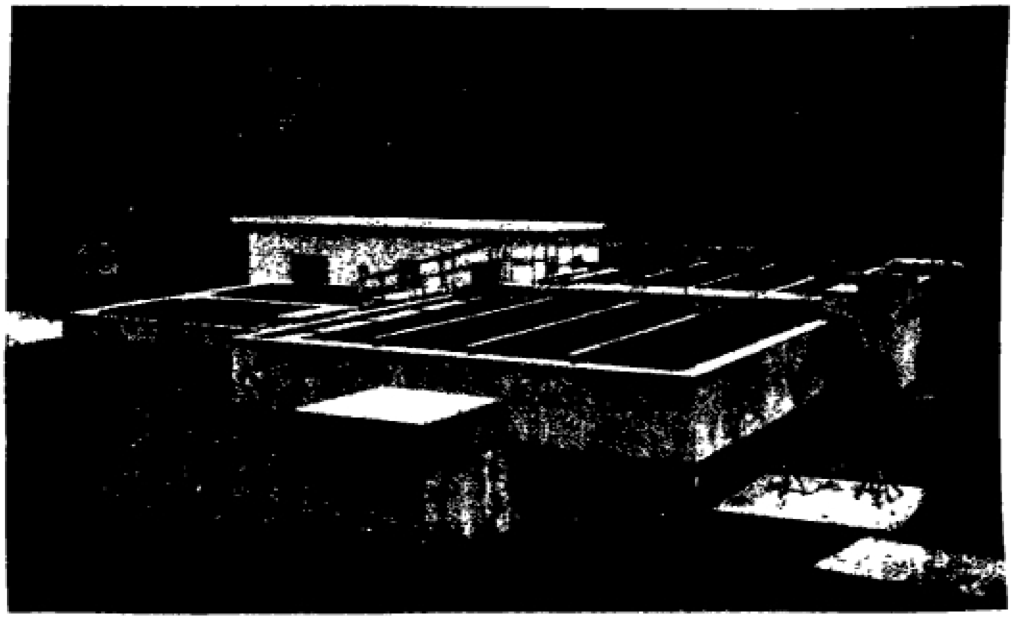
Ruiru town water supply.
Filter backwash water tank left. Alum mixing and dosing units in the middle,circular horizontal settling basins are used.

Ruiru town water supply.
Settling tank bottom.

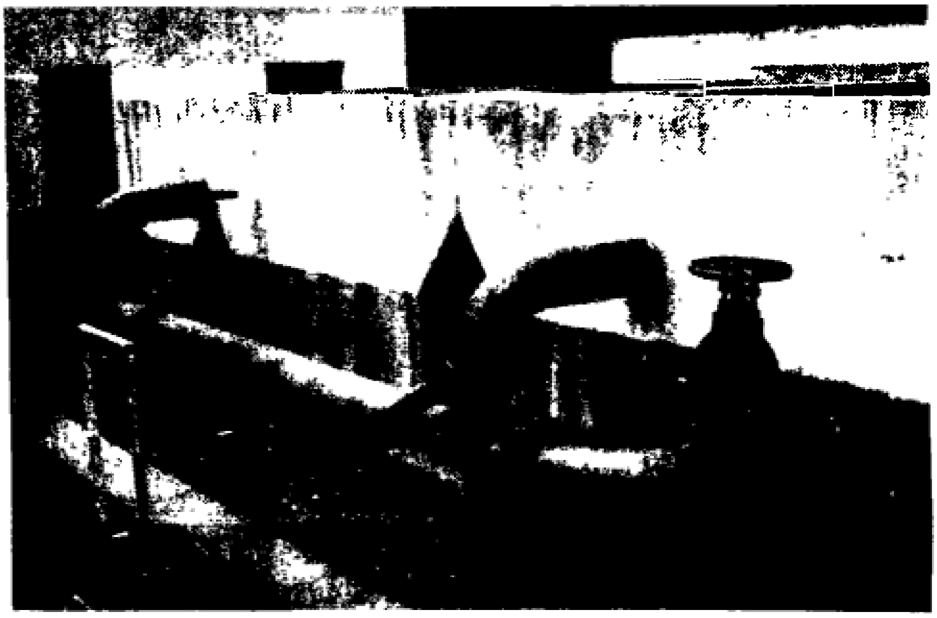
Ruiru town water supply. Soda ash addition and chlorination after filtration.



