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REPUBLIC OF KENYA

MINISTRY OF WATER DEVELOPMENT

THE STUDY

ON

THE NATIONAL WATER MASTER PLAN

SECTORAL REPORT
(C)

GROUNDWATER RESOURCES

JULY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

Interpretation of Report

The original objective of this NWMP Study is to propose a nationwide framework for orderly planning and development of water resources in the country. The Study also deals with the formulation of individual development schemes. However, it should be noted that the plans formulated in this Study remain at a national level and do not provide complete details at local level. Further details should be examined in subsequent studies on each river basin, district, and project basis which are separately recommended in this Study.

Administrative Division of Districts

In this Study, the original 41 districts were considered and various statistical data, particularly socio-economic information, were collected for these districts. During the progress of the Study, six districts were detached from the original ones and established as new districts. In the report, the data on these new districts are grouped together with the corresponding original districts as shown below.

	Original Districts	New Districts	Data included in:
1.	Machakos	Makueni	Machakos/Makueni
2.	Kisii	Nyamira	Kisii/Nyamira
3.	Kakamega	Vihiga	Kakamega/Vihiga
4.	Meru	Tharaka-Nithi	Meru/Tharaka-Nithi
5.	Kericho	Bomet	Kericho/Bomet
6.	South Nyanza	Migori	South Nyanza/Migori

(Note: The last three Districts were established very recently.
The report refers only to the names of the original 41 districts.)

The administrative boundary map used in this Study is the latest complete map set covering the whole country (41 Districts, 233 Divisions and 976 Locations), prepared in 1986 by the Survey of Kenya, Ministry of Land, Housing and Physical Planning.

Data and Information

The data and information contained in the report represent those collected in the 1990-1991 period from various documents and reports made available mostly from central government offices in Nairobi and/or those analyzed in this Study based on the collected data. Some of them may be different from those kept in files at some agencies and regional offices. Such discrepancies if any should be collated and adjusted as required in further detailed studies of the relevant development projects.

Development Cost

The cost and benefit estimate was based on the 1991 price level, and expressed in US$ equivalent according to the exchange rate of US$1 = KShs25.2 prevailing at that time. The same exchange rate was used in calculating the development cost in K£/KShs currency.

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SECTORAL REPORT (C)
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LIST OF SYMBOLES USED

E	:	Abbreviation of exponent. for example, 1.05E-1 equals 1.05×10^{-1}
Q	:	Pumping rate [m^3/sec]
r	:	Distance (Diameter) from the pumping well [m]
s	:	Drawdown [m]
s_o	:	Final drawdown [m]
s_r	:	Recovery [m]
s'	:	Residual drawdown (= s_o - s_r) [m]
S	:	Storage coefficient
t	:	Time since pumping started (= t_o + t') [sec]
t_o	:	Time when pumping stopped [sec]
t'	:	Time since pumping stopped [sec]
T	:	Transmissivity [m^2/sec]
W	:	Well function

C1. INTRODUCTION

In this master plan, the groundwater study aims at : (1) describing the present conditions of groundwater, (2) evaluating groundwater potential, and (3) formulating groundwater development plans for future water demands.

1.1 Scope

The scope of this study is to :

1) describe and evaluate groundwater resources in Kenya
2) identify the present condition of groundwater use
3) make databases for data management and groundwater management
4) develop an implementation strategy for low cost groundwater development
5) formulate groundwater development plan
6) propose promising projects
7) prepare recommendations for groundwater development and management policy

1.2 Contents of the report

The contents of this report are as follows :

Chapter 1 comprises an introduction of this report.

Chapter 2 covers physical environment in Kenya.

Chapter 3 describes present condition of groundwater use and groundwater resources evaluation for development

Chapter 4 describes groundwater source development, geographical distribution of development needs and groundwater development plan

Chapter 5 evaluates development cost and cost of operation and maintenance and also analyses cost effectiveness of six (6) types of systems

Chapter 6 prepares recommendations for groundwater development and management policy

C2. PHYSICAL ENVIRONMENT

2.1 Location

The Republic of Kenya is located within the eastern side of the African continent. It is bordered on the southeast by the Indian Ocean, which serves the Republic as an important outlet and means of international maritime contact (Ref. C.13). It shares international boundaries with former East African Community neighbours, the Republic of Uganda in the west, the United Republic of Tanzania in the south, and is also bordered by Ethiopia in the north, the Republic of Sudan in the northwest, and the Republic of Somalia in the east.

The Republic of Kenya lies approximately between latitudes 5°20'N and 4°40'S; and between longitudes 33°50'E and 41°45'E. It is almost bisected both by the Equator and by latitude 38°E. It covers an area of about 592,000 km^2 with a water surface of some 11,230 km^2 (2%).

Kenya is divided into eight (8) provincial and forty-one (41) district units for both administrative and industrial census purposes.

The latitudial location of Kenya along the equator and the greatly varied surface configuration ranging from sea level to heights over 5,500 m above sea level combine to create a physical environment varying from almost equatorial characteristics to polarial ones in highlands.

2.2 Physiography

The relief of Kenya can be described as being both simple and diversified (Ref. C.13). The country's topography is fairly simple; two distinct physical regions, the lowland and upland. The lowland is largely a low potential environment, while the upland must be viewed as the backbone of the country.

Kenya is also characterized by the most complicated and diversified physical environments. Various landform and landscape types, for example, equatorial, tropical, savannal, aeolian, glacial, volcanic, tectonic, etc, are present in Kenya (Figure C2.1).

Kenya's structural geology is dominated by a gentle dome-shaped asymmetrical shield. The land rises very gently westwards from the east until about 3000 feet (915 m) above sea level. Above the height, the climb to the west becomes steeper and a more obvious obstacle to transportation routes as the true upland environment is reckoned with (Figure C2.1). Although the various features of the country have different origins, generally the entire terrain is dominated by a succession of extensive well-preserved plateaus at different heights. The height of these plateaus and their apparent similarity in form can be used as a rational basis for dividing the country into eight (8) physiographic units (Figure C2.2):

1) Coastal Belt and Plains

2) Duruma - Wajir Low Belt
3) Low Foreland Plateau
4) Kenya Highlands (Western and Eastern Highlands)
5) Kenya Rift Valley
6) Nyanza Low Plateau
7) Nyanza Lowlands
8) Northern Plainland

The present drainage pattern is fairly simple because the pattern has been influenced to a large extent by the Kenya Highlands. The main rivers drain radially either from the central highlands or from the southern foothills of the Ethiopian Highlands. Generally, the main rivers drain towards the east to the Indian Ocean, others have internal drainage into the lakes of the Rift Valley, while the rest drain into Lake Victoria. The country is divided into five (5) drainage units as shown in Figure C2.3 and the following table :

Drainage basin units of Kenya

Drainage basin	Code	Area (km^2)	%
Lake Victoria	1	46,229	8.0
Rift Valley	2	130,452	22.5
Athi River	3	66,837	11.5
Tana River	4	126,026	21.7
Ewaso N'giro	5	210,226	36.3
Total		579,770	100.0

Lake Victoria basin contributes the largest volume of runoff although Ewaso N'giro and North basin has the largest area.

2.3 Climate

The main factors which control the climate are latitude, altitude, topography, character of prevailing winds and the distance from the sea or from any sizeable water body. The pressure belts are also important.

Kenya strides across the equator and has a geographical diversity (Ref. C.13). The climate conditions are controlled, therefore, by its location and the wind system of Inter-Tropical Convergence Zone (ITCZ).

Kenya is dominated particularly by the following three (3) distinct air masses.

1) From about April until about August, the southeast monsoon persists more or less with the same vigour and consistency. The monsoon brings the source of the main rains in Kenya from the Indian Ocean.

2) From July to October, the Congo airstream brings unstable and convectional storms and dominates the western parts of Kenya.

3) During the months from November to March, very dry winds from Sahara Desert which is called the harmattan dominate the western part of the country. In the eastern parts of the country, the north-east monsoon brings some rains to the coastal lands.

The distribution of monthly rainfall at the representative rainfall gauging stations is shown in Figure C2.4 (same as Figure B2.3 of Sectoral Report B). In the western and central parts of the country, especially in Lake Victoria basin, there is no distinct dry season but with double maxima in April and August. The coastal area shows a remarkable single maximum in May. The annual mean rainfall was estimated at 621 mm in Kenya (Figure C2.5, same as Figure B2.4 of Sectoral Report B)

2.4 Geology

Water availability and water quality depend on the geology and geography of the area. All the four major geologic areas (Precambrian-Cenozoic) are represented in the complex geologic column of Kenya (Ref. C.10). Table C2.1 shows the stratigraphical divisions of major rocks and respective major earth movements. The lower portion of the column of the classical Rift Valley system is represented by volcanics as well as igneous and metamorphic complexes divided into four major systems which are mostly Pre-cambrian. The Palaeozoic is well developed in the northeast and southeast. The Cainozoic is well developed and mostly important in terms of surface coverage and is represented by sedimentary and volcanic rocks of Tertiary and Quaternary. Tables C2.2 and C2.3 represent Palaezoic-Mesozoic succession of sediments and Cainozoic succession in Kenya, respectively. Table C2.5 shows the chronology of volcanic eruptions in Kenya. Tables C2.4 and C2.6 represent Quaternary sediments in northeast Kenya and a correlated sequence of events along the Kenya coast, respectively.

The present major faults certainly seem to be younger if the freshness of their scarps is judged. The earliest fault probably appeared in late Miocene, and another phase of major faulting is known to have occurred in Pliocene and Quaternary times.

2.5 Vegetation and Surface Cover

The range of climatic condition is reflected in six (6) ecological zones (Ref. C.13).

1) The Alpine moorlands and grasslands zone at high altitudes above forest line
2) The humid to dry sub-humid climatic belt suitable for forestry and intensive agriculture
3) The humid to dry sub-humid climatic belt suitable for agriculture where soils and topography permit
4) The semi-arid zone (rangeland with marginal agricultural potential and potentially productive land)
5) The arid zone (rangeland of low potential with a very dry form of bushed grassland)

The arid and semi-arid lands (ASAL) areas cover 83% of the land area of Kenya. These areas are distributed among 22 districts.

C3. GROUNDWATER RESOURCES EVALUATION

There are two types of groundwater aquifers. An unconfined aquifer is one which the water surface is free and the groundwater pressure is equal to atmospheric pressure. A confined aquifer is one where the water bearing layer is covered by an impermeable confining layer. The water in the aquifer is under pressure over atmospheric pressure. The pressure is released, when the confining layer is punctured and the water level rises to the piezometric level which is determined by the pressure condition present in the aquifer.

3.1 Existing Borehole Data and New Database

3.1.1 Existing borehole data

Boreholes have been drilled by government departments, corporations and related institutions, private firms and by individuals. Borehole drilling is preceded by the following procedure:

a) A letter of request for drilling in the case of government departments or related in situation,

b) Completion of either Forms WAB245 and WAB26 or Forms 245B and WAB29, depending on the location of the project,

c) Investigation and recommendation of the drilling by MOWD,

d) Authorization for the filling by Water Appointment Board within MOWD. when a borehole has been drilled, it is assigned a serial number, listed and plotted on a base map. Borehole data are filed in both Groundwater and Drilling Sections of MOWD.

Registered completion records received by March 1991 accounted for 9462 boreholes. The Water Act provides that certain data should be submitted within one month of the completion of a borehole. The standard form (WAB.28) should include information on location, ownership, purpose of use, date of construction, well dimension, property of aquifer, pumping test data, water potability, monitoring frequency of water level, rock type, initial yield, and casing installation.

Step-drawdown pumping tests and a recovery test have been generally conducted for a drilled borehole, but a constant-discharge pumping test has rarely been carried out for the drilled boreholes in Kenya. Therefore, transmissivity and storage coefficient values have seldom been analyzed. Recovery test data can be analyzed, only when pre-pumping is done at a constant rate, to estimate hydraulics of aquifers and drawdown of wells. These recovery test data, however, have not been estimated and analyzed. The existing recovery test data matches the above-mentioned condition shown in Databook (D.3). Transmissivity and storage coefficient were calculated as shown in Databook (D.3).

Groundwater is extremely variable in chemical composition and this variation occurs both spatially and seasonally. Only 1435 of all registered boreholes have water quality data as shown in Databook (D.3). Water quality analyses have been conducted by the Water Laboratory of MOWD (Table C3.1) and other agencies for geochemical interpretation and classification of potability. Cassification of potability should include water temperature, electric conductivity, PH, total dissolved solids (TDS), total hardness, colour, turbidity, permanganate No., chloride (Cl), Nitrite (NO_2), Nitrate (NO_3), Iron (Fe), Manganese (Mn), Fluoride (F), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Bicarbonate (HCO_3), Sulphate (SO_4), Silica (SiO_2), Carbonate (CO_3), e.t.c.

The major uses of boreholes are public water supply, agricultural, domestic and industrial, and livestock in order as shown in the following table. Observation and exploratory boreholes are included in spite of their small portion. About half of the boreholes have no information available ("Unknown" and "Undescribed" in table below). Most of those are supposed to of public water supply and/or livestock uses, particularly for those in ASAL area.

Number of boreholes by use.

Borehole use	No. of boreholes	Percentage (%)
Public water supply	2137	22.6
Agricultural	948	10.0
Domestic	434	4.6
Industrial and commercial	224	2.4
Livestock	177	1.9
Observation	62	0.6
Exploratory	52	0.5
Other	973	10.3
Unknown	2496	26.4
Undescribed	1959	20.7
Total	9462	100.0

Rock type remarkably affects aquifer characteristics. The country is considered to consist of three major rock types, that is, volcanic, metamorphic basement, and sedimentary rocks. The number of boreholes in each rock type are shown in the following table.

Number of boreholes by rock type

Rock type	No of boreholes	Percentage (%)
Volcanics	3882	41.0
Basements	1592	16.8
Sediments	878	9.3
Volcanics over basements	162	1.7
Sediments over basements	67	0.7
Sediments over volcanics	72	0.8
Volcanics over sediments	52	0.6
Other	20	0.2
Unknown	255	2.7
Undescribed	2482	26.2
Total	9462	100.0

Groundwater abstractions have seldom been investigated in Kenya except in two studies (Chilton, 1970; Swarzenki & Mundorff, 1977) regarding a rather small part of the country for one or two years. The completion borehole record demands information on initial yield for all boreholes, but annual or seasonal values of actual groundwater abstraction have not been investigated nationwide.

