INSTITUTE of HYDROLOGY

GROUNDWATER CONDITIONS
IN
BARINGO DISTRICT, KENYA

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GEOLOGY

The project area forms part of the Kenya Rift Valley. Intense volcanic and tectonic activity, with intervening periods of erosion and sedimentation, has occurred in the area since the mid-Miocene. The geology of the area is extremely complex as a result and this is reflected by a wide range of groundwater conditions.

Figure 1 shows the principal rock types and main structures. This has been prepared from 1:125000 geological maps published by the Geological Survey of Kenya[1,2] and the East African Geological Research Unit of Lancaster University[3].

The geology of the area can be divided into two broad types. Most of the area consists of volcanic rocks which consist predominantly of phonolites, trachytes, basalts and tuffs. The sequence becomes progressively younger in age towards the main rift valley and also includes sedimentary formations of generally alluvial or lacustrine origin. The remaining area includes the Kerio Valley and the main Rift Valley of Lake Baringo and Bogoria where Quaternary sediments also of alluvial and lacustrine origin occur.

Numerous, tensional faults occur throughout the area in a predominantly north-south direction and are often marked by prominent escarpments. Faulting has been particularly intense in the area west of Lake Bogoria, where the Plio-Pleistocene sequence of lavas and tuffs has been dissected into many, ribbon-like graben structures.

Recent tectonic activity is restricted mainly to the Baringo-Bogoria basin, in the form of hot springs and shallow-focus earthquakes.

[1] *McCall, G.J.H., 1967 - Geology of the Nakuru-Thompson Falls - Lake Hannington Area. Geol. Surv. Kenya Report No.78.*

[2] *Walsh, J., 1969. Geology of the Eldama Ravine - Kabernet Area. Geol. Surv. Kenya Report No.82.*

[3] *Chapman, G.R., Lippard, S.J., Marlyn, J.E., 1978. The Stratigraphy and Structure of the Kamasia Ragen, Kenya Rift Valley. Quarterly Journal Geol. Soc. of London 135 pt 3.*

AVAILABILITY OF GROUNDWATER DATA

Springs

Groundwater contributes significantly to rural water supplies, which are obtained mainly from springs and spring fed streams draining the Kamasia Hills and the Rift Valley scarps. The springs are low yielding and arise at higher elevations from the volcanic sequence where permeable horizons intersect the ground surface. A systematic survey of these springs has not yet been carried out. Those springs recorded on 1:50000 topographical maps are shown in Figure 2. The spring discharge contribution to gauged rivers in the Perkerra catchment estimated from baseflow analysis to be not less than 15 million m^3/year. No records are available for the springs which occur elsewhere in Baringo District, although we understand a survey of springflow west of Lake Baringo is being undertaken.

Thermal springs, such as Loboi or Maji-ya-Moto, are also used for water supplies. The main thermal springs are shown in Figure 2. Those springs, which occur around and to the west of Lake Bogoria and also north-east of Lake Baringo, have been studied in some detail by the UNDP Geothermal Exploration Project[1]. The annual discharge of the thermal springs around Lake Bogoria has been estimated to be 6.7 million m^3.

Boreholes

The development of deeper groundwater sources using boreholes is at an early stage. A total of 37 boreholes have been identified in the Baringo District (excluding 5 boreholes drilled for carbon dioxide supplies) from the well records of the Ministry of Water Development and reports of the Geological Survey. Borehole locations are shown in Figure 2 and an inventory giving details of each borehole is presented in Appendix A. Twenty-three of the boreholes are situated in the southernmost part of Baringo District in the Eldama Ravine-Lake Solai area. These are mainly associated with the estates in this area and to the south. Elsewhere, borehole supplies serve rural communities but the density of boreholes is very low, large areas having no recorded boreholes. The distribution of boreholes reflects the high cost of borehole construction and operation and the availability of more easily accessible sources of water supply, such as springs or perennial streams.

[1] *Glover, R.B., 1972. Chemical Characteristics of Water and Steam Discharges in the Rift Valley of Kenya. U.N. - Govt. of Kenya Geothermal Exploration Project.*

The majority of the boreholes obtain supplies from the Plio-Pleistocene lavas and tuffs. In the south-eastern part of Baringo District boreholes have been drilled into the sedimentary infills of minor grabens similar to the adjacent Lake Solai catchment area, where many boreholes obtain supplies from similar deposits.