Kahuti II A water supply. Sedimentation basin inlet.

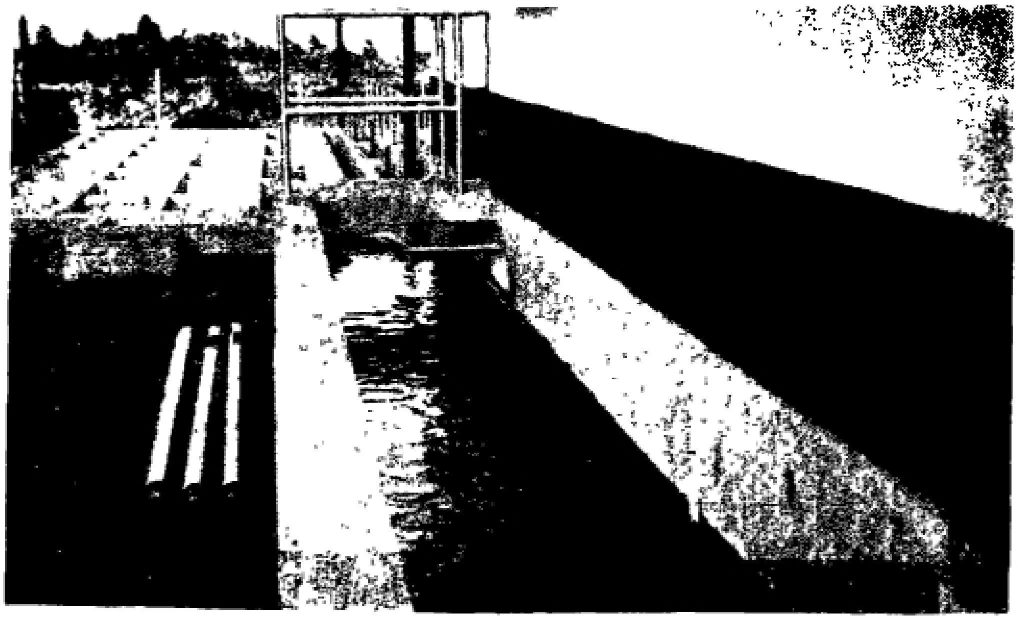


Tetu-Thegenge water supply.



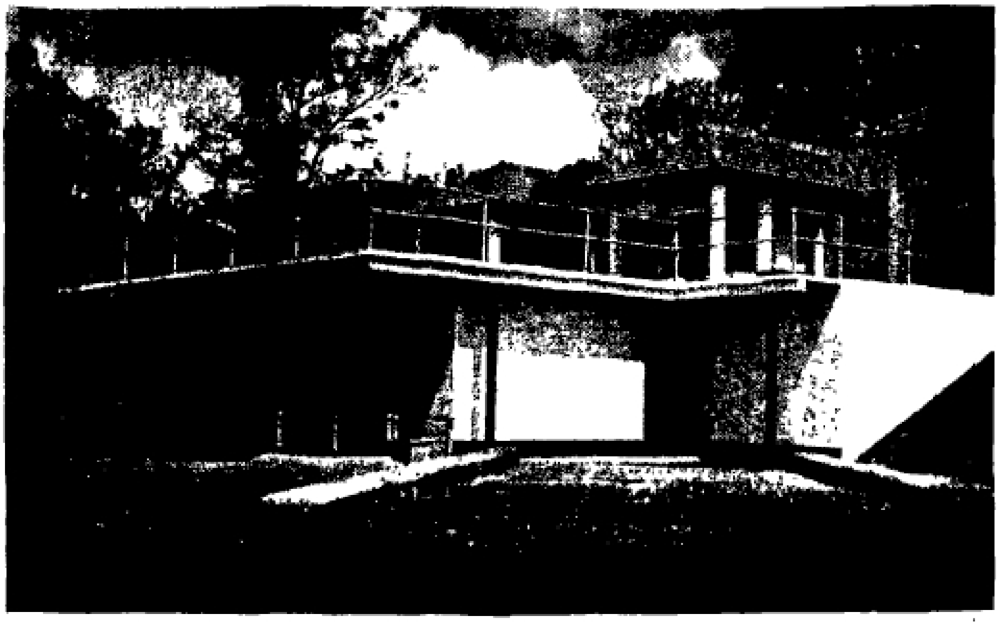
Tetu-Thegence water supply.
Sand filters.