Annual and seasonal small groundwater levels have seldom been measured nationwide. The completion borehole record demands information on struck and rest water levels for all boreholes and initial water levels are available nationwide.

3.1.2 New database

(1) Borehole database

Borehole data prior to 1985 for the whole country are stored on the Wang VS-15 computer at the Ministry of Water Development. In the National Water Master Plan Study, borehole data after 1986 were inputted and stored on the new database system, a Vax station and Macintosh computers, for data management.

Information for each borehole is stored according to 31 codes (Table C3.2):

- Borehole reference number
- Location (district code; longitude; latitude; elevation)
- Name of owner
- Purpose of well use
- Date of construction
- Status of the borehole
- Well dimension (depth; casing diameter; length and type; screen length)
- Aquifer (rock type; rest and struck water levels)
- Pumping test (discharge; drawdown; pumping hours; recovery hours)

- Potability
- Monitoring frequency of water level

The coding of these parameters is described in detail in Table C3.3.

The most relevant data are stored on the computer. The chemical properties are only indicated as a potability code. The logging data are expressed as a rock type code. The completion borehole record demands information on initial yield and water levels for all boreholes, but monitoring of groundwater abstraction and water levels have seldom been carried out and data of groundwater abstraction and water levels are not stored on the computer.

(2) Groundwater quality database

Water quality data stored in the MOWD were compiled as shown in Databook 3 and a database of water quality was newly prepared under this study and stored on the Vax station and Macintosh computers for data management. The following chemical parameters are included in the database : water temperature, electric conductivity, pH, total dissolved solids, total hardness, colour, turbidity, permanganate no., chloride, nitrite, nitrate, iron, manganese, fluoride, sodium, potassium, calcium, magnesium, bicarbonate, sulphate, silica, carbonate, etc. as shown in Table C3.4 .

3.2 Basic Characteristics of Groundwater

3.2.1 Use of boreholes

Aquifer tests and well surveys were carried out to obtain supplemental information on existing boreholes and confirm the present condition of aquifers. On a local contract basis, 45 and 594 boreholes were investigated for aquifer tests and well surveys, respectively. The field work was completed in the middle of February 1991. Figure C3.1 shows the location of boreholes served for the well survey.

The results of the well survey show the following condition of pump operation :

Condition of pump operation

	Hourly (hours)	weekly (days)	Annually (days)
Average	12.02	6.57	341.81
Minimum	0.42	1	48
Maximum	24	7	365
Number of data	300	330	331

The groundwater abstraction was seldom observed in Kenya except for two reports (Chilton, 1970 ; Swarzenski & Mundorff, 1977). Both reports refer to a rather small part of the country for one or two years. Chilton estimated an annual ratio of 15.3 %, a ratio of annual production to the sum of initial yield of all boreholes in Nairobi.

An utilization ratio, a ratio of annual production to the sum of initial yield of boreholes completed and in use except for boreholes abandoned and unknown, was estimated to be 0.48 based on the results of well surveys as shown in Table C3.5. The utilization ratio was calculated for data of 114 boreholes obtained in the well surveys.

If the ratio, a ratio of production to the sum of initial yield of all boreholes including abandoned and unknown boreholes, would be estimated from the data of the well surveys carried out during the NWMP study, the ratio is calculated to be 22.6 %.

The present groundwater abstraction rates by drainage basin are estimated using the above-mentioned ratio (Table C3.6 and Figure C3.2). The total present groundwater abstraction rate in Kenya is estimated at 57.21 million m^3/year, which is equivalent to about 1.5 times of the value estimated by TAMS in 1980. The following table shows the present groundwater abstraction rates by major drainage basin :

Estimated present groundwater abstraction rates by basin

Drainage basin	Basin area (km2)	Annual rainfall (mm/year)	Rainfall (million m^3/year)	Abstraction (million m^3/year)
1 Lake Victoria	46,229	1,368	63,241	9.34
2 Rift Valley	130,452	562	73,314	11.67
3 Athi River	66,837	739	49,393	27.76
4 Tana River	126,026	697	87,840	4.79
5 Ewaso N'giro	210,226	411	86,403	3.65
Total	579,770	621 (*)	360,191	57.21

Note (*) weighted average

In terms of the groundwater abstraction rate, the major uses of boreholes in the country are agricultural, public water supply, and domestic as shown in the following table.

Estimated present abstraction rates by use

Use of boreholes	Abstraction (million m^3/year)
Agricultural	11.75
Public water supply	11.13
Domestic	3.46
Irrigation	2.08
Livestock	1.07
Exploratory	0.10
Observation	0.08
Others	7.89
Unknown	19.65
Total	57.21

It is noted that the above result represents an approximate estimate based on a limited number of sampling by the well survey carried out during the NWMP study.

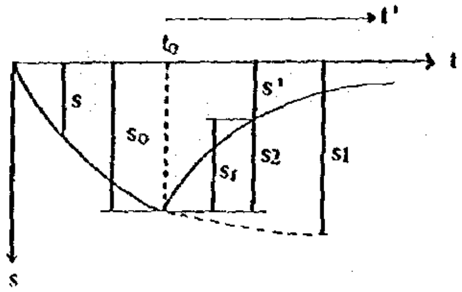
3.2.2 Drawdown Analyses of Recovery Test Data

Recovery test data can be analyzed, only when the pre-pumping is done at a constant rate, to estimate hydraulics of aquifers and drawdown of wells (Ref. C.3).

(1) Recovery test as an important part of the aquifer test

When pumping is stopped, water level of well and aquifer rise towards their initial or rest levels. The time - drawdown measurements taken during the constant - rate pumping period and the time - recovery measurements taken during the recovery period provide two different sets of information from a single aquifer test.

During the recovery period, water level measurements can be made without being affected by pump vibrations and momentary variations in pumping rate. The time - recovery data for the pumped well are more accurate than the time - drawdown data of the constant - rate pumping test.



s_0	:	Final drawdown [m]
s_r	:	Recovery [m]
s'	:	Residual drawdown (= s_0 - s_r) [m]
t_0	:	Time when pumping stopped [sec]
t'	:	Time since pumping stopped [sec]
t	:	Time since pumping started (= t_0 + t') [sec]
r	:	distance from the pumping well [m]

The residual drawdown at any time during the recovery period is the difference between s_1 and s_2.

$$s' = s_1 - s_2 = \frac{Q}{4\pi T} W(u) - \frac{Q}{4\pi T} W(u') \qquad \text{(1)}$$

$$u = \frac{S}{4T}\left(\frac{r^2}{t}\right), \quad u' = \frac{S}{4T}\left(\frac{r^2}{t'}\right) \qquad \text{(2)}$$

Q	:	Pumping rate [m³/sec]
W	:	Well function
T	:	Transmissivity [m²/sec]
S	:	Storage coefficient

When the value of u in equation of the well function is less than 0.01, that is, when r^2/t becomes very small, an approximation method developed by Cooper and Jacob permits a solution. Therefore, equation (1) is approximated by

$$s' = \frac{Q}{4\pi T} \{(-0.5772 - \log_e u) - (-0.5772 - \log_e u')\}$$
$$= \frac{Q}{4\pi T}\left\{\log_e \frac{4T}{S}\left(\frac{t}{r^2}\right) - \log_e \frac{4T}{S}\left(\frac{t'}{r^2}\right)\right\}$$
$$= \frac{2.303Q}{4\pi T} \log \frac{t}{t'} \qquad \text{(3)}$$

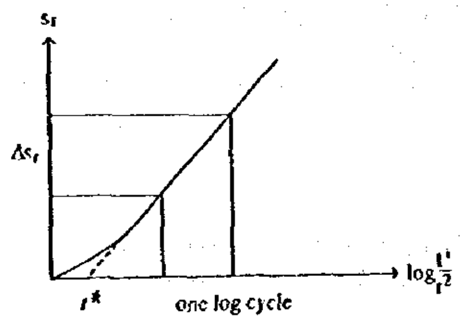
Similarly, the residual drawdown at any time during the recovery period is the difference between s_0 and s_r.

$$
\begin{aligned}
s_r &= s_o - s' \\
&= \frac{Q}{4\pi T} W(u_o) - \frac{Q}{4\pi T} W(u') \\
&= \frac{2.303Q}{4\pi T}\left(\log\frac{2.25Tt_o}{Sr^2} - \log\frac{t}{t'}\right) \\
&= \frac{2.303Q}{4\pi T}\left(\log\frac{t'}{r^2} - \log\frac{S}{2.25T} - \log\frac{t_o}{t' + t_o}\right)
\end{aligned}
\qquad \text{(4)}
$$

The value of $\log t_o/(t' + t_o)$ should be zero when the pumping period is large. Therefore, equation (4) is

$$
s_r = \frac{2.303Q}{4\pi T}\left(\log\frac{t'}{r^2} - \log\frac{S}{2.25T}\right) \qquad \text{(5)}
$$

When t' becomes large, the plot of observed data falls on a straight line as shown in the following Figure.



The value of t'/r^2 is usually chosen over one log cycle so that equation (5) becomes:

$$
T = \frac{2.303Q}{4\pi\Delta s_r} \qquad \text{(6)}
$$

Storage coefficient is determined by projecting the straight line to the zero residual drawdown intercept which defines $\log t'/r^2$.

$$
S = 2.25\,T \log\frac{t'}{r^2} \qquad \text{(7)}
$$

(2) Drawdown analyses

Water levels of well and aquifer drawdown towards their levels after starting a pump. Drawdown of the pumping water levels depends on aquifer property and production rate. Boreholes should be designed in order to avoid drawdown of the pumping water level into the top of the pump above the screened part of the boreholes. Average struck and rest water levels in Kenya are 77.2 and 40 m, respectively.

The data of existing recovery tests and recovery tests obtained in the field surveys of NWMP were analyzed and drawdown analyses were carried out for 927 boreholes as shown in Table C3.7. The results of the above-mentioned drawdown analyses show that only 71 boreholes could continue to be pumped up at the rate of their initial yield for 20 years of pumping within the maximum drawdown of 10 meters, as shown in Table C3.8. These boreholes are regarded to be "safe-yielding boreholes". The ratio of safe-yielding boreholes to all the boreholes is equivalent to the ratio of safe abstraction to the potential abstraction. Therefore, the ratio of safe-yielding boreholes to all the boreholes represents an index for estimating the safe abstraction rate.

The ratios of safe-yielding boreholes to all the boreholes were calculated by location and the average ratio was estimated to be 0.0766 in the country. Based on the above estimation, the safe abstraction rates of boreholes by location were estimated (Table C3.9). Total safe abstraction rate in Kenya is estimated to be 193 million cubic meters per year.

3.2.3 Aquifer characteristics by rock type

Rock types remarkably influence groundwater occurrence. The country is simplified to consist of the three major rock types ; basement rocks, volcanic rocks and sedimentary rocks.

The influence of rock type on aquifer characteristics is summarized as shown in the following table and Table C3.10 :

Aquifer characteristics by rock type

Rock type	Elevation (m)	Total depth (m)	Water level		Pumping test		Specific capacity (m^3/hr/m)
			Struck (m)	Rest (m)	Yield (m^3/hr)	Drawdown (m)	
Volcanics (V)	1762.74	124.70	93.96	48.68	7.45	37.05	0.20
Basements (B)	1266.59	79.59	55.30	26.40	4.54	31.08	0.15
Sediments (S)	439.48	81.22	54.25	34.80	5.55	17.39	0.32
(V) over (B)	1079.47	82.53	54.39	28.53	7.39	25.87	0.29
(S) over (B)	1073.65	91.28	51.16	25.97	5.67	32.28	0.18
(S) over (V)	1265.85	90.44	63.22	28.98	7.57	24.14	0.32
(V) over (S)	1332.28	106.71	79.37	26.60	10.76	41.22	0.26
Others	1054.23	103.95	63.00	38.88	4.58	19.39	0.24
Unknown	1391.61	78.66	55.76	25.68	4.89	24.44	0.20

1) The boreholes in volcanics have the highest value of elevation, 1763 meters, whereas those in sediments have the lowest, 439 meters.

2) The total depth of boreholes in volcanics is the deepest, an average of 125 meters. Boreholes in basements and sediments are shallower, mean values of 80 and 81 meters, respectively.

3) The struck water level of boreholes in volcanics is the deepest, 94 meters, whereas that in sediments is the shallowest, 54 meters.

4) The rest water level of boreholes in volcanics is the deepest, 49 meters, whereas that in basements is the shallowest, 26 meters.

5) The boreholes in volcanics have the highest value of artesian pressure, 45 meters, whereas those in sediments have the lowest, 20 meters. Artesian pressure is the pressure of struck water level minus rest water level.

6) The yield in volcanics is the highest, 7.5 cubic meters per hour (m^3/hr), whereas that in basement rocks is the lowest, 4.5 cubic meters per hour (m^3/hr). The yields denote tested yields quoted in the borehole completion records. The tested yields should be considered to tend to reflect the pump capacities of the pumps rather than the actual potential.

7) The specific capacity in basement rocks is the lowest, 0.15 cubic meters per hour per meter ($m^3/hr/m$) whereas that in sediments is by far the highest, 3.4 cubic meters per hour per meter ($m^3/hr/m$). Thus the sediments have a higher groundwater potential than the basement rocks.

8) The boreholes in volcanics have the highest value of drawdown, 37 meters, whereas those in sediments have the lowest, 17 meters.