Very few boreholes have been drilled into the alluvial or lacustrine deposits of the Kerio Valley and around Lake Baringo or into the sedimentary deposits of the Plio-Pleistocene sequence. This is presumably due to low population densities in these areas and sufficient water supplies from more accessible sources.

GROUNDWATER REGIONS

A complex relationship exists between geology and groundwater conditions. In order to describe the main features of the hydrogeology, within the limitations of the data, the study area can be divided into two broad physiographic units: the Kapasia Hills-Kerio Valley and the internal drainage basin of the main rift valley. To illustrate more localized variations in the groundwater conditions each of these areas has been divided into regions having particular groundwater conditions. The main aquifer types in each region are summarized in Table 1 and the areas are shown in Figure 2.

The hydrogeology of the study area can be described in general terms only owing to the absence of hydrogeological data over most of the study area. The available information has been supplemented by borehole data from adjacent areas, such as the Laikipia Plateau and areas to the south and south-east in particular, which have similar geological conditions and where boreholes are used for water supply[1,2,3].

[1] *McCall, G.J.H., 1957. Geology and Groundwater Conditions in the Nakuru Area. Min. Public Works (Hydraulic Branch), Tech. Report No.3.*

[2] *McCann, D.L. 1972. A Preliminary Hydrogeologic Evaluation of the Long-Term Yield of Catchments related to Geothermal Prospect Areas in the Rift Valley of Kenya. U.N. - Govt, of Kenya Geothermal Exploration Project.*

[3] *Sir Alexander Gibb & Partners, 1980. Greater Nakuru Water Development Plan, 1980 - 2000 Preliminary Design Study.*

DISTRIBUTION OF MAIN AQUIFER TYPES IN BARINGO DISTRICT TABLE 1

	Weathered Zone Aquifers in Lava Sequences	Sedimentary Deposits
Kapasia Hills - Kerio Valley		
A1 Kerio Valley		Alluvium
A2 Kapasia Hills	Pliocene trachytes and basalts, Miocene phonolites	Pliocene sediments
Baringo - Bogoria Basin		
C1 South	Plio-Pleistocene trachy-phonolites and tuffs Intensely fractured	Sedimentary infills of minor grabens
C2 Central		Quaternary alluvial and lacustrine sediments
C3 North	Pleistocene volcanics	

AQUIFER TYPES AND DESCRIPTIONS

The lava flows have a very low permeability. Hence the volcanic sequence yields groundwater supplies only as a result of included weathered zones and sediments. Fractures and joints also form permeable zones where these are not clay-filled but are of greater importance in controlling groundwater movement.

Weathered Zone Aquifers of the Kapasia Hills

The weathered zones are the principal source of springs and borehole supplies in the Kapasia Hills, where they occur in the Miocene phonolites, and the Pliocene Kabernet trachytes and Kaparaina Basalt Formation, and to the north and south of Lake Baringo in the Pleistocene lava sequences.

Weathered surfaces are probably the most common aquifer type throughout most of the area. These developed when the lava flow surfaces were exposed to weathering and may be associated also with the accumulation of sedimentary deposits prior to being covered by successive flows. The weathered surfaces do not appear to exceed more than one metre in thickness and form a series of locally connected, thin, stratiform aquifers within a succession of lava flows.

Some lavas have rubbly surfaces formed at the time of extrusion and shrinkage joints may develop during rapid cooling of the lava. Whilst such zones form good aquifers they may be localized and infrequent.

The intersection of weathered or fractured zones with the ground surface gives rise to numerous low yielding springs along the foothills of the Kapasia Hills. The springs commonly discharge from perched aquifers and their distribution and discharge are related to local geology, topography and recharge. Elsewhere, the weathered zones occur under confined conditions. Small supplies in the weathered zones, commonly encountered at relatively shallow depth, may be unconfined, whilst the artesian head associated with the deeper main supplies will vary according to the proximity of the source of recharge.

The weathered zones have a very low transmissivity of between 5 to 10 m^2/d. As they probably rarely exceed one metre in thickness their permeability would range from 5 to 10 m/d. Although no determinations of storage coefficients have been made we would anticipate the confined weathered zones to have low values of less than 1×10^{-4}.

The yield from boreholes appears to increase with depth as more zones are intercepted. Generally, drilling is continued until a supply sufficient for local use is obtained. The frequency of weathered zones varies considerably and cannot be easily predicted. Generally the Miocene phonolites comprise thick flows and therefore may have fewer weathered zones than other lava types. In the Miocene phonolites of the Laikipia Plateau borehole logs indicate that about two-thirds of boreholes intersect two or more weathered zones[1]. Whilst the variation in drilled depths and depths to main supplies must also reflect the elevation of the particular site, the median drilled depth of boreholes penetrating weathered zones is 130 m and the median depth to main supply is 105 m. Borehole depths ranging from 100 to 200 m are required generally to obtain an adequate supply.