Aguthi water supply dosing point.



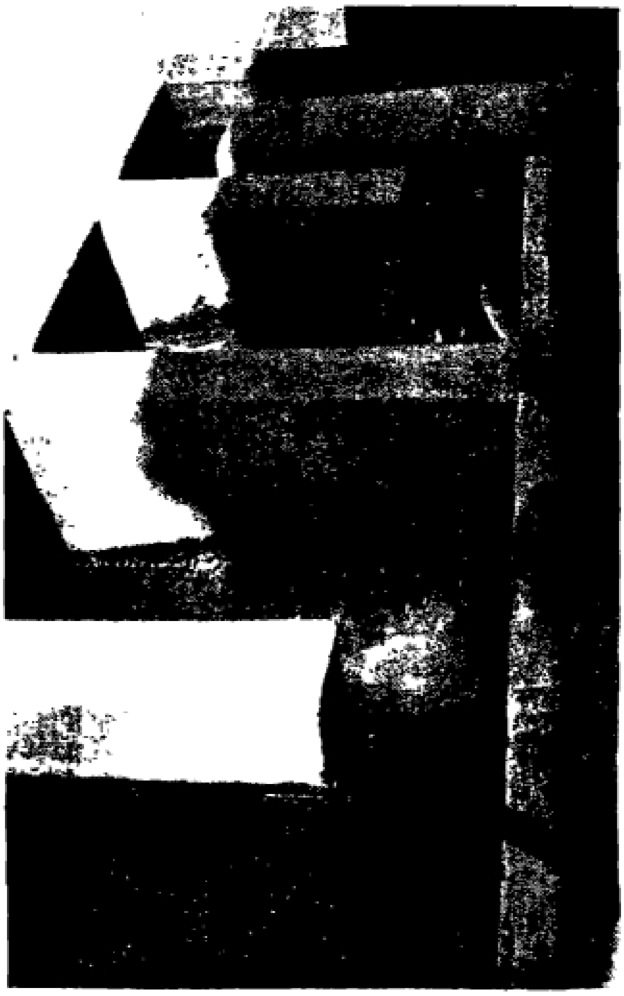
Aguthi water supply.
Hydraulic coagulation channel and baffle walls flocculation.

Machakos water supply reservoir.
Water intake is by siphoning so a pump is used at one time.