3.2.4 Aquifer characteristics by province and district

The average aquifer characteristics by province are summarized as shown in the following table and those by district in Table C3.11 :

Aquifer characteristics by province

Province	Elevation (m)	Total depth (m)	Water level Struck (m)	Water level Rest (m)	Pumping test Yield (m^3/hr)	Pumping test Drawdown (m)	Specific capacity ($m^3/hr/m$)
Nairobi	1721.30	152.50	112.50	56.70	7.70	39.50	0.19
Central	1835.35	129.58	96.94	45.86	7.84	41.81	0.19
Coast	240.62	67.96	42.31	23.81	5.80	14.27	0.41
Eastern	1258.65	92.57	64.74	34.55	5.40	31.83	0.17
North Eastern	377.09	122.93	98.63	79.19	4.83	20.23	0.24
Nyanza	1319.42	76.00	54.58	19.30	6.39	31.13	0.21
Rift Valley	1728.17	112.56	83.40	46.54	6.70	35.60	0.19
Western	1348.50	53.04	35.04	11.70	3.66	19.43	0.19

1) The elevations of boreholes in the Central (especially Nyandarua District), Rift Valley (especially Nakuru, Narok and Kericho Districts), and Nairobi Provinces, composed of volcanics in geology, are the highest, 1835, 1728, and 1721 meters, respectively.

2) The total depths of boreholes in the Nairobi, Central (especially Kiambu Districts), composed of mainly volcanics in geology, and North Eastern (especially Mandera District) Provinces, composed of mainly older sedimentary rocks in geology, are the deepest, 153, 130, and 123 meters, respectively.

3) Boreholes in the Nairobi, North Eastern (especially Garissa District), and Central (especially Nyandarua District) Provinces have the deepest value of struck water levels, 113, 99 and 97 meters, whereas those in the Western (especially Kakamega District) Province, composed of basement rocks and in the Coast (especially Lamu District) Province, composed of sedimentary rocks, have the lowest, 35 and 42 meters, respectively.

4) Boreholes in the North Eastern (especially Garissa District)Provinces have the deepest value of rest water levels, 79 meters, whereas those in the Western (especially Kakamega District) Province, composed of basement rocks, and in the Coast (especially Lamu District) Province, composed of sedimentary rocks, have the lowest, 11 and 24 meters, respectively.

5) Boreholes in the Nairobi and Central (especially Kiambu District) Provinces have the largest value of artesian pressure, 56 and 51 meters, respectively, whereas those in the Coast (especially Lamu and Mombasa Districts) and North Eastern (especially Garissa District) Provinces, composed of sedimentary rocks, have the lowest, 18.5 and 19 meters.

6) The yields of boreholes are lowest in the Western (especially Kakamega District) and Eastern (especially Embu and Kitui Districts) Provinces, which are composed of metamorphic rocks in geology; and North Eastern (especially Wajir and Mandera Districts) Province, 3.7, 5.4, and 4.8 cubic meters per hour per meter ($m^3/hr/m$), respectively, whereas the yields of boreholes in the Central (especially Kiambu District) and Nairobi Provinces are highest, 7.8 and 7.7 cubic meters per hour per meter ($m^3/hr/m$), respectively.

7) The boreholes in the Central (especially Muranga District) and Nairobi Provinces have the largest value of drawdown, 42 and 40 meters, respectively,while those in the Coast (especially Lamu and Mombasa Districts) Province have the lowest, 14 meters.

8) The boreholes in the Eastern (especially Kitui and Machakos Districts) Province have the lowest value of specific capacity, 0.15 cubic meters per hour per meter ($m^3/hr/m$) ,while those in the Coast (especially Lamu and Mombasa Districts) Province have the largest, 0.43 cubic meters per hour per meter ($m^3/hr/m$).

3.2.5 Aquifer characteristics by drainage basin

The influence of drainage basin on average aquifer characteristics is summarized as shown in the following table and Table C3.12 :

Aquifer characteristics by major drainage basin

Basin	Elevation (m)	Total depth (m)	Water level Struck (m)	Water level Rest (m)	Pumping test Yield (m^2/hr)	Pumping test Drawdown (m)	Specific capacity $(m^3/hr/m)$
Lake Victoria	1399.61	70.87	50.59	19.33	4.98	26.41	0.19
Rift Valley	1839.24	113.15	86.82	55.12	7.29	25.07	0.29
Athi River	1431.87	115.88	84.02	40.85	7.16	35.25	0.20
Tana River	1244.18	109.17	75.08	38.40	6.58	39.15	0.17
Ewaso N'giro	1309.70	111.67	88.58	52.52	5.25	39.50	0.13

1) The elevations of boreholes in the Rift Valley Basin, composed of mainly volcanics in geology, are the highest, 1839 meters, whereas those in the Tana River, composed of mainly sedimentary rocks, are the lowest, 1244 meters.

2) The total depths of boreholes except for in the Lake Victoria basin which is composed of mainly basement rocks in geology, are about 110 meters.

3) The boreholes except for in the Lake Victoria basin have almost the same values of struck water levels, about 80 meters.

4) The boreholes in the Rift Valley and Ewaso N'giro basin have the highest values of rest water levels, 55 and 53 meters, respectively, whereas those in the Lake Victoria Basin, have the lowest, 19 meters.

5) The boreholes except for in the Athi River basin have almost the same value of artesian pressure, about 30 meters.

6) The yields of boreholes are lowest in the Lake Victoria and Ewaso N'giro basins, 5.0 and 5.3 cubic meters per hour (m^3/hr), respectively, whereas the yields in the Rift Valley and Athi River basins, 7.3 and 7.2 cubic meters per hour (m^3/hr), respectively, are the highest

7) The boreholes in the Ewaso N'giro and Tana River basins have the largest value of drawdown, 40 and 35 meters, respectively,while those in the Rift Valley and Lake Victoria basins, have the lowest, 25 meters.

8) The boreholes in the Ewaso N'giro basin have the lowest value of specific capacity, 0.13 cubic meters per hour per meter $(m^3/hr/m)$, while those in the Rift Valley have the largest, 0.29 cubic meters per hour per meter $(m^3/hr/m)$.

Areas of maximum yield (exceeding 190 litres per minute) are found in the extreme south-east and around Lake Victoria as shown in Figure C3.3. Lowest yield basins are around Lake Turkana, in the North Eastern province, around the Tana River, the Western province and in the area south of Narok.

3.2.6 Shallow wells

Unconfined groundwater occurs in the Quaternary sediments consisting of river sands, in the fractured parts of faults and in the syncline parts of folds, in the weathered upper parts of rocks and in granitic rocks with various stages of weathering and fracturing.

Unconfined groundwater is utilized in the form of water holes and hand-dug, hand-drilled and machine-drilled shallow wells at a few meters to over 50 m in elevated areas.

Overall the country, there is only limited information available at present with regard to the extent of shallow aquifers and their structure. However, some studies have been conducted in Western Province, Kwale District and Wajir. The study of shallow groundwater resources should be continued to cover other areas particularly in ASAL areas, because there are no other alternatives for people and their livestock in those areas. According to the Kenya administrative boundaries map (1988) published by Survey of Kenya, water holes and wells are shown as Figure C3.4. Water holes and wells are distributed nationwide except in volcanic rocks areas.

3.2.7 Groundwater Quality

Groundwater constitutes one portion of the earth's water circulation system known as the hydrologic cycle. Groundwater dissolves parts of the soils and rocks as it infiltrates and percolates through them. The cations occurring in groundwater are commonly calcium, magnesium, sodium, iron, manganese, and potassium. The anions are mostly carbonate, bicarbonate, sulphate, chloride, and nitrate.

Whether groundwater of a given quality is suitable for a particular purpose depends on the criteria or standards of acceptable quality for that use. Water standards or quality limits of water supplies for drinking, industry, and irrigation apply to groundwater.

(1) Guidelines of water quality for various purposes

1) Drinking

The basic requirements for drinking water are as follows:

- Free from disease causing organisms.
- Contain no compounds that affect human health.
- Fairly clear (low turbidity and little colour).
- Not saline
- Contain no compounds that cause an offensive taste or smell.
- Do not cause corrosion or incrustation of the water supply.
- Do not strain clothes washed in it.

It is practically impossible to establish rigid water standards for chemical quality The permissible level for each ion may be a function of water availability and socio-economic factors. In general the guidelines most accepted are set out by the World Health Organization (Ref. C.18).

2) Livestock use

In general no criteria exist for livestock use. There is a wide range of ions, bacteria, and viruses affecting water quality. A guideline for evaluating water quality for livestock use is as shown in the following table.

Guidelines of water quality for livestock use

Parameter	Threshold	Limit
TDS	2500	5000
Calcium	500	1000
Magnesium	250	500
Sodium	1000	2000
Bicarbonate	500	1500
Chloride	1500	3000
Fluoride	1	6
Nitrate	200	400
Sulphate	500	1000
pH	6.0 - 8.5	5.6 - 9.0

Unit : mg/l

3) Irrigation

Good water has the potential to allow maximum economical returns. Poor water causes soil and cropping problems which will reduce yields. Water considered "unsuitable" under the prior concept of quality may really be "usable" under certain conditions. In fact, poor water is often better than no water. Some guidelines on classification of irrigation water are shown in Tables C3.13 and C3.14 (FAO, Ref. C.5).

(2) Regional characteristics of groundwater quality

Groundwater is extremely variable in chemical composition and this variation occurs both spatially and seasonally. Only 15 percent of 9462 boreholes have water quality data logged on the new database. These data are too few to meaningfully assess groundwater quality by province and by drainage basin and this situation should be rectified by more intensive monitoring. Groundwater quality on a provincial basis are summarized in the following table :

Groundwater quality by Province

Parameter	Province Nairobi	Central	Coast	Eastern	North Eastern	Nyanza	Rift Valley	Western
PH	7.9	7.5	7.5	7.4	7.9	7.8	7.9	6.7
Turbidity(NTU)	28.9	42.9	36.2	26.2	32.8	39.3	25.6	27.6
Oxygen absorbed	3.05	2.66	1.12	1.86	0.64	4.83	11.3	0.16
Conductivity	859	494	3291	1109	2315	719	1074	354
Iron	1.48	2.00	1.26	2.3	0.99	1.25	1.57	0.89
Manganese	0.70	0.42	27.9	2.9	29.2	2.90	0.79	1.52
Calcium	43.3	17.3	135.1	63.4	151.9	57.6	52.2	18.6
Magnesium	8.16	7.13	117.3	41.3	123.7	34.6	31.9	13.5
Sodium	164.0	77.2	746.7	143.3	375.6	106.0	209.0	13.7
Potassium	19.3	12.3	16.5	23.8	17	15.1	15.4	4.0
Hardness	48.4	68.4	369.8	348.7	239.8	238.7	161.9	78.4
Chloride	72.4	35.4	1063	142.5	793.6	117.8	153.8	15.6
Fluoride	6.59	1.78	1.16	1.9	5.69	2.38	3.33	2.04
Sulphate	32.3	11.1	160.2	151.0	259.9	107.2	102.0	20.6
TDS	521	314	2122	750	2101	585	916	181

Remarks : Units are mg/l except for conductivity (micro S/cm) and hardness (mg/l CaCO3)

Groundwater in the Western, Central, Nyanza, and Nairobi Provinces contains little dissolved solids and consequently has low electric conductivity. It is generally satisfactory for all domestic purposes from a chemical point of view. Groundwater in the Coast and North Eastern Provinces is more saline due to sea water intrusion along the coast and evaporate deposits inland.

Overall, The Coast, North Eastern and Eastern Provinces have generally poor quality groundwater. Further, most of the unprotected shallow wells may have low bacteriological quality due to contamination by animal droppings and poor drainage/salinity practices.

The fluoride content of groundwater far exceeds the recommended WHO drinking-water guideline value of 1.5 mg/l in the Nairobi, North Eastern, and Rift Valley Provinces with values of 6.6, 5.7, and 3.3 mg/l, respectively. This factor raises one of the more intractable problems with groundwater utilization since removal of fluoride is not technically easy and economically feasible for rural and small-community water supply as discussed in Appendix C.2.

Groundwater quality on a major drainage basis is summarized in the following table:

Groundwater quality by major drainage basin

Parameter	Major drainage basin Lake Victoria	Rift Valley	Athi River	Tana River	Ewaso N'giro
PH	7.61	7.84	7.64	7.23	7.93
Turbidity(NTU)	31.00	23.65	36.02	25.46	11.24
Oxygen absorbed	3.32	18.55	1.57	5.32	0.84
Conductivity	625.39	1047.90	1425.34	991.96	1356.11
Iron	1.33	1.10	1.24	1.83	3.40
Manganese	2.39	0.56	10.09	0.43	9.32
Calcium	46.39	33.27	68.21	38.92	103.16
Magnesium	26.91	19.11	48.07	30.17	67.33
Sodium	102.16	215.44	289.10	180.20	261.60
Potassium	12.16	14.44	17.38	14.62	32.84
Hardness	163.35	108.75	161.54	203.96	312.25
Chloride	88.31	154.24	319.12	227.11	322.81
Fluoride	6.27	2.67	3.44	1.27	2.59
Sulphate	94.23	96.99	106.76	56.45	162.12
TDS	497.65	988.19	927.50	792.44	1189.75

Remarks : *Units are mg/l except for conductivity (micro S/cm) and hardness (mg/l CaCO3)*

Groundwater in the Lake Victoria and Tana River drainage basins includes less dissolved solids and consequently has lower electric conductivity. Groundwater in the Athi River and Ewaso N'giro drainage basins is more saline due to sea water intrusion along the coast and evaporate deposits inland.

The fluoride content of groundwater far exceeds the WHO guideline value in the Lake Victoria and Athi River drainage basins with values of 6.3 and 3.4, respectively.

(3) Geographical distribution of water quality

Regional maps are very useful for understanding the overall features. Regional mapping requires interpolation and extrapolation of available data to predict the expectations in places where data are absent. It must be emphasized that the regional maps are based on limited data and should be also used with caution and as a guide to the true condition.

1) Electrical conductivity and total dissolved solids

Electrical conductivity is often also expressed by the total dissolved solids (TDS) content. The relation between electrical conductivity and TDS depends on the ions in the water. In general, especially for irrigation purposes, 1000 micro S/cm is often equivalent to 600 or 700 mg/l TDS.

The recommended maximum limit for human consumption is believed to be 750 micro S/cm. In places where no other water is available, water with double or triple this limit is used. The limits for irrigation and livestock are believed to be 2000 and 8000 micro S/cm, respectively.