Test yields of the weathered zone aquifers range from 1.4 to 18 m^3/h, with a median of 8 m^3/h. A more representative indication of borehole yields is provided by the specific capacity (yield per unit drawdown). Only seven pumping test results are available for the weathered zone aquifers, giving a range in specific capacities of 3.5 to 9.1 m^2/d with an average of 6.2 m^2/d. The lower values appear to be associated with the volcanic sequence north of Lake Baringo (area C3).

In the Eldama Ravine area (C1) the weathered zones are associated with tuffs. However, the unaltered pyroclastics have a high porosity but low permeability owing to their fine-grained nature and poor sorting. Welded tuffs have hydraulic characteristics similar to those of lava flows and only form local aquifers where joints and fractures have developed. Tuffs tend to decompose to clay and do not form good aquifers but instead store groundwater which supplies deeper aquifers through fissure connections.

[1] *Bristow, C.M., Temperley, B.N., 1964. Geology and Groundwater Conditions of Central Laikipia. Min of Nat Res (Water Development Dept), Tech. Report No. 2.*

Fractures and joints link the weathered zone aquifers into a single hydraulic unit, although clay-filled fractures produce local discontinuities in the piezometric surface. No boreholes appear to have been sited to deliberately intersect fracture zones as groundwater drains freely through most of the fracture zones to depths beyond acceptable recovery. Whilst such a situation exists in area C1, where fracturing is particularly intensive, this may not be the case in the areas of higher elevation. The fractures should act as local recharge zones, particularly where connected to surface drainage, and hence unconfined water table conditions should be encountered at a depth similar to the elevation of the piezometric surface of the weathered zones.

Sedimentary deposits of the Kerio Valley and Baringo-Bogoria basin

Whilst sedimentary deposits occur in the Kapasia Hills within the lava sequence they occur predominantly in the Kerio Valley (area A1) and in the central area of the main rift valley (area C2). Minor, sediment infilled grabens also occur in the southern area of the main rift valley (area C1).

Sedimentary deposits occur within the lava sequence. These range from localized infills of palaeo-channels by coarsers, alluvial material to extensive deposits of up to 350 m in thickness. The principal sedimentary deposits occur in the Kamasia Hills and around Marigat. They include the Ngorora Formation (silts, diatomites, tuffs and grits) and the Kapthurin Formation (coarse alluvium, silts and tuffs). The outcrops of these deposits, shown in Figure 1, occur in recharge areas and, hence, they could form potentially productive aquifers but no boreholes have yet been drilled into these deposits in the Baringo District.

Fine grained lacustrine deposits of unknown thickness occur in area C2 between Lake Baringo and Bogoria deposited in a previously more extensive lake. These sediments grade laterally into coarser alluvial material towards the valley flanks and are recharged by rivers draining towards Lake Baringo. A borehole (C2115) was drilled into the alluvial/lacustrine deposits at Mukutan. Water was encountered at 3 m although the rest water level was 24 m suggesting perched aquifers are present. The test yield was only 2.3 m^3/h.

There are no test data available for the alluvial sediments but, as these are comprised predominantly of fine sand, permeabilities of about 1 m/d are likely. Coarser deposits could have permeabilities of up to 100 m/d. The shallower, coarse alluvial deposits are likely to be unconfined with storage coefficients in the range of 1×10^{-2} to 1×10^{-1}, although semi-confined conditions are likely to be more widespread with storage coefficients of 1×10^{-3}.

The alluvial deposits of the Kerio Valley (area A1) will have generally similar characteristics to the alluvial areas bordering the Baringo-Bogoria basin. Whilst four boreholes have been drilled to the west of the Kerio River only one borehole (C4838) has been drilled on the east bank for which full results are not yet available. These boreholes were drilled to depths of between about 90 to 160 m. On the west bank water supplies were encountered at depths of about 60 to 90 m with generally no significant change in head, suggesting unconfined conditions. However, the borehole on the east bank at Kabluk encountered water at 5 m with a final rest water level of 13 m indicating that shallow perched aquifers are present. The yield of this borehole was 14 m^3/h but no test results are yet available.