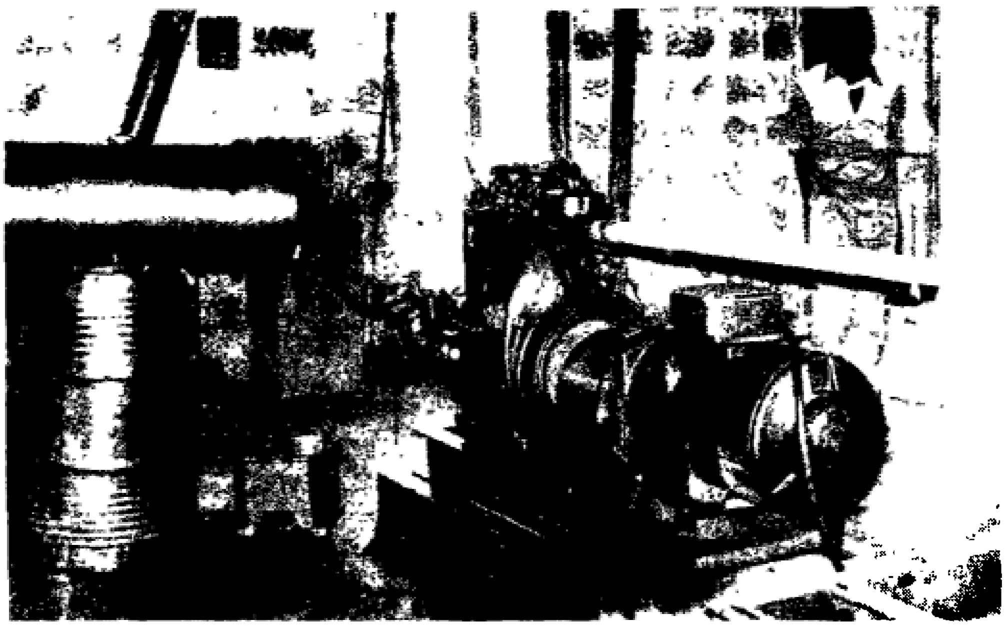


Machakos water treatment plant.
Compact and suits the environment.

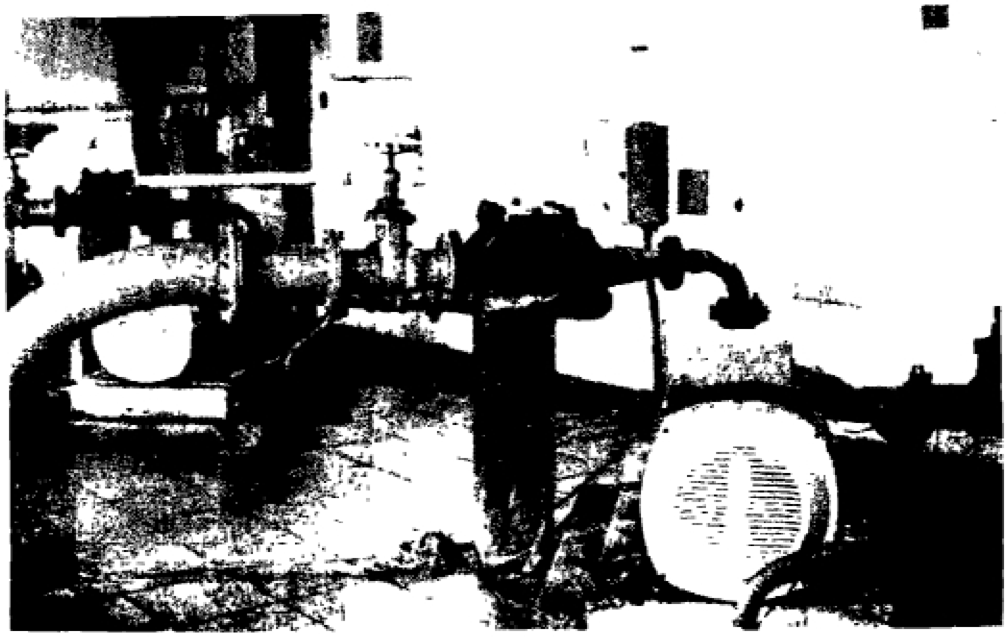
Free flow dosing unit
at Machakos water works.



Machakos water works
proper point alum
dosing.



Electirc pump set at Muranga II town water supply.



One of borehole water intake pump units at Kitui town.