In the ASAL area, electrical conductivity is more than 1000 micro S/cm (Figures C3.5 and C3.6). The serious problem in groundwater development in the ASAL areas is that of saline water, which has resulted in failure of several boreholes.

2) Fluoride (F)

Fluoride is naturally present in some food and water. There is no evidence of harmful effects associated with the relatively low levels. At levels above 1.5 mg/l, the maximum limit guided by WHO, mottling of teeth has been reported very occasionally, and at 3.0 to 6.0 mg/l, skeletal fluorosis is observed. When a concentration of 10 mg/l is exceeded, crippling fluorosis can follow.

High fluoride content is believed to be related to geology, particularly with volcanic rocks in the Rift Valley area and the Central part of Kenya (Figures C3.7 and C3.8). It is believed that the fluoride content originates from volcanic and fumarolic gases. In the ASAL areas, high content of fluoride may be related to the degradation of fluorite.

3) Iron (Fe)

Although iron is an essential element in human nutrition, drinking water is not considered to be an important source. At levels of 0.3 mg/l, maximum limit of WHO guidelines, iron stains laundry and plumbing fixtures and causes an undesirable taste. The presence of iron may lead to deposits in pipes and at levels higher than 0.3 mg/l there may be increased maintenance costs.

In the western and southeastern parts of the country, high contents of iron greater than 0.3 mg/l are common (Figures C3.9 and C3.10).

4) Sodium (Na), calcium (Ca), and magnesium (Mg)

The taste threshold for sodium is about 200 mg/l, the guideline value of WHO. The threshold value for livestock is 1000 mg/l and the limiting concentration is 2000 mg/l. In the ASAL areas, high contents of sodium more than 200 mg/l are predominant (Figures C3.11 and C3.12).

The hardness of water is caused by calcium and to a lesser extent magnesium. The taste threshold for calcium is in the range of 100 to 300 mg/l depending on the associated anion. The limiting value for livestock is 1000 mg/l. The taste threshold for magnesium is less than that for calcium. The limiting concentration for livestock is 500 mg/l. In the ASAL areas, contents of calcium and magnesium higher than 100 mg/l are common (Figure C3.13 to Figure C3.16).

5) Sodium absorption ratio (SAR)

The sodium absorption ratio is the property of soil extracts and irrigation water used to express the relative activity of sodium ions in an exchange reaction with the soil. Effects from sodium are to some extent negated by calcium and magnesium.

Irrigation water is classified on the basis of its electrical conductivity and SAR. According to this classification, groundwater is classified as having high or very high salinity and high or very high sodium content especially in the ASAL areas (Figures C3.17 and C3.18).

3.3 Hydrogeological Maps

Hydrogeological maps were prepared on the scales of 1:250,000 (33 sheets) and 1:1,000,000 (1 sheet) and compiled in the form of "Atlas of Groundwater in Kenya". Hydrogeological maps are composed of the following information on the basis of the above-mentioned reports, the existing borehole data and groundwater investigation results. Figure C3.19 shows a reduced copy of the 1:1,000,000 map and Figure C3.20 expresses hydrogeological cross section maps. Figure C3.19 (2/2) shows a groundwater recharge potentiality map as discussed in Appendix C.6.

3.3.1 Contents of hydrogeological maps

(1) Topographic and geological features

Topographic and geological features are presented on the hydrogeological map.

(2) Aquifer classification

Mapping of parameters related to aquifers and non-aquifers shows thickness of aquifer, thickness of aquiclude, depth to unconfined aquifer or depth to confined aquifer and depth to basement. These elements are presented by isolines or patterned areas to denote thickness or depth. Vertical cross sections are illustrated on the hydrogeological map.

(3) Existing boreholes

Location of existing boreholes is illustrated with information on borehole use on the hydrogeological map.

(4) Water quality classification

Water quality data are illustrated as diagrams for geochemical interpretation. These data are also presented by isolines or patterned areas to show the characteristics of water quality.

(5) Groundwater level

Groundwater level contours are illustrated using initial data of rest water levels and water levels investigated in this study.

(6) Groundwater recharge capacity

Potential groundwater recharge rate (precipitation minus evaporation) is illustrated.

(7) Groundwater abstraction

Groundwater abstraction data investigated in this Study are tabulated as tables and figures in this Sectoral Report (C) and Databook (D.3).

(8) Geophysical sounding data and logging data

The geophysical sounding data which give information on the thickness of aquifers are illustrated on the hydrogeological map and as figures in this Sectoral Report (C) and Databook (D.3). At the same time, the logging data are illustrated on the hydrogeological cross section maps.

(9) Groundwater potential classification

Groundwater potential is shown in terms of well yields or specific capacity. Where test data are available, the potential is also given in terms of permeability, transmissivity, or storage coefficient.

3.3.2 Legend of hydrogeological maps

Legend of hydrogeological maps is summarized as follows:

(1) Background information

All background information presents mainly the location and names of important localities and the geographic names, international and administrative boundaries.

(2) Groundwater and rocks

Intergranular aquifer, fissured aquifer, and strata with local and limited groundwater resources or with essentially no groundwater resources are classified. It is particularly important to show the continuation of the aquifer and strata.

(3) Lithology

The lithology of the strata in boreholes is represented by ornaments. The ornaments are based upon the International Legend for Hydrogeological Maps published by

UNESCO in 1983 (Ref. C.17).

(4) Detailed hydrogeological information

Detailed hydrogeological information on springs, surface water, boreholes and faults is shown by the use of symbols, lines, and ornaments.

(5) Stratigraphy

It is generally convenient to indicate at least the approximate age of the strata depicted. Stratigraphic symbols are used according to the general legend of UNESCO geological maps.

(6) Climatology

Climatological features, e.g. precipitation, evaporation, and temperature, are presented.

(7) Vertical cross-sections

The geology and hydrogeology are illustrated by the use of vertical cross-sections upon the back side of the map.

3.4 Groundwater Occurrence

Water storage and transmitting capacities of rocks are attributed principally to hydrogeological properties. These capacities of rocks are a function of their lithology. Sandstones of Tertiary and Quaternary ages with almost the same granular properties would occur in similar aquifers. Variation in age of the rocks becomes important especially in very old rocks where post-depositional alterations have affected the primary porosity of the rocks.

The hydrogeological areas of Kenya can be regarded as simplified geological areas. The major three hydrogeological areas are classified as follows (Figure C3.19):

1) Volcanic Rocks (Patterns 3 and 4 of Figure C3.19)
2) Pre-cambrian metamorphic basement rocks (Pattern 5 of Figure C3.19) and Pre-cambrian intrusive rocks (Pattern 9 of Figure C3.19)
3) Sedimentary rocks (Patterns 1, 2, 6, 7, 8 of Figure C3.19)

3.4.1 Volcanic rock area

The volcanic rocks cover about 26% of the country, more commonly in Western Kenya, where the volcanics exhibit a linear alignment with the Rift Valley System. The general pattern is north-south, stretching from Tanzania into Sudan and Ethiopia.

The lithology is widely variable and includes phonolites, trachytes, tuffs and basalts. Groundwater is stored typically in the old weathered surfaces between lava flows and older formations (mainly the metamorphic basement rocks) as well as between successive lava flows. Fractures, faults, fissures, and joints are also suitable sites for groundwater storage.

The thickness of the volcanic overburden varies from nil to several hundred meters and hence groundwater occurs at greatly varying depths. This also means that several aquifers are stuck in a borehole.

The aquifers in the volcanic areas are confined. Yield, depth to aquifers, and static water level vary enormously within the volcanic rocks. The yield is about 7.5 m^3/hr with a standard deviation of about 6.5 m^3/hr. The depth to main aquifer is about 94 metres with a standard deviation of about 58 metres. The artesian pressure is about 45 metres.

The groundwater in the volcanic area is generally of bi-carbonate type (Ref. C.14) with low total dissolved solids (TDS) or low electric conductivity. There are local pockets of high fluoride content which are believed to be of volcanic and fumarolic origin.

3.4.2 Pre-cambrian metamorphic basement rock and intrusive rock area

The Pre-cambrian rocks are widely distributed in the central, western and northwestern parts of Kenya and cover about 17% of the country

The lithology is dominated by granites, gneisses, schists and sediments. These rocks are deeply weathered in places although the extent of weathering differs. Where faults and fractures are distributed both laterally and vertically, groundwater occurs in rather deep horizons.

The aquifers in the basement area are rather confined. Yield, depth to aquifers, and static water level vary within rocks. The yield is about 4.5 m^3/hr with a standard deviation of about 5.2 m^3/hr. The depth to main aquifer is about 55 meters with a standard deviation of about 40 meters. The artesian pressure is about 31 meters.

The confined groundwater is generally hard at moderate electric conductivity.

In the upper parts of the basement rocks, at various stages of weathering and fracturing, unconfined groundwater occurs locally at depths varying from a few to several tens of meters. The water level fluctuates considerably and may dry up in the dry season.

3.4.3 Sedimentary Rock Area

The sedimentary rock area accounts for about 55 % of Kenya, predominantly in its eastern, northwestern parts and around Lake Victoria. The rocks range in age from Paleozoic to Cenozoic and are composed of sands, clays, sandstones, shales, and limestones.

The average depth to aquifers is about 54 meters with a standard deviation of about 48 meters. The artesian pressure is lowest (about 20 meters), but the specific capacity is highest at about 0.32 $m^3/hr/m$.

(1) Quaternary sediments

The Quaternary sediments area accounts for almost one-third of the country, stretching essentially from the Tanzanian border to the Ethiopian border , and as far east as longitude 38° E.

The lithology is dominated by alluvial, lake and beach sands, coral reefs, and limestones. The sediments are loose and permeable.

The aquifers are generally shallow and unconfined. The success ratio of boreholes is very high.

The serious problem in groundwater development is that of salt water, which has caused the failure of boreholes. The groundwater is generally of a chloride type. The origin of the saline water is believed to be due to accumulation of solute evaporate minerals within the sediments which have not been removed by groundwater circulation. However, salty groundwater in the coastal parts is believed to be due to the seawater intrusion.

(2) Older sedimentary rock area.

The older sediments are distributed in the south-eastern and northeastern corners of the country. The three major sedimentary rocks, sandstones, limestones and shales dominate the lithology.

The aquifers are typically confined and deep. Considerable faulting and folding is believed to have occurred and the groundwater occurs in the syncline parts of the folds, and the fractured parts of faults. The groundwater is generally of a chloride type (Ref. C.14).

C4. GROUNDWATER DEVELOPMENT PLAN TOWARDS YEAR 2010

4.1 Source Development

Groundwater is the most universally available supply of water. It is usually clean and free from pathogens as it has been naturally filtered as it passes through subsurface rock materials. It, however, may be contaminated as a result of the abstraction method or by polluted surface water entering the well. Some problems of groundwater may be also introduced as a result of over-pumping.

From the viewpoint of engineering, the type of aquifers, unconfined or confined aquifer, has an important influence on the kind of wells.

The construction of shallow wells has been recognized as a low cost solution for water supply ,especially, in the rural areas. The kind of methods, materials, and equipment to be used should be taken into account; the execution of the works should be of a simple nature; maintenance of structures and pumps should be as limited as possible; and equipment to be used should be manufactured locally.

4.1.1 Shallow wells

A Shallow well within the context of the Ministry of Water Development is understood to be a groundwater producing well fulfilling the following conditions:

a) Hand dug
b) Not exceeding 50 metres in depth

From the middle of the 1980's, the scope of the definition of a shallow well seems to have been extended to include machine drilled wells not exceeding 50 to 60 metres in depth.

The factors which have led to a high occurrence of shallow wells in the country are thought to be:

a) Low cost of shallow well construction compared to a borehole
b) Insufficient number of water supply facilities to cater for the water demand

The water quality of shallow wells is largely as a matter of conjecture since no systematic studies have been carried out with the possible exception of Western Kenya and South Coast. Organic contamination may be a problem in high density population areas. Pollution from agricultural chemicals and fertilizers is also thought to be a potentially significant source of pollution.

(1) Quaternary sediments

The most promising areas for the construction of shallow wells are alluvial and lake sediments . The Quaternary sediments consisting of river sands have good yield. In the alluvial aquifers consisting of sediments towards the lake and marine, the salinity of groundwater increases. In the ASAL areas Quaternary sediment aquifers contain saline groundwater and may dry up in the dry season. Despite water quality problems in the ASAL areas these sediments are suitable for construction of hand-drilled shallow wells.

The safe yields of the Quaternary alluvial and colluvial sediment aquifers are estimated at 10 and 5 cubic meters per day (m^3/day), respectively.

(2) Older sedimentary rocks

The most promising areas for the construction of shallow wells are colluvial sediments. In the older sedimentary rocks considerable faulting and folding is believed to have occurred and the groundwater occurs in the fractured parts of faults and in the syncline parts of the folds. In the ASAL areas the older sedimentary aquifers have saline water and may dry up in the dry season. The older sedimentary rocks are suitable for construction of hand-dug and hand-drilled shallow wells despite of water quality problem.

The older sedimentary rock aquifers are estimated to have a safe yield of 5 cubic meters per day (m^3/day).

(3) Pre-cambrian metamorphic basement rocks

Groundwater occurs locally in the weathered upper parts of the rocks at depths varying from a few to several tens of meters. The groundwater quality is usually good with the exception of occasional high iron or manganese. The water level fluctuates considerably. The weathered parts of the metamorphic basement rocks are suitable for construction of machine-drilled shallow wells and hand-dug shallow wells.

The safe yield of the metamorphic basement rocks is estimated at 5 cubic meters per day (m^3/day).

(4) Pre-cambrian granite

Groundwater occurs locally in granitic rocks, at various stages of weathering and fracturing, at depths ranging from a few meters in the valley bottoms to over 50 m in elevated areas. Groundwater in weathered and fractured granite is slightly milky (due to kaoline particles) and has a high fluoride concentration exceeding the standard of 1.5 mg/l . Well construction can be done by hand-drilled or machine-drilling.

The safe yield of the granite rocks is also estimated at 5 cubic meters per day (m^3/day).

(5) Volcanic rocks

Shallow wells can not be constructed in the volcanic rocks because of the hardness of the rocks and the considerable depth of the groundwater. Only machine-drilled boreholes with pumps are feasible.

