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SOIL AND WATER MANAGEMENT Report No. 4

KENYA
MARGINAL/SEMI-ARID LANDS PRE-INVESTMENT INVENTORY

PN-ABT-759

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MARGINAL/SEMI-ARID LANDS

PRE-INVESTMENT INVETORY

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MARGINAL/SEMI ARID LANDS PRE-INVESTMENT STUDY

Soil and Water Management

Final Report

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Summary

This report, a part of a Pre-Investment study of the Marginal-Semi Arid lands conducted within Embu, Kitui and Machakos Districts of the Eastern Province, and Baringo and Kiriyo - Maraquet Districts of