Minor, sediment infilled grabens occur in the south-eastern part of Baringo District in Emsos-Solai area. Boreholes P 84 and P 120 were drilled into these sediments, which include both fluvial and lacustrine deposits. Water was encountered at shallow depths of 20 to 60 m. The highest specific capacities of Baringo District were recorded at these sites, of 600 and 1782 m^2/d respectively, giving corresponding transmissivity values of 443 and 950 m^2/d.

Six dry boreholes were drilled west of Emsoss Escarpment in similar minor grabens with sediments. It would appear that the intensive faulting in this area allows groundwater to penetrate to considerable depth.

GROUNDWATER MOVEMENT

There are insufficient data with which to prepare groundwater contour maps of the area. However, the general directions of groundwater flow are indicated in Figure 2. These are based on the available water level data, the groundwater contour map prepared by McCann[1] for the southern part

1 *McCann, D.L., 1974. Hydrogeologic Investigation of Rift Valley Catchments U.N. - Govt of Kenya Geothermal Exploration Project.*

of the area, and spring elevations. The position of the groundwater divides shown in Figure 2 are based on the dip of the lava sequence and do not coincide with the surface water divides.

The weathered zones are connected by fissures and joints into a relatively continuous, single hydraulic unit. However, where the fissures are clay-filled they tend to produce local discontinuities in the piezometric surface.

Groundwater flows through interconnected weathered zones from the Kamasia Hills, which form a groundwater divide at an elevation of about 2000 m, eastwards towards the Kerio Valley and westwards towards the Baringo-Bogoria basin. The flow then turns to a northerly direction along the axis of each valley. In the Baringo-Bogoria basin the predominant northward flow along the centre of the valley relates to preferred flow in the fracture zones. The piezometric surface declines from 1400 m in area C1 to 800 m at 1^{o}N in area C3, a gradient of 0.005. However, it is not possible to quantify reliably the flow through the main valley due to the complex nature of the groundwater conditions.

Lake Baringo is a freshwater lake in an internal drainage system. This suggests that a proportion of the surface runoff entering the lake moves downwards through the underlying sediments to the deeper volcanic sequence. This water then joins the northward flow of groundwater from the south to move north-eastwards towards Lake Rudolph.

GROUNDWATER RECHARGE

Recharge occurs directly from precipitation and indirectly from runoff. Rainfall is much less than evaporation in the areas of low elevation but greatly exceeds evaporation in the areas of higher elevation. Hence, conditions for direct recharge from rainfall are more favourable in the areas of high elevation, whereas in the valley floor indirect recharge from runoff assumes greater importance. The most favourable conditions for recharge are where perennial rivers follow major fracture zones, such as in the Perkerra catchment.

Part of the infiltration in the areas of high elevation gives rise to springs along the scarp slopes. The discharge of these springs form the baseflow of the larger rivers contributing to recharge of the valley floor. The remaining infiltration moves through fractures and weathered zones towards the valley but a large proportion probably penetrates to considerable depths through the fracture system, part of which re-emerges as thermal springs. Hence, the proportion of recharge available as a resource is mainly restricted to springflow and that within an acceptable depth of recovery. However, it is not possible to distinguish at this stage the volume of recharge actually available as an exploitable resource.

Groundwater levels were measured at five boreholes in or adjacent to the southern part of Baringo District from May 1972 to May 1973. However, as four of these boreholes are confined the changes in water level represent fluctuations in the piezometric surface and, consequently, cannot be used to estimate recharge. The remaining borehole is unconfined with a seasonal fluctuation of 0.25 m but the recharge area cannot be delineated, and, indeed, may only be associated with local fracture zones.

A rainfall-runoff model has been used to estimate recoverable water (direct groundwater recharge and surface runoff) for ungauged catchments. The estimate for the Kabernet area is in agreement with similar estimates made by McCann (1974) for areas to the south of the study area. The model results have been used to estimate infiltration as a percentage of the mean annual precipitation for the meteorological stations at Kabernet, Nginyang, Tangulbei and Marigat to thereby estimate direct recharge for the four main groundwater regions of Baringo District as given in Table 2. Lake areas have been excluded.

GROUNDWATER QUALITY

Water analyses are available for the major rivers, thermal springs, boreholes and Lakes Baringo and Bogoria. The sampling distribution, shown in Figure 2, relates largely to the investigation of geothermal waters by the UNDP Geothermal Project. Appendix B presents chemical analysis data, which is only available for the southern area of the Rift Valley (area C1).