The volcanic rocks near the ground surface have been sufficiently weathered and eroded in areas lying in the central districts of the country on either side of the Rift Valley. In these volcanic materials, successful shallow wells exist.

Figure C4.1 and Table C3.9 show the detailed safe abstraction rate of shallow wells by location. The total safe abstraction rate of shallow wells in Kenya is estimated to be 425 million cubic meters per year

4.1.2 Boreholes

(1) Drawdown

Water levels of well and aquifer drawdown towards their levels after starting a pump. Drawdown of the pumping water levels depends on aquifer property and production rate. Boreholes should be designed in order to avoid the drawdown of the pumping water level into the top of the pump above the screened part of the boreholes. Average struck and rest water levels in Kenya are 77.2 and 40 m, respectively. The maximum drawdown should be within about 10 meters by the year 2010 from the viewpoint of groundwater conservation.

(2) Safe abstraction rate

Figure C4.2 and Table C3.9 show the detailed safe abstraction rate of boreholes by location. The safe abstraction rate of boreholes in Kenya is estimated at 193 million cubic meters per year.

Figure C4.3 shows the detailed total safe abstraction rate by location. The total safe abstraction rate is equivalent to about 8 % of the total potential abstraction rate as discussed in Chapter 3.2.2(2).

4.1.3 Water quality risk

The guideline values for distributed water, especially in urban areas, should be virtually the same as those which were published in the WHO guidelines.

In the case of rural and small community water supply, the WHO guideline values have to be often considered as long-term goals rather than rigid standards. At the same time, the parameters of water quality must necessarily be limited in number (WHO,1985) as discussed in Appendix C.1. Taking into account local geographical, socio-economic, dietary, and industrial conditions in the country shows that following water quality parameters should be used in assessing and measuring the quality of water intended for water supply :

1) Bacteriological aspects
2) Chemical and physical aspects
   - Turbidity
   - Colour
   - Taste and odour
   - Electrical conductivity
   - Fluoride
   - Iron

In fact, data of bacteriological quality, colour, and taste and odour are rarely available as shown in the groundwater database. Some data of turbidity are found in the database, but the number is too little to be used as criteria for checking of drinking-water. The last three parameters (electrical conductivity, fluoride, and iron) were selected as water quality criteria for rural and small community water supply.

Water quality parameters for rural and small community water supply

Parameter	Unit	Permissible	Limit
Electrical conductivity	micro S/cm	750	2000
Fluoride	mg/l	1.5	3.0
Iron	mg/l	0.3	1.0

Figures C4.4 to C4.6 show water quality risk maps for electrical conductivity, fluoride, and iron, respectively. Figure C4.7 shows an integrated risk map of water quality. It should be emphasized that risk condition of water quality in areas near boundaries of the country and ASAL areas may be uncertain due to scarcity of data.

4.2 Geographical Distribution of Development Needs

4.2.1 Public water supply

Public water supply is a vital component in the economic and social development of countries and regions. Experience has shown that clean and safe water supply is the foundation on which rests the health and cultural progress of countries.

Generally, investment in water supply creates opportunity for four types of benefits, namely, (1) higher income, (2) increased and more reliable subsistence, (3) improved health, and (4) increased leisure. The most important direct benefit from a new water supply is a reduction in the time and energy previously used in collecting water. This reduction will increase the labour quality, improve hygiene and health, and increase leisure.

Related to these benefits, agricultural production and a better sense of well-being will be generally improved. In turn, the insecurity caused by a shortage of food will disappear and the country or community can engage in long-term planning rather than relief works.

4.2.2 Public health

Water provides a favourable habitat for the reproduction, development, and growth of many disease organisms and their vectors. Rough estimates show that between 20 and 30 infectious diseases may be affected by changes in the abundance and distribution of water. Disease pathogens may be transmitted directly from person to person, or through a vector, and warm, moist, or wet habitats are particularly favourable to both pathogens and vectors. As a result, people living near water bodies in the humid tropics are potentially exposed to a wide range of infectious diseases. These water related diseases are recognized by their mode of transmission or spread.

According to the results of socio-economic report (Sectoral Report (A)) as shown in the following table and Table C4.1, the districts which appeared in the largest numbers of out-patient of infectious diseases related to water supplies were: (a) Kilifi where 92 thousand suffered from these diseases; and (b) Machakos/Makueni, 90 thousand; and (c) Kakamega, 86 thousand. About 8% of the total out-patients in the country were suffering from these infectious diseases. The most widespread disease among them was diarrhoeal disease. In 1989, one in about 25 people suffered from diarrhoeal disease.

Number of out-patient of infective diseases

Province	Total of infective diseases	percentage
Nairobi	14248	1.01
Central	263705	7.97
Coast	246235	12.59
Eastern	269171	6.77
North Eastern	21340	5.61
Nyanza	282886	7.56
Rift Valley	350721	6.68
Western	134902	4.96

4.2.3 Irrigation

Irrigation water is supplied to soil for the purpose of crop production to supplement the water available from rainfall. The places where receive much rainfall do not require any irrigation water for crop production. While less rainfall area needs more irrigation water in accordance with the rainfall availability. The ASAL areas need more water for crop production compared with humid areas.

In general major water sources for irrigation are river water, lake water, spring water and groundwater. Among those sources, other than groundwater has economical advantage. In the ASAL areas, availability of surface water is very limited and only groundwater is promising. Priority of groundwater use for irrigation is low compared with domestic use.

Surface water shows that Basin 2 and Basin 5 have only one twentieth or one hundredth availability compared with Basin 1 as tabulated below.

Available Unit Surface Water

Unit : liter/sec/km^2

	Basin 1	Basin 2	Basin 3	Basin 4	Basin 5
Amount	25.7	1.3	4.6	14.8	0.4

4.2.4 Livestock

According to the IPAL report (Ref. C.1), sheep and goats need about 5 liters of water per day (l/day). Cattle need about 20 liters per day and camels have to come to a watering place only once a week but they take almost 100 liters each. These figures are theoretical because livestock in arid areas are not watered every day. The frequencies are 3 days for sheep and goats, 2 days for cattle and 1 or 2 weeks for camels.

According to the IPAL report, sheep and goats which need water every third day can graze an area of 25 km from the water point. Cattle have to be watered every second day and their walking distance is 10 km. Camels which have to be watered once in a week can go as far as 50 km from the water point. From the above figures, the effective grazing areas on one day around a water point are estimated : 550 km^2 for camels, 314 km^2 for cattle, and 392 km^2 for sheep and goats.

4.2.5 Wildlife

Wildlife utilization and tourism are presently a major part of land use in the ASAL areas. About 95 per cent of the land area of the Kenya Wildlife Service's (KWS) protected area system (National Parks and Reserves) lies in the ASAL areas. The major part of this is in Zone VI ,where on arid areas defined by Agro-ecological Zone, pastoralists and wildlife compete for range resources.

The droughts of the 1980's caused the greatest loss and upheaval to pastoralists in both arid and very arid lands of the ASAL areas. In order to reduce the loss of wildlife, boreholes and shallow wells should be necessary for wildlife in the case of droughts.

4.3 Water Balance

Two different meanings of a water balance can be defined. A frequently used water balance in hydrology is the water balance expressed as inflow vs. outflow + or - change in storage. The other one is the water balance available expressed as volume vs. required water demand. A water balance can be established for different periods, for example, several years, a year, and a season. The latter meaning is applied for water balance calculation in this study.

(1) Water balance by basin

The results of water balance calculations for the years 1990, 2000, and 2010 are shown in Figures C4.8 to C4.10. Sub-basins with the deficit of groundwater against total of domestic, industrial and livestock water demands already exist in 1990, especially in urbanized sub-basins. Such sub-basins gradually expand with the increase in demand toward the year 2010.

(2) Water balance by location

The results of water balance calculations for the years 1990, 2000, and 2010 are shown in Figures C4.11 to C4.14. Locations with the deficit of groundwater against domestic, industrial and livestock water demands already exist in 1990, especially in urbanized locations. Such locations gradually expand with the increase of demand toward the year 2010.

4.4 Groundwater Development Plan

In line with one of the program pursuit to increase public water supply coverage, three levels of water service, namely: Level I (point source), Level II (communal faucets) and Level III (individual house connections) would be provided according to the size of water supply area.

(1) Level I (the point source) is generally a well which has a distance to the farthest user of not more than 4 kilometers.

(2) Level II is a communal faucet system which is generally intended for rural areas where houses are densely clustered enough to justify a piped distribution system with a faucet for use of several households.

(3) Level III refers to individual house connections generally for urban areas.

4.4.1 Rural water supply project

For each location the potentiality of groundwater resources development was assessed based on four relative criteria :

(1) Groundwater development potentiality (GA) :

The groundwater development potentiality (GA) was classified as follows :

Groundwater development potentiality

	Potentiality
GA1	high
GA2	moderate
GA3	low
GA4	extremely low

(2) Groundwater quality risk (GQ)

The groundwater quality risk (GQ) was classified based on the following criteria :

Groundwater quality risk

	Risk	Remarks
GQ1	good	meeting WHO guidelines
GQ2	moderate	over WHO guidelines, but within a usable limit
GQ3	not favourable	

(3) Share of groundwater development between boreholes and shallow wells (GS)

The share of development was classified by location in consideration of hydrogeological characteristics :

Share of groundwater development

	Percentage of share	
	Boreholes	Shallow wells
GS1	0 ≤ B/H <20	80< S/W ≤ 100
GS2	20 ≤ B/H <40	60< S/W ≤ 80
GS3	40 ≤ B/H <60	40< S/W ≤ 60
GS4	60 ≤ B/H <80	20< S/W ≤ 40
GS5	80 ≤ B/H <100	0< S/W ≤ 20

(4) Cost effectiveness of groundwater exploitation (GC)

The cost effectiveness of groundwater exploitation (GC) was assessed for six pumping systems by location as shown in detail in Table C5.3 and Figures C5.1 to C5.6. The criteria were used to define priority of development between groundwater and other water harvesting.

Water supplies depending on groundwater should have standby boreholes fully equipped and operational in order to alleviate interruption of water supply.

4.4.2 Urban water supply

A primary assumption is that surface sources will take precedence over groundwater sources in the development for urban water supply because of easy accessibility and cheaper abstraction cost in most cases. In the case that surface water can not meet water development requirement of urban water supply, groundwater will be utilized instead of surface water. There are some cases that groundwater can not match the water development requirement due to water quality constraint. In this case, maximum affordable development of roof catchment and subsurface dam may be considered instead of groundwater.

According to the results of domestic and industrial water supply study (Sectoral Report (D)), following urban centers have to utilize groundwater as a source for their water supply.

	Urban Center	Location	Water demand 1990 (m^3/day)	Water demand 2000 (m^3/day)	Water demand 2010 (m^3/day)	Outer radius of development (km)
*	Msambweni	Msambweni	1298	3394	5427	45
*	Isiolo	Isiolo	3023	9559	18914	82
	Garba Tula	Garba Tula	340	898	1590	22
	North Horr	North Horr	374	795	1244	24
	Korr	Korr	130	2166	3411	39
	Kargi	Kargi	764	1910	3290	42
	Marsabit	Mountain	2201	5350	9078	65
	Sololo	Sololo	658	1652	2832	44
	Moyale	Moyale	1493	3548	5956	39
	Mudo Gashe	Madogashe	359	773	1141	23
	Ijara	Ijara	173	409	545	16
	Kotile	Kotile	173	409	545	23
	Elwak	Elwak	1730	2876	4242	45
*	Wajir	Wajir Town	3428	7469	12493	91
	Buna	Buna	1087	2040	3094	57
	Bute	Bute	353	664	1008	22
	Nyabikaye	Bugembe	525	980	1405	25
	Wamba	Wamba	593	1449	2651	50
	Barogoi	Elbarta	512	1265	2294	64
	Lodwar	Lodwar	1980	4543	7881	60
*	Nyahururu	Nyahururu	152	3863	4550	60
*	Rumuruti	Rumuruti	395	530	636	23

Note: * means urban centers which groundwater will contribute to half amount of the demand.

A detailed groundwater study including physical prospecting would be indispensable for developing groundwater for the urban water supplies.

4.4.3 ASAL livestock water supply

Water capacity and water needs determine the radius of the grazing area around the water points. The grazing areas for different species are defined by three circles with different radii : 50 km for camels, 10 km for cattle, and 25 km for sheep and goats.

Priority should be given to the development of shallow wells rather than boreholes,whose development costs are exorbitant. Various studies, in the Western Province (Kenya-Finland Western Water Supply Programme), the Coast Province (Kenya-Sweden Rural Water Supply Programme), the North Eastern Province (Swarzenski & Mundorff, 1977), and the South western Marsabit District (Integrated Project in Arid Lands), have shown that there are adequate unconfined groundwater aquifers and that shallow wells would adequately cater to the water needs of the areas. Shallow wells with windmills are the most promising alternative for cattle watering. Windmills are relatively cheap and easy in operation and maintenance.

4.4.4 Irrigation

The use of groundwater for irrigation is evaluated for boreholes by location as shown in Chapter 5. The costs of irrigation water supply for six (6) types of different systems are presented in Table C5.3 and Figures C5.1 to C5.6. The water supply system of a borehole with a diesel generator pump is estimated to be the most proper system. From the viewpoint of nationwide average costs, however, the combination of low yields and high pumping depths makes groundwater an expensive source for irrigation compared with surface water sources. Groundwater irrigation potential area is estimated to be only 1,500 ha in the whole country. While surface water irrigation potential area is about 470,000 ha in total (see Sectoral Report (E)).

Groundwater use for irrigation will contribute little to the nationwide irrigation potential of the country except for some special cases;

- schemes which have in economic and financial feasibility of applying groundwater
- schemes which have no alternative for water source except groundwater.

4.4.5 Wildlife water supply

The droughts of the 1980's caused the greatest loss and upheaval to pastoralists in both arid and very arid lands of the ASAL areas. In order to reduce the loss of wildlife, boreholes and shallow wells should be necessary in the case of droughts.