ESTIMATED ANNUAL DIRECT RECHARGE TABLE 2

	Area (km^2)	Precipitation (million m^3/year)	Infiltration (as percentage of rainfall)	Direct Recharge (million m^3/year)
Kapasia-Kerio (A)	2011	1900	10	190
Southern Main Valley (C1)	2591	2480	10	248
Central Main Valley (C2)	1285	788	3	16
Northern Main Valley (C3)	1722	357	2	7
Totals	7609	5525		461

The alkaline volcanic sequence has given rise to a predominantly sodium bicarbonate composition for both the surface waters and groundwaters. The average conductivity (EC) of borehole samples from the southern area of the Rift Valley is about 630 μmhos. The surface waters have generally higher calcium and magnesium than the groundwaters, which may locally give rise to calcium bicarbonate waters in the recharge areas. Fluoride and conductivity values increase in the direction of groundwater flow from recharge areas at higher elevations towards the valley centre. The presence of relatively shallow, thermal waters in the Emining area is suggested by the higher groundwater temperatures (33 - 45°C) in this area.

The groundwaters are of acceptable potable quality, except for fluoride concentrations, which in the floor of the Rift Valley exceed World Health Organisation permissible limits[1]. In the southernmost area the fluoride values average 3.1 mg/l, ranging from 1.6 to 4.5 mg/l. The concentration increases towards the valley centre and relates to thermal water occurrence, the Lake Bogoria thermal springs having an average fluoride level of 127 mg/l. From chemical data for the study area and the Solai-Wasseges catchments to the south-east, fluoride levels of less than 2 mg/l are likely in the recharge areas, whilst fluoride levels of 3 to 5 mg/l or more occur in the centre of the main valley. This would suggest that the Pleistocene volcanic area north of Lake Baringo (area C3) may also contain unacceptable levels of fluoride but that areas of the valley floor recharged by waters draining the escarpment (such as area C2) and the high elevation recharge areas should have more acceptable fluoride levels.

GROUNDWATER DEVELOPMENT

Present Borehole Abstraction

The number of boreholes drilled in Baringo District since 1930 is shown in Figure 3. This illustrates the development of borehole supplies for the southern estate areas in the period of the post-war years and the growing use of boreholes for rural water supplies since Independence.

[1] *WHO International Standards for Drinking Water, 3rd Edition, Geneva 1971.*

Drilled Boreholes, 1930 - 1981

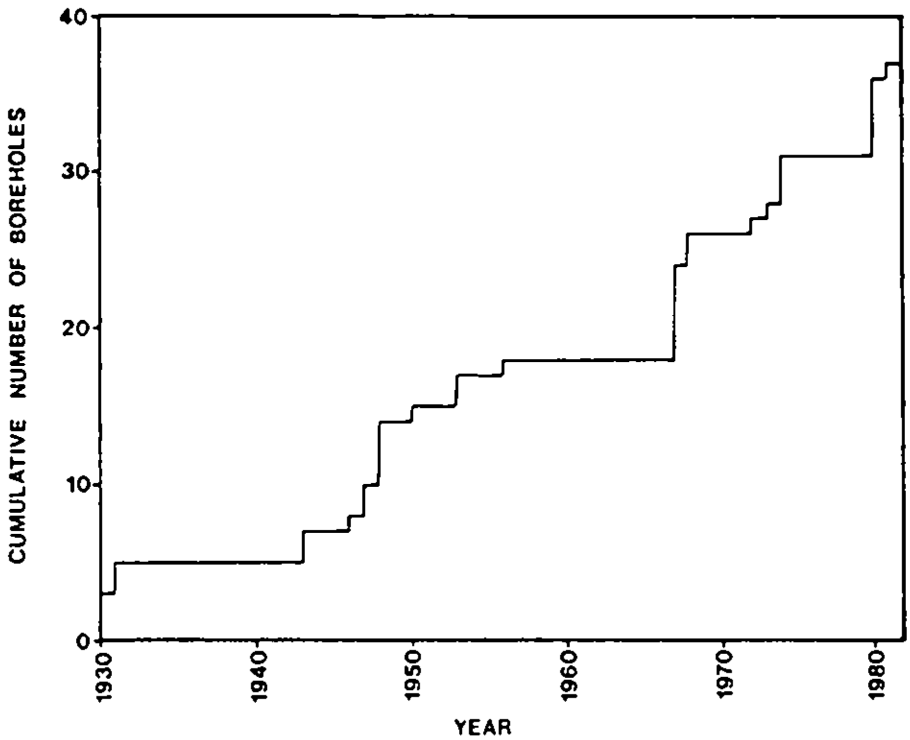

Figure 3

ANNUAL BOREHOLE ABSTRACTIONS TABLE 3

Region	Number of Boreholes	Sum of Test Yields	Estimated Annual Abstraction (million m^3/year)
Kapasia Hills A1	4	53.60	0.094
Eldama Ravine C1	14	94.10	0.165
Lake Baringo C2	3	12.30	0.023
Korosi C3	10	95.06	0.166
Totals:	31	255.06	0.448

The total reported test yields and estimated annual abstraction from boreholes is given in Table 3 for each groundwater region. This is based on 60 per cent of reported test yields and a pumping duration of eight hours per day. The average test yield has been used to estimate the abstraction from seven recent boreholes for which details are unavailable. Only 18 boreholes are reported to be in current use, which, together with the seven recent boreholes, have a total tested yield of 185 m^3/h, or an annual abstraction of 0.33 million m^3.

Development Potential

Direct and indirect recharge greatly exceed the present abstraction from boreholes and local overabstraction is unlikely with the present density of boreholes. However, a significant proportion of the recharge is probably conveyed by fractures to depths beyond acceptable economic recovery, which restricts the potential for groundwater resource development. It is not yet possible to quantify the amount of recoverable recharge and local conditions will determine the resources available for borehole abstraction. Hence, only a broad indication of the groundwater potential is possible at this stage owing to the scarcity of data and the variability in local groundwater occurrence.

The only area of limited groundwater potential that can be identified from borehole records is the Loboi River area in the centre of the main valley (Figure 2). Dry boreholes have been drilled in this area, fluoride levels are generally high (about 5 mg/l) and thermal waters are present. This area appears to be an extension of that identified by McCann (1974) in the Olobanita area to the south.

Weathered Zones

Weathered zones form the predominant aquifer type in area A1, C1 and C3. Springs and spring-fed streams are the main source of supply in these areas at present, the use of borehole supplies being at an early stage. Sustained borehole yields of about 5 m^3/h (60 per cent of median tested yield) are likely in these areas with supplies obtained from depths of 100 to 200 m. The main constraints on the use of boreholes in the weathered zone aquifers are the depth to suitable supplies and the low borehole yields, which are suitable for small-scale water demands only. However, boreholes could provide a supply to supplement other sources during periods of peak demand in local, conjunctive use schemes.

Recharge estimates suggest that greater use of borehole supplies is possible, in the Kapasia Hills and the Eldama Ravine area in particular. Direct recharge in the Kapasia Hills (area A2) would support up to six boreholes per km^2 at the mean annual average abstraction rate and a daily pumping duration of eight hours. However, this density does not take account of local groundwater conditions nor does it allow for the loss from springs or the deep infiltration in fracture zones. Hence, we would suggest that two boreholes per km^2 should be set as an upper borehole density limit until more information can be obtained for this area, and on the weathered zones or groundwater recharge in general. A similar borehole density would be applicable to the south-western area of Baringo District (area C1).

In the valley floor areas, such as area C3 north of Lake Baringo, direct recharge is very low and the development potential of the weathered zones is correspondingly limited. Indirect recharge, which cannot yet be estimated reliably, assumes greater importance in this area and, consequently, boreholes should be sited close to perennial streams.

Sedimentary Deposits

The sedimentary deposits have a favourable groundwater potential. These include the coarser sediments of the Kerio Valley and around Lake Baringo, and the Kapthurin Formation around Marigat in particular. The best supplies should be obtained where coarser deposits are present and where recharged by runoff, provided that downward leakage to deeper aquifers does not occur. However, exploratory investigations of these deposits should first be carried out to obtain information on groundwater occurrence and aquifer characteristics.

FURTHER INVESTIGATIONS

We recommend the following further investigations directed at obtaining additional information to quantify groundwater availability.

The precise location, abstraction regime and current status of all existing borehole supplies should be ascertained. Any operation and maintenance difficulties should also be assessed. A survey of spring locations and discharge should also be carried out.

We do not recommend a regional programme of exploration, but selected areas, for which data is presently unavailable, such as the areas of sedimentary deposits, should be investigated at an early stage for planning purposes. This should comprise an investigation of the type outlined below, which includes a drilling and test pumping programme to determine aquifer parameters and to assess the ability of boreholes to sustain continuous abstraction for prolonged periods.

A sampling programme for stable isotopes (deuterium and oxygen-18) together with chemical analyses from groundwater sources throughout the area should be carried out. This will aid the study of groundwater recharge and flow, particularly the relationship of Lake Baringo to the surrounding alluvium, and to identify those areas where fluoride levels may be unacceptable.