Priority should be given to the development of shallow wells rather than boreholes,whose development costs are exorbitant. However, shallow wells in unconfined aquifers may dry up especially in droughts. Boreholes with windmills are the most promising alternative. Windmills are relatively cheap and easy in operation and maintenance.

The grazing areas for different species have great variance, but it may be reasonable to assume that the average grazing area for major species is within 5 to 10 kilometers. In this case, a borehole with a windmill will be constructed in each area of 100 km^2.

4.5 Water Quality Monitoring

The internationally recognized and authorized guidelines for drinking water quality are those recommended by the World Health Organization (1985) and these guidelines have been adopted by many countries including Kenya. These guidelines should be recognized as a means to an ultimate goal. It will be necessary to take account of the variety of geographical, socio-economic, dietary and industrial conditions. In fact, poor water is often better than no water.

A noteworthy aspect is that the water quality data of groundwater are available only for 15 % of all the boreholes in the country and that most of the boreholes have not been observed and monitored since the completion. This situation should be rectified by more intensive monitoring of boreholes for public water supply, observation and exploratory, which are equivalent to about 24 % of all boreholes in the country, at a regular interval, for example twice a year, each in the dry and rainy season. At the same time, the groundwater quality monitoring is indispensable to make clear a variety of conditions and define specific levels of drinking water standards, especially for the small-community water supply. The monitoring of private boreholes may be left as the owners obligation by setting forth relevant regulations.

4.6 Groundwater Resources Assessment

Water resources assessment requires knowledge of suitable water resources as well as socio-economics. It is important to :

1) evaluate existing hydrogeological data,
2) identify and execute periodical and additional field investigations required,
3) prepare hydrogeological maps,
4) evaluate continuously existing data collection system and propose improvements of the system,
5) evaluate groundwater quality and improve continuous monitoring systems,
6) estimate groundwater recharge by computer simulation and field investigation.

(1) Proper Pumping Tests

Pumping tests should be conducted to determine the performance characteristics of a well and the hydrogeological parameters of the aquifer.

The first purpose of the tests, a well-performance test, records of drawdown and yield under controlled conditions is to give a measure of the production capacity of the completed well and also provide information needed for the selection of pumping equipment. Step-drawdown tests, which the well is pumped at successively greater discharges for relatively short periods, are available.

The second purpose of the tests is to provide drawdown and recovery tests data, from which the principal parameters of the aquifer, transmissivity and storage coefficient, can be calculated. This type of test is also called an aquifer test. The aquifer test consists of pumping a well at a constant rate (constant-pumping test) and recording the drawdown in the pumping well and in nearby observation wells observed at specific times. The test is also called a constant-pumping test

(2) Monitoring Wells Network

Observation wells for monitoring groundwater would be indispensable to make clear mechanisms of recharge to groundwater from precipitation or of drawdown due to over-pumping and movement of groundwater and contaminants. The data obtained from regular monitoring should be stored into the database for groundwater management.

The purpose of monitoring wells is to (1) determine the static water levels or potentiometric surfaces of all aquifers, (2) permit access for the collection of water samples to detect contaminants, (3) monitor the movement of groundwater and contaminants, and (4) calculate and estimate groundwater abstraction rates.

There are 66 observation boreholes in the country, mainly in the Nairobi conservation area according to the borehole database. Observation records have seldom been obtained except for the Nairobi conservation area. Even in the Nairobi conservation area, observation have not been continued due to financial constraints, lack of transport, lack of suitable equipment, lack of provision for servicing and maintenance of the equipment, shortages of staff with adequate levels of training, and lack of understanding of boreholes' owners.

It would be necessary for monitoring wells to have airlines which can monitor static water levels.

(3) Installations of Airlines and Abstraction Meters

It should be made mandatory for future boreholes to be equipped with airlines and groundwater abstraction meters in order to monitor rest water levels and evaluate groundwater abstraction rates.

(4) Equipment for Groundwater Surveys, Development and Monitoring

Each district should have groundwater exploration equipment such as terrameters or resistivity meters, water level instrument such as dippers, thermometers, portable water quality meters such as PH meters and electric conductivity meters, and simple surveying equipment such as altimeters and compass.

4.7 Drilling policy

Two thirds of Kenya is considered to be arid and semi-arid lands and these areas have necessitated the development of groundwater as groundwater is considered the only alternative source of water in these areas. The past activities in these areas where groundwater has been developed have led to the establishment of administrative centres and other public institutions as the population of such centres grow. Beside the high demand for expansion and reliability, groundwater has been favoured because of the water borne diseases caused by surface water.

In the urban and well watered areas, groundwater has been developed because of high demand and reliability. In general, industrialists and farmers have realized that the only way to expand and meet their targets is to have reliable sources of water. Groundwater management should be adequate to avoid present and future potential detrimental effects, such as excessive water depletion, deterioration of water quality, and land subsidence due to excessive pumping.

The Ministry's intention is to approach groundwater development on a regional basis which was started in 1981. This intention fits well in the Government Policy of District Focus for Rural Development. So far, the areas that have benefited from this approach are Kwale District assisted by UNDP, Sololo and Dabel in Marsabit District and Tharaka in Meru District Sponsored by SIDA, and Kajiado, Narok and South Nyanza sponsored by (JICA).

The groundwater development approach on a district basis has gotten the following advantages,

1) Community participation has been introduced. Consumers participate in all phases of projects. Women in water supply played an important role including operation and maintenance, water fee collection, and other management issues.

2) It became easier to supply, distribute and replace materials and spare parts

3) It became easier to monitor and evaluate projects for improvement.

The major constraints are shortage of drilling rigs and funds for implementation. Professionals and sub-professionals to manage the drilling rigs are recruited from universities and the Kenya Water Institute of the MOWD.

While pursuing this approach on a district basis, the MOWD has encouraged the licensing of competent drilling contractors who undertake drilling works on commercial basis. The drilling Section of the MOWD ensures that boreholes are drilled by carrying out supervision on the drilling contractors in order to maintain the professional standards.

Many rural communities have benefited a lot from this approach on a district basis and this approach should be continued in future.

C5. DEVELOPMENT COST AND COST EFFECTIVENESS

5.1 Development Cost

The objective of the cost study is to provide estimates of construction costs and operation and maintenance costs for each water supply technology. Both costs are used for a cost effectiveness analysis and for the determination of costs per cubic meters produced (Ref. C.27).

Information on costs was obtained from the Ministry of Water Development, from other water projects and from various private companies (Tables C5.1 and C5.2). The costs were converted to 1991-price levels to enable comparison, if necessary.

The estimates of construction costs were considered to contain the following items :

costs of materials
costs of labour
costs of transport
costs of depreciation of construction equipment

5.1.1 Water source

(1) Shallow wells

Shallow wells(dug wells or hand drilled tube wells) are recommended in certain areas, mainly near laggas. Inner lining of dug wells will be done with rings of stone or concrete rings precast or cast in situ,etc. The wells must be protected from pollution by a well cover. Groundwater abstraction is done by a hand pump and may be done by a windmill in certain areas.

(2) Boreholes

Boreholes are feasible at various places in Kenya. The abstraction method depends on the safe yield and drawdown of the boreholes and the water demand of communities. Water abstraction will be done by a motor pump, a hand pump, a windmill or a solar pump. The unit cost of drilling, casing, development, testing, etc. depends on the local conditions and number of boreholes to be drilled.

Cost estimates of a borehole fitted with a hand pump were available from LBDA, SIDA, WRAP and manufactures. The costs vary considerably , mainly due to the depth of drilling.

The costs do not include survey costs to determine the suitable sites of shallow wells and boreholes for cost effectiveness analysis.

5.1.2 Pumping system

(1) Hand pumps

Hand pumps are easy to install and are not expensive. Hand pumps require regular and skilled maintenance, which if well organized, improves considerably the reliability of operation. Hand pumps can pump water from a maximum pumping head of 60 meters, but generally the pumping head should be less to assure a reasonable abstraction and reduce the exhaustion of the pump. Abstraction rate of hand pumps is usually between 0.5 and 3 cubic meters per hour (m^3/hour), but the abstraction rate is assumed to be 10 m^3/day for the analysis.

The most common types of hand pumps installed in Kenya are NIRA (KFWWSP) and SWN (LBDA) for shallow depth, Afridev (KFWWSP), SWN (LBDA) for medium depth , and India Mark II(KFWWSP). The Afridev and India Mark II are manufactured locally.

The total cost of a hand pump is estimated at Ksh 14,500 to 32,000.

(2) Windmills

Windmills are relatively cheap in operation, but installation of windmills is very expensive. The windmills may be combined with a hand pump if occasionally there is no wind. A diesel engine can be used as an another alternative. If only wind power is used, a storage tank is required as minimum. The windmills can pump water from a maximum pumping head of 100 meters, but the pumping head is assumed to be 60 meters to assure a reasonable abstraction. Abstraction rate of windmills is usually to several tens of cubic meters per day and the abstraction rate is assumed to be 10 m^3/day for the analysis.

The total cost of a windmill is estimated at Ksh 270,000.

(3) Diesel and Electric pumps

Diesel pumps in remote areas often lack fuel, spare parts and personnel to maintain. On the other hand, electric pumps require less maintenance and are more reliable. Electric pumps are preferred where a reliable supply of electricity is available.

The total cost of a diesel generator and pump is estimated at Ksh 225,000 to 525,000. The total cost of an electric pump is equivalent to 75 % of that of a diesel generator pump.

(4) Solar pumps

Solar photovoltaic pumps are used to convert sunlight directly into electricity. Photovoltaic power is becoming increasingly popular for water pumping in remote areas. Sophisticated technology is required and the solar pumps are not easy to repair. The solar pumps would produce the same water output over the course of an entire day if it runs for 6 hours. Abstraction rate of solar pumps is usually to several tens of cubic meters per day, the abstraction rate is assumed to be 10 m^3/day for the analysis. The maximum pumping head is assumed to be 60 meters.

The total costs of a solar pump is estimated at Ksh 400,000 excluding installation.

5.2 Cost of Operation and Maintenance

The organization of operation and maintenance (O & M) is one of the most important factor for water supply planning. The policy of the government is that O & M of water supply facilities is undertaken primarily through joint efforts between the government and the beneficiaries. Therefore, it is very important that the beneficiaries participate in the decision making at the earliest stage of the planning. Cost recovery is an essential element in the water supply planning. The government policy is also that the water price in urban areas should cover both O & M and construction costs of water supply and the water price in rural areas should cover at least the direct O & M costs

The involvement of the beneficiaries (community) is promoted in several programs (LBDA, KFWWSP). In general, communities are expected to participate in all phases. and usually form water committees which are responsible for the water supply.

The O & M costs include:

Operation	:	1) fuel or electricity
		2) salaries of operators,attendants, etc
		3) transport and offices
Maintenance	:	1) spare parts
		2) tools
		3) costs of repair

Costs of replacement due to expiry of the lifetime of materials are not included in the O & M costs.

(1) Shallow wells

The operation and maintenance of shallow wells are not required. The annual O & M costs include:

Operation	:	none
Maintenance	:	none
Lifetime	:	20 years

(2) Boreholes

In general, operation is not required for boreholes. Rehabilitation of well screen should be regularly required.

The annual O & M costs include:

Operation	:	none
Maintenance	:	1 % of construction cost
Lifetime	:	20 years

(3) Hand pumps

Improvements to hand pumps are made continuously in the world and some types are now manufactured in Kenya. In general, operation is not required for hand pumps unless a pump attendant is paid. The costs of maintenance were Ksh/year 200 in LBDA and Kwale. KEFINCO estimated the maintenance cost at Ksh/year 500-1000. The deeper the watertable is, the high maintenance cost usually becomes.

The annual O & M costs include:

Operation	:	none
Maintenance	:	5 % of the investment cost of a pump
Lifetime	:	6 years

(4) Windmills

An attendant is usually required and his salary should be included in the operation. The maintenance includes routine work tightening of nuts and bolts, changing lubricating oil, and greasing parts.

The annual O & M costs include:

Operation	:	Ksh/year 12,000
Maintenance	:	5 % of the investment of a pump
Lifetime	:	20 years

(5) Motor pumps

An electric pump and a diesel engine driving a pump through a generator require regular maintenance to be done by a mechanic. Salaries of mechanics are estimated at 20 % of electricity or fuel costs consumed. The operation cost of a motor pump also include electricity and fuel costs consumed.

The annual O & M costs include:

Operation	:	salaries, electricity and fuel consumed
Maintenance	:	5 % of the investment cost of a pump and generator
Lifetime	:	10 years

(6) Solar pumps

A solar pump has recently been introduced and not many units have been installed. The O & M is very easy but major problem may be the breakage of panels by various causes such as wind. The maintenance cost, therefore, comprise replacement of panels.

The annual O & M costs include:

Operation	:	none
Maintenance	:	5 % of the investment cost of a pump and generator
Lifetime	:	10 years

5.3 Cost Effectiveness

The lowest cost water supply technology applicable in a given circumstance will be the most cost effective.

The cost effectiveness analysis measures average cost per cubic meter capacity (US$/$m^3$) of each system over its lifetime. The lowest cost system applicable in a given condition can be the most "cost effective". The present values of cost per cubic meter capacity (US$/$m^3$) are expressed using a technique of discounting.

The methodology of cost effectiveness analysis includes the following steps:

1) Estimate of the investment, O & M and replacement costs
   - Investment costs : drilling, engines, pumps:
   - O & M costs :staff salaries, electricity and fuel consumed, spare parts
   - Replacement cost : engines, generators, pumps
2) Estimate of the safe yield in cubic meters per year (m^3/year)
3) Discounting of all costs to express in their present value
4) Calculation of the average cost effectiveness per cubic meters capacity of water (US$/$m^3$) over the lifetime at present value.

The discount rate is based on what economists would consider to be the buyer's best alternative investment. If the best alternative is investing money in a bank at 10 percent interest, the discount rate is assumed to be 10 percent.