Exploratory Drilling Investigations

We have selected four provisional locations where exploratory drilling and testing would provide information on the thickness and aquifer characteristics of the sedimentary deposits to thereby indicate their potential for development. These locations are as follows:

(1) Kerio Valley. A site west of Kaption would be used in conjunction with the results of a recently drilled borehole further south at Kabluk (C4838), to investigate the groundwater conditions of the Kerio Valley beds in an area of indirect recharge and coarser deposits; to assess aquifer thickness and characteristics; and to examine the inter connection between the alluvium and deeper aquifers.

(2) Baringo Basin

(a) *North of Marigat, near the Nazegul River.* This site would investigate the sequence of coarse deposits comprising the Kapthurin Formation in an area of indirect recharge and in probable connection with the high elevation recharge area of the Kapasia Hills. The geological sequence, aquifer characteristics and thickness would be investigated.

(b) *Ngambo, south of Lake Baringo.* The area comprises alluvial and lacustrine deposits of unknown thickness receiving recharge from the Perkerra and Molo rivers. The aquifer types, their thickness, characteristics and regimes would be investigated.

(c) *Mukutan, east of Lake Baringo.* This site would investigate the aquifer characteristics and interconnection in an area of coarser alluvium on Chesowanja sediments recharged by the Mukutan river.

In each area a preliminary geological survey would be required to identify suitable locations. This should be initially carried out by the use of satellite imagery and aerial-photographs followed by a ground reconnaissance. A geophysical resistivity survey of each area should be carried out to test the use and interpretation of such techniques to identify variations in the thickness of sediments.

Two boreholes should be drilled at each site, comprising a 200 m diameter exploratory/production well and a 100 mm diameter observation well 25 m from the exploratory well. The provisional depth of each well should be 125 m. As each well will be drilled into unconsolidated formations, slotted casing (or screen) and possibly also a gravel pack will be required together with sieve anlaysis of selected samples and a full geological description of the strata encountered.

A controlled pumping test using a suitable pump should be carried out at each site. This should comprise a five-stage, step-drawdown test at different pumping rates between 30 and 100 per cent of the maximum potential yield. Each step should continue without interruption for three hours. After full recovery of the water levels a constant rate test of not less than seven days duration should be carried out. Drawdowns should be measured at frequent intervals in both the production and observation wells during each test together with recovery following the constant rate test.

Water samples should be taken for chemical and stable isotope analysis during each test.

APPENDIX A

BOREHOLE INVENTORY FOR BARINGO DISTRICT

Area	Borehole	Map	Locality	Grid Ref.	Elevation (m)	Depth (m)	Depth water struck (m)	Depth to Rest water Level (m)	Date Drilled	Tested yield (m^3/h)
A	C4838	90/3	Kabluk			143		13	1981	14
A2	C3526	90/4	Karbartonjo	107703	2134	166	64	56	1968	Dry
	C3506	90/3	Kabernet	045549		152	103	13	1968	13.62
	C4722	90/3	"			155		30	1980	18.0
	C4780	90/3								
C	P84	105/3	Ngendalel	783082	1533	62			1930	9.54
	P94	105/3	Ol Kokwe	783135		27			1930	Dry
	P120	105/3	"	785145	1501	30	20	13	1930	6.9
	P138	105/3	Magurin	712061		112	110	110	1931	Dry
	C284	105/3	"	712048	1676	66			1943	Dry
	P148	104/4	Ngubereti	235067	1601	95	85	79	1931	4.5
	C478	104/4	Legetewet	223044	1431	123	117	78	1946	7.74
	C285	105/3	Magurin	765021	1676	111	102	102	1943	Abandoned
	C2484	105/3	"	765021	1830	122	111	102	1956	4.02
	C583	105/3	Sertonji	738085	1061	183			1947	Dry
	C616	104/4	Sagasakat	185092	2042	96	81		1947	10.14
	C626	104/3	Eldama	091095	1890	152	140	121	1948	4.5
	C708	104/3	"	038042	2134	177	116	113	1948	1.4
	C722	104/3		051063	2134	140	130	50	1948	8.64
	C711	118/2			1646	141	139	47	1948	5.46
	C1406	104/4	Legetewet	223046	1631	143	136	87	1950	9.12
	C2124	104/3	Toronjo	873143	2606	134	70	55	1953	3.24
	C3433	104/3	Eldama	050064	2134	128	115	33	1967	10.9
	C3935	104/4	Chemogoch		1585	152	128		1973	Dry
	[C525]	104/4	Kiptuim	190040		183			1947	
	[C526]	104/4	"	176068	1660	162	107		1946	
	[C576]	104/4	"	206996	1685	123			1947	
	[C1280]	104/4	Esageri	148026		112			1950	
	[C2928]	104/4	Kiptuim	176667		164				

Area	Borehole	Map	Locality	Grid Ref.	Elevation (m)	Depth (m)	Depth water struck (m)	Depth to Rest water level (m)	Date Drilled	Tested yield (m^3/h)
C2	C2115	91/4	Mukutan		1266	61	5	24	1953	2.3
	C4077	104/2	Marigat		1020	226	220	84	1974	11.0
C3	C3437	91/2	Tangulbei	963897	1219	183	99	93	1967	9.06
	C3440	91/1	Chepkonghio	748998					1967	
	C3461	77/3	Losikipiomoi	951145	915	134	108	101	1967	4.38
	C3470	90/2	Chemalingot	307088	1036	122	117	30	1967	9.06
	C3466	91/1	Chepkonghio	793991	914	76	40	38	1967	12.72
	C3868	91/1	Nginyang	672052	915	121	91	9	1972	9.84
	C4062	91/2			1524				1974	
	C4061	91/2			2068			120	1974	
	C4786		Oldebesi							
	C4787		Mugukin							

Note: Borehole reference numbers in parentheses were drilled for CO_2 supplies

PUMPING TEST RESULTS FOR BARINGO DISTRICT

Borehole	Test Rate (m^3/h)	Duration (hr)	Depth to Pumping water level (m)	Drawdown (m)	Specific Capacity (m^2/d)	Transmissivity (m^2/d)	Geology
C3506	13.6		54	41.1	8	8	Kabernet trachytes
P120	3.6		13	0.05	1728	950	Sediment infilled graben
P84	4.25		42.87	0.17	600	443	
C2484	4.02		113	10.7	9.1	9	L. Bogoria trachyphonolites
C2124	3.24			12.2			Trachytes and phonolites
C3433	10.9	50	79	45.7	4.3		Eldama Ravine tuffs
C4077	8.3	8	116	31.7	8.3		Tuffs
C3461	3.9	24	128	27.1	3.9		Tachyphonolite/Tuffs?
C3470	3.4	30	92	62.4	3.4		Tuffs, diatomite/ Basalt?

APPENDIX B

CHEMICAL ANALYSES

Location	Temp. (°C)	pH	EC µmhos	Na	Ca	Mg		HCO_3 mg/ℓ	SO_4			SiO_2	Fe	Date
Boreholes														
C616	29	7.25	850	120	5.8	33.1	22.2	492	16	11.7	1.6	82		6/71
P148	35	7.45	660	138	11.2	6.8	27	367	49	26.5	3.1	60		6/71
C1406	44	7.6	790	163	11.5	7.4	33.3	483	16	22.9	2.7	64		6/71
C711	36	7.25	485	108	3.9	0.7	23.8	259	12.5	16.5	2.6	76		6/71
C795	29	6.9		124	3.9	0.2	8.7	326	15	6.9	4.1	87		5/72
C943	29	7.3	520	116	4.2	0.3	11.8	304	13.2	8.2	4.5	76		5/71
P120	24	7.02	460	100	4.8	1.0	10.5	182	56	12.0	4.4	66		5/72
Springs														
Loboi	36	7.05		128	2.6	1.1	15	330	11.5	11	4.1	89		7/71
Maji-ya-Moto	33.4	7.3		118	6.6	1.2	14.9	297	10.5	10.3	4.1	88		7/71
Emsos	35	7.55		105	6.3	2.8	12.8	245	16	10.3	4.95	57		7/71
				72	11	3	12	268	5	30	2.6	55		7/74
Rivers														
Rongai		7.8	170	27	5.2	1.3	14.9	78	8	7.9	1.2	60		12/71
Ndolaita		7.2	420	113	1.7	0.9	13.5	268	17	9	4.5	89		12/71
Wasseges		7.75		33.5	12	4.6	6.6	131	4	9.3	0.95	30		7/71
		8.1		36	21	9	11	156	8	18	Nil	25		5/74
Lakes														
Baringo	26	8.6		159			19	406		34.9	6	55		6/72
Bogaria		9.97		31370	2.0	0.2	544	9520	318	6435	1143	336		7/71