The cost effectiveness analysis over a 20 year period was carried out for existing boreholes with information on location, well depth, water levels, etc. by location. Six (6) different types of pumping systems were considered:

1) Borehole installed with a diesel pump
2) Borehole installed with an electric pump
3) Borehole installed with a hand pump
4) Borehole installed with a solar pump
5) Borehole installed with a windmill
6) Shallow well installed with a hand pump

Table C5.3 and Figures C5.1 to C5.6 show the results of cost effectiveness analysis by location. The most effective type is a shallow well installed with a hand pump, followed by the types of a borehole with a hand pump, a borehole with an electric pump, a borehole with a windmill, a borehole with a diesel pump and a borehole with a solar pump.

The construction of a shallow well with a hand pump has been generally recognized as a low cost solution for water supply in the rural areas. This fact is also justified in Kenya. The second alternative is the construction of a borehole with a hand pump.

In the urban areas and local centers, the construction of a borehole with a diesel pump is estimated to be the most cost effective in the case that fuel is always available. If electricity is always available, the construction of a borehole with an electric pump may be recognized as the most promising alternative.

In the rural and isolated areas, a windmill is recognized as an another alternative. A solar pump is the last alternative.

C6. ORGANIZATION, MANPOWER, AND TRAINING

6.1 Present Organization, Manpower, and Training

The Department of Water Development, the Ministry of Water Development carries out water resources planning, development and management. The groundwater -related activities are managed by the Groundwater Section of this Department.

(1) Geologist

According to the "Scheme of services for geologists" issued by the Permanent Secretary / Director of Personnel Management, Office of the President (Ref. C.12), the term "geologist" is applicable to any of the following geological scientists : (1) geologist, (2) geophysicist, (3) hydrogeologist, and (4) geochemistry who have specialized in any of the following fields of geological sciences : (1) geology, (2) geophysics, (3) hydrogeology, and (4) geochemistry, respectively.

Geologists are designated and graded as follows : (1) chief geologist, (2) principal geologist, (3) senior geologist, (4) geologist I, (5) geologist II, (6) geologist III.

(2) Groundwater Inspector

The duties and responsibilities of the Inspector are 1) to assist geologists in hydrogeological and geophysical survey, 2) to collect and arrange field groundwater data for analysis, 3) to inspect and monitor boreholes and wells, 4) to draw hydrographs and other simple hydrogeological maps, 5) to carry out minor repairs of geophysical and allied equipment, 6) to train junior staff in groundwater activities, and 7) Receive and register boreholes completion records from the field.

(3) Staff of MOWD and NWCPC

Staffing of the Groundwater Section, Drilling Section and Research Division the Department of Water Development, MOWD and NWCPC is shown in the following table :

Staff of the groundwater - related section, MOWD and NWCPC

Grade	MOWD Groundwater Section	MOWD Drilling Section	NWCPC
Chief geologist	vacant	vacant	1
Principal geologist	1	1	-
Geologist I	3	1	-
Geologist II	5	15	-
Geologist III	1	-	-
Mechanical engineer	-	1	-
Superintendent	-	2	-
Senior inspector	1	1	1
Inspector	2	66	2

as of Dec, 1991

Staff of Groundwater Research Section of Research Division, MOWD

Grade	
Head (Ass. director)	1
Senior research officer	1
Research officer I	4
Research officer II/III	1

Table C6.1 shows a list of provincial and district geologists. Seven (7) provincial geologists in seven (7) districts, (Nyeri, Mombasa, Tana River, Machakos, Kajiado, Nakuru, and Kakamega), are included in this table.

(4) Staff of Basin Development Authorities

Five (5) Basin Development Authorities have several geologists and they manage groundwater planning, development, and monitoring.

(5) Universities and Institutes

The Department of Geology, University of Nairobi, offers a 3-year course which leads to a B.Sc. in geology. The Department offers M.Sc. and Ph.D. programmes by coursework, examination, and thesis in geology. The courses have not often been in operation due to a lack of financial support and scholarships.

The Water Development Staff Training School of MOWD is the only institution which generates the non-professional technical cadre of personnel unique to the Ministry's requirement. The Staff Training Schools has trained over 2500 students since 1973. Trainees were distributed within the Ministry for on-the-job training as inspectors, bailiffs and assistant and are trained as draftsmen and technicians. Facilities at the Staff Training School were inadequate to meet future sectoral manpower requirement, so the Kenya Water Institute was developed by MOWD.

6.2 Manpower Requirement and Training

New Scheme of Service should propose three grades in the groundwater cadre. The first grade is groundwater hydrologist and the second one is shallow wells inspector.

(1) Groundwater hydrologist

The duties and responsibilities of the groundwater hydrologist are as follows :

1) Management and analyses of groundwater monitoring data
2) Management and analyses of pumping tests data
3) Management and analyses of water quality data

The number of the groundwater hydrologists should be proposed as follows :

1) One groundwater hydrologist I
2) Two groundwater hydrologist II
3) Two groundwater hydrologist III

(2) Shallow well inspectors I and II

The duties and responsibilities of the shallow well inspectors are as follows :

1) Collecting information on present conditions of shallow wells
    --- Location data (latitude, longitude, altitude, etc.)
    --- Purpose of use
    --- Rest water level
    --- Pumps and operation hours
    --- Abstraction rate

2) Collecting information on operating and maintaining of shallow wells
    --- Degree of community participation in operation and maintenance
    --- Number of serviced population and livestock
    --- Operation and maintenance costs
    --- Cost recovery

3) Training and education
    --- Preparation of operation and maintenance manuals
    --- Training in operation and maintenance

4) Handing-over of shallow wells to communities

The shallow well inspectors should undertake their work in each district and the number of the inspectors should be increased to be 2 persons per district. At the same time, the number of groundwater inspectors should be increased to be 2 persons per district.

(3) Training

A groundwater hydrologist should be a geologist who is qualified as a hydrologist or a hydrologist who has qualification of geology. Geologists of MOWD should have qualification of groundwater-related hydrology through participation in seminars and workshops. Universities should offer some courses, such as groundwater engineering, geophysics, and physical geography, which leads to B. Sc. in groundwater hydrology.

The Kenya Water Institute should offer groundwater hydrology course which leads to groundwater inspector and shallow well inspector.

C7. RECOMMENDATIONS

Water resources planning, development, and management are carried out by the Department of Water Development, the Ministry of Water Development. The groundwater-related activities are managed by the Groundwater Section in collaboration with Drilling Section, other Sections of Water Resources, Planning and Design and Research Division. The recommendations below are aimed at increasing the knowledge of the groundwater resources development and management for effective utilization in the future.

7.1 Proper Pumping Tests

Proper pumping tests (including step-drawdown pumping tests, a constant-discharge pumping test, and a recovery test in order) should be conducted to determine the performance characteristics of a well and the hydrogeological parameters of the aquifer.

7.2 Monitoring Wells Network

Observation wells for monitoring groundwater should be indispensable to make clear the mechanisms of recharge to groundwater from precipitation or of drawdown due to over-pumping and movement of groundwater and contaminants. The data obtained from regular monitoring should be stored in a database for groundwater management.

7.3 Installations of Airlines and Abstraction Meters

Airlines and abstraction meters should be made mandatory for future boreholes to be equipped in order to monitor rest water levels and evaluate groundwater abstraction rates.

7.4 Water Quality Standards and Monitoring

The internationally recognized and authorized guidelines for drinking water quality are those recommended by the World Health Organization (1985) and these guidelines have been adopted by many countries including Kenya. These guidelines should be recognized as means to an ultimate goal. It will be necessary to take into account the variety of geographical, socio-economic, dietary, and industrial conditions. In fact, poor water is often better than no water.

Groundwater quality monitoring is indispensable to make clear the various conditions of water quality and also to define specific levels of drinking water standards, especially for the small-community water supply.

Water laboratories for water quality analysis and pollution control should be necessary at the district level because water samples should be analyzed as soon as possible after sampling of the water.

7.5 Treatment of Groundwater with High Contents of Fluoride and Iron

There are five treatment techniques to remove inorganic contaminations: (1) reverse osmosis, (2) activated alumina systems, (3) ion exchange systems, (4) granular activated carbon systems, and (5) distillation.

Bone char and bone meal devices have been made an advance by the Central Public Health Engineering Research Institute of India and were also tested in Kenya.

The most common method for removal of iron and manganese are (1) aeration-filtration, (2) chrolination-filtration, and (3) potassium permanganate-manganese greensand filtration.

Methods for low cost removal of fluoride and iron should be established or introduced and the equipment should be manufactured locally as discussed in Appendix C.2.

7.6 Instrument for Groundwater Surveys and Monitoring

Each district should have groundwater exploration instrument such as terrameters or resistivity meters, water level instrument such as dippers, portable water quality meters such as PH meters and electric conductivity meters, and simple surveying equipment such as altimeters and compass.

7.7 Equipment of Drilling and Construction Teams of Boreholes and Shallow Wells

A drilling rig is essential to be equipped at the district level and teams for the construction of boreholes and shallow wells are also essential, especially in the ASAL area.

7.8 Computer Terminals for Data Management and Groundwater Management

The computer databases on boreholes and groundwater quality were developed for new computer system. Completion records from new boreholes and monitored and observed data from existing boreholes should be inputted into the system. Each district should have a computer terminal for entering these data and for groundwater management.

7.9 Groundwater Research Activities

The researchers of MOWD should continuously do a "state of the art review". Applied researches should be necessary rather than basic researches, especially in developing countries. The Research Division of MOWD should come up with a solution on how to solve groundwater related problems. The following researches are recommended :

1) Research on protection and conservation of groundwater resources,
2) Research on groundwater modelling technique using computers,
3) Research on low cost technology including efficiency of a hand pump, as discussed

in Appendix C.3,

4) Research on community participation in existing and future water supplies, especially those in which groundwater is and will be utilized as a water source, as discussed in Appendix C.3,
5) Research on generalization of data collection and data management,
6) Research on new techniques including remote sensing and electromagnetic method.

The Research Division should recommend some solutions on how to solve and manage.

7.10 Material Standards of a Borehole and Shallow Well

Materials used for well construction should be of good quality that does not corrode easily with groundwater.

1) Borehole

   Boreholes should be properly constructed by installing proper casings and screens, gravel packing, etc. The materials should be tested by Kenya Bureau of Standards on Material Branch of the Ministry of Works.

2) Shallow well

   Shallow wells need an inner lining of materials such as brick, stone masonry, concrete rings cast insitu or precast concrete rings. The materials should be tested at the same way. The wall lining above the ground, concrete apron and wall top should be also tested.

7.11 Borehole Geophysical Soundings

Rock samples during borehole construction may not precisely represent the underground due to many factors like caving-in, maxing, etc. Some geophysical soundings should be necessary in order to delineate the hydrogeologic nature. The most popular soundings are 1) resistivity 2) spontaneous potential 3) micro-resistivity 4)Gamma logging 5) Neutron logging 6) caliper logging 7) temperature 8) water resistivity.

7.12 Promotion of Competent Geologists and Registered Hydrologists

It is recommended that competent geologists and registered hydrogeologists should be involved in the supervision planning, completion of drilling and reporting of borehole completion in order to maintain the required standards.

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Definitions

Adsorption.
The assimilation of gas, vapor, or dissolved matter by the surface of a solid.

Alkaline.
Any of various soluble mineral salts found in natural water and arid soils having a pH greater than 7. In water analysis, it represents the carbonates, bicarbonates, hydroxides, and occasionally the borates, silicates, and phosphates in the water.

Alluvial.
Pertaining to or composed of alluvium or deposited by a stream or running water.

Alluvium.
A general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semisorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope.

Anion.
A negatively charged ion that migrates to an anode, as in electrolysis.

Aquiclude.
A saturated, but poorly permeable bed, formation, or group of formations that does not yield water freely to a well or spring. However, an aquiclude may transmit appreciate water to or from adjacent aquifers.

Aquifer.
A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.

Aquifer test.
A test involving the withdrawal of measured quantities of water from or addition of water to, a well and the measurement of resulting changes in head in the aquifer both during and after the period of discharge or addition.

Aquitard.
A geologic formation, group of formations, or part of a formation through which virtually no water moves.

Bedrock.
A general term for the rock, usually solid, that underlies soil or other unconsolidated material.

Carbonate rocks.
A rock consisting chiefly of carbonate minerals, such as limestone and dolomite.

Cation.
An ion having a positive charge and, in electrolytes, characteristically moving toward a negative electrode.

Colluvium
A heterogeneous mixture of loose, incoherent rock frogments, scree and mud, which has *moved down to the base of a slope under gravity, the result of mass-movement.*

Confined aquifer.
A formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

Contamination.
The degradation of natural water quality as a result of man's activities. There is no implication of any specific limits, since the degree of permissible contamination depends upon the intended end use, or uses, of the water.

Drawdown.
The distance between the static water level and the surface of the cone of depression.

Electrical conductivity.
A measure of the ease with which a conducting current can be caused to flow through a material under the influence of an applied electric field. It is the reciprocal of resistivity and is measured in mhos per centimeter (or foot).

Evaporate deposits
A sedimentary rock composed of minerals precipitated from a solution, and dried out by evaporation.

Extrusive rocks.
Igneous rocks formed from magma that flows out on the Earth's surface. These rocks cool rapidly, producing a fine crystalline structure.

Fault.
A fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture.

Hydrogeologic.
Those factors that deal with subsurface waters and related geologic aspects of surface waters.

Igneous rocks.
Rocks that solidified from molten or party molten material, that is, from a magma.

Intrusive rocks.
Those igneous rocks formed from magma injected beneath the Earth's surface. Generally these rocks have large crystals caused by slow cooling.

Ion.
An element or compound that has gained or lost an electron, so that it is no longer neutral electrically, but carries a charge.

Kaolin.
A general term for a group of clay minerals.

Metamorphic rocks.
Any rock derived from pre-existing rocks by mineralological, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust.

Observation well.
A well drilled in a selected location for the purpose of observing parameters such as water levels and pressure changes.

Pollution.
When the contamination concentration levels restrict the potential use of groundwater.

Pumping test.
A test that is conducted to determine aquifer or well characteristics.

Recharge.
The addition of water to the zone of saturation; also, the amount of water added.

Residual drawdown.
The difference between the original static water level and the depth to water at a given instant during the recovery period

Rest (Static) water level.
The level of water in a well that is not being affected by withdrawal of groundwater.

Safe abstraction rate.
Maximum abstraction rate which can be made continuously upon groundwater over a given period.

Sedimentary rocks.
Rocks resulting from the consolidation of loose sediment that has accumulated in layers.

Specific capacity.
The rate of discharge of a water well per unit of drawdown, commonly expressed in m^3/day/m or gpm/ft. It varies with duration of discharge.

Storage coefficient
The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Transmissivity.
The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is given in cubic meters per day through a vertical section of an aquifer one meter wide and extending the full saturated height of an aquifer under a hydraulic gradient of 1.

Unconfined aquifer.
An aquifer where the water table is exposed to the atmosphere through openings in the overlying materials.

Yield(Well yield).
The volume of water discharged from a well in cubic meters per day or gallons per minute.

TABLES

Table C2.1 Representative rocks of Kenya

Systems	Representative Rocks	Tectonic Events	Main Economic Uses (after Pulfrey,1960)
Recent	Soils, alluvials, sands. Hot springs-trona and other evaporites. Volcanic ashes	Rise to present sea level. Minor volcanicity and grid faulting.	Limestones, cement, diatomite, gypsum, bentonitic clays, kaolin
Pleistocene	Moraines on highest peaks.Coral reefs and sandstones at coast. Interior sediments, alkaline and pyroclastic lavas.	Grid faulting, major volcanic eruptions in rift south of Nakuru, Nyambeni and Marsabit areas. 3rd major faulting of Rift Valley and Kano Rift, alkaline and carbonatite intrusions.	Limestones, cement, diatomite, gypsum, bentonitic clays, kaolin
Tertiary	Coastal sediments. Large quantities of volcanic rocks of the highlands. Interior Miocene Beds	1st and 2nd major faulting of Rift Valley. Warpings, major regional uplift in central Kenya alkaline and carbonatite intrusions.	Limestones, building stones, carbon dioxide, ballast, lead, barytes
Cretaceous	Danissa Beds, Maheran Sandstones, Freretown limestones and siltstones	Stability. Probable commencement of carbonatite intrusions	
Jurassic	Limestones and shale in coastal areas. Daua Limestone Series and Mandera Series	Slight uparching and tilting: Faulting in N.E. Kenya	Limestones and shales, shales, gypsum
Triassic Permian Carboni-ferous (Karroo)	Duruma Sandstones, Mansa Guda Formation	Gentle tilting, warping and tilting of mesozoic rocks. Erosion	Ballast
Bukoban	Kisii Series-Acid and basic volcanics, quartzites and other sediments	Gentle warping faulting. Dolerites and pegmatites intruded	Soapstone, cassiterite
Basement (The Mozambique Belt)	*Quartzites, crystalline* limestones schists, gneisses including Kusae, Kasigau Series, Turoka and other formations	*3rd period of N.E. trend folds in* north Kenya. Early recumbent folds. Major period of orogenesis. Granites, granodiorites, pyroxenites, eclogites etc. intruded	Asbestos, Kyanite marble, limestones, vermiculite, garnet
Kavirondian	Arenaceous and argillaceous sediments. Conglomerates, hornblende andesites etc.	Metamorphism with isoclinal folding with N.E. and S.E. trending axes. Granites, syenites and dolerites intruded.	Gold, silver
Nyanzian	Sandstones, conglomerates, quartzites, phyllites, limestones, pelites volcanics and ironstones	Slight metamorphism of Abium and Embu Series. Granites, epidiorites, Gabbros	Gold, copper, zinc, chromite, cobalt, silver, corundum and other minior minerals

Source : Ojany, F.F. and R.B. Ogendo, Kenya: A Study in Physical and Human Geography, 1988

Table C2.2 Succession of Palaeozoic-Mesozoic sediments in Kenya

System	Stage	North-east Kenya		Coastal Kenya	
		Marehan Sandstones			
Cretaceous	Neocomian	Marehan Danissa Beds Series		Freretown Limestone	
	- - - - - - - - - - - -				
Jurassic	Tithonian	Mandera Series			
		Dakacha Limestones			
		Hereri Shales			
	Kimmeridgian	Seir Limestones			
		Muddo Erri			
		Limestone	Daua	Rabai Shales	
		Rahman Shales	Limestone		
	Oxfordian		Series		
	Callorian	Rukesa Shales		Miritini Shales	
	Bathonian	Murri Limestones		Kibiongoni Beds	
	Bajocian			Kambe Limestone	
	Lias?	Didimtu Beds		- - - - - - - - - - - - - - - -	
Trias	- - - - - - - - - - - -	Mansa Guda Formation		Mazeras Sandstones/ Shimba Grits	
				Mariakani Sandstones	Duruma
		- -		Maji ya Chumvi Beds	Sandstones
Permian-Carboniferous?				Taru Grits	
Pre-Cambrian		Matamorphosed Sediments of the Basement System			

Dashed lines (-----) denote unconformities.
Source : Ojany, F.F. and R.B. Ogendo, Kenya: A Study in Physical and Human Geography, 1988

Table C2.3 Cainozoic succession in Kenya

Period	Interior and west Kenya	North-east Kenya	Coastal Kenya
Recent	Soils including laterites. Alluvium, spring deposits and evaporites in interior lakes e.g. Magadi trona	River soils including Kankar limestones, laterites and surface sands	Alluvium and beach sands
Upper Pleistocene	Loams, sheet limestone, mudstones, siltstones, tuffs, pumice lavas, fluviatile sediments	Red and brown clays having nodules	Windblown sands, Raised alluvial deposits
Middle Pleistocene	Lake beds in floor of Rift,Kanjeran Beds. Rawe Fish Beds	Thin laminated limestones, sandstones, conglomerates and ironstones. El Wak Beds	Kilindini sands, Mombasa Crag, coral reefs
Lower Pleistocene	Miriu Gravel. Lower Rawe Beds. Kanam Beds	Gypsum, limestones, sand-stones and clays. Wajir Beds	Magarini sands?

Source : Ojany, F.F. and R.B. Ogendo, Kenya: A Study in Physical and Human Geography, 1988

Table C2.4 Quaternary sediments in north-east Kenya

Recent	River soils and windblown sands		
Upper Pleistocene	Red and brown clays with calcareous nodules		
Middle Pleistocene	Thin laminate limestones		Partly contemporaneous with El Wak Beds
	Ferruginous sandstones and conglomerates		
	Gypsite and gypsum	Wajir Beds	
	Impure limestones		
Lower Pleistocene?	Sandstones	Wajir Beds	
	Clays and sands		

Source : Ojany, F.F. and R.B. Ogendo, Kenya: A Study in Physical and Human Geography, 1988

Table C2.5 Chronology of volcanic eruptions in Kenya

Period	Volcanic Events
Recent	Teleki and Andrew cones in N. Kenya, geothermal activities-hot springs. Upper Menengai volcanics. Basalts in Rift Valley, Simbi Crater. Olivine basalts of Chulu Hills
Upper Pleistocene	Eruption of the main cones in Rift Valley floor-Longonot, Suswa. Early eruptions in Chulu Hills. Eruption of tuffs, pumice showers, Kijabe basalts and Eburu volcanics and comendites. Parasitic vents of Mt. Kenya
Middle Pleistocene	Extensive eruption of pyroclastics in Naivasha area. Aberdare tuffs and trachytes. 2nd major eruption of Mt. Kenya
Lower Pleistocene	Homa basalts. 1st major eruption of Mt. Kenya. Olivine basanites, basalts and trachytes in Limuru, Kijabe and Simba areas. Initial activities in Homa area.
Pliocene	Main eruption of Lower Menengai volcanic series. Nephelinites, trachytes, pyroclastics, phonolites and tuffs in Rift Valley and Naivasha. Londiani agglomerates, Kedowa, Mau, Kinangop and Bahati tuffs. Beginnings of Sattima series-Laikipia and Aberdare eruptions. Main eruption of Mt. Elgon.
Middle Miocene	Londiani and Rumuruti phonolites, Simbara Series. Gwasi and Samburu volcanics. Extensive fissure eruptions-Kapiti, Yatta and Kericho phonolites.

Source : Ojany, F.F. and R.B. Ogendo, Kenya: A Study in Physical and Human Geography, 1988

Table C2.6 A correlated sequence of events along the Kenya coast

Geological time-scale	Terminology of climactic stages	Sea level changes (Kenya)	Major palaeogeographical events at the coast (partly after Caswel,1956)	Kenya artifact cultures	General Pleistocene terminology	Alpine glacial sequence of Europe	Sea level changes (Europe)
Pleistocene	Post-pluvial Nakuran Makalian	Rise and aggradi-tion to the present sea level	Deposition of windblown sands Deposition and silting in Ports Tudor and Reitz, and drowning and silting of creeks	Wilton, Gumblian, Elementaitan	Post-glacial period	Post-glacial	Flandrian trans-gression
Upper Pleistocene	Gamblian pluvial			Magosian, Stillbay, Capsian	Last glacial period	Wûr m glaciation	Generally low
	Third interpluvial	15 feet (4.6 m) OD 30 feet (9.1 m) OD	15 feet (4.6 m) raised beach, caves and platform 30 feet (9.1 m) marine platform 100 feet (30.5 m) knickpoint	Fouresmith	Last interglacial period	Last interglacial	25 feet (7.6 m) OD 60 feet (18.3 m) OD
Middle Pleistocene	Kanjeran pluvial	C-150 feet (45.7 m)	Cutting of deep channels	Pseudo-Stillbay, Acheulian	Penultimate glacial period	Riss glaciation	Very low
	Second interpluvial	C-100 feet (30.5 m)	Coral reefs grow 200 feet (61 m) knickpoint 120 feet (36.6 m) terrace	Acheulian	Penultimate interglacial period	Great interglacial	170 feet (51.8 m)
Lower Pleistocene	Kamasian pluvial	C-200 feet (61 m)	Cutting of marine platform upon which the coral grew	Chellean	Ante-penultimate glacial period	Mindel glaciation	Very low
	First interpluvial	C-220 feet (61 m)	250 feet (76.2 m) knickpoint		Ante-penultimate interglacial period	First interglacial	200 feet (61 m)
	Kageran pluvial				Early glacial period	Gunz glaciation	Lower
Pliocene		C-300 feet (91.4 m)	Deposition of Midadoni beds, Deposition of Magarini sands in a *semi arid condition*				C-300 feet (91.4 m)

Source : Ojany, F.F. and R.B. Ogendo, Kenya: A Study in Physical and Human Geography, 1988

Table C3.1 Unit of chemical constituents and analytical method used by the Water laboratory of MOWD

PARAMETERS	UNIT	ANALYTICAL METHOD USED
pH	pH Scale	Electromeric
Colour	mf pt/l	Lovibond comparator
Turbidity	N.T.U.	Turbidimeter
Permanganate No. (20 min. boiling)	mgO_2/ l	Permanganate oxidation
Conductivity (25°C)	µS/cm	Conductivity meter
Iron	mgFe/l	Calorimetric
Manganese	mgMn/l	A.A.S
Calcium	mg/Ca/l	EDTA titrimetric
Magnesium	mg/Na/l	Flame photometer
Potassium	mgK/l	
Aluminium	mgAl/l	-
Total Hardness	$mgCaCO_3$/ l	E.D.T.A. titrimetric
Total Alkalinity	$mgCaCO_3$/ l	Acid titration to pH 4.5 using pH meter
Chloride mg Cl/l	mgCl/l	Argentometric titration
Flouride	mgF/l	Ion (Electrode) analyser/Alizarin visual method
Nitrate	mgN/l	-
Nitrite	mgN/l	Azo dye, calorimetric
Ammonia	mgN/l	-
Total Nitrogen	mgN/l	-
Sulphate	$mgSO_4$/ l	Turbidimetric
Orthophosphate	mgP/l	Spectrophotometric
Total Suspended Solids	mg/l	Filtration and drying at 105°C
Free Carbon dioxide	mg/l	Titrimetric
Dissolved Oxygen	mg/l	DO meter
TDS	mg/l	Evaporation/calculation from conductivity
Others		

COMMENTS: All methods are adopted from the standard Methods for the Analysis of Water and Wastewaters by AWWA & APHA.

Table C3.2 Information codes for a borehole datum

	Parameter	Type of data	Unit	Data description
1	ID	Borehole number		NUMBER(5)
2	COMPLETION	Completion date		NUMBER(6)
3	STATUS	Status		CHAR(1),
4	USE	Use		CHAR(2),
5	OWNER	Owner		CHAR(1),
6	MONITORING	Monitoring frequency		CHAR(1),
7	POTABILITY	Potability of water		CHAR(1),
8	LONGITUDE	Longitude	degree	NUMBER(8,4),
9	LATITUDE	Latitude	degree	NUMBER(8,4),
10	ALTITUDE	Altitude or elevation	meter	NUMBER(4),
11	MAPNO	Map sheet number		CHAR(11),
12	GRIDX	UTM X grid reference		NUMBER(6),
13	GRIDY	UTM Y grid reference		NUMBER(6),
14	BASIN	Drainage basin		CHAR(3),
15	DISTRICT	District code		NUMBER(2),
16	TOTALDEPTH	Total depth	meter	NUMBER(3),
17	HORIZONS	Number of producing horizons		NUMBER(1),
18	ROCK	Rock type		NUMBER(2),
19	STRUCKDEPTH	Struck water level	meter	NUMBER(3),
20	RESTWL	Rest water level	meter	NUMBER(3),
21	DIAMETER	Diameter at base	centimeter	NUMBER(3),
22	CASING	Type of openings		CHAR(1),
23	BASE	Base blank	meter	NUMBER(3),
24	LENGTHOPEN	Length of openings	meter	NUMBER(3),
25	TESTNO	Number of pumping tests		NUMBER(1),
26	DISCHARGE	Discharge	liter/min	NUMBER(4),
27	DRAWDOWN	Drawdown during the pumping test	meter	NUMBER(5,1),
28	HOURS	Length of pumping	hour	NUMBER(2),
29	RECOVERY	Length of recovery	hour	NUMBER(2),
30	TVALUE	Transmissivity	m2/min	NUMBER(8,6),
31	SVALUE	Storage coefficient		NUMBER(8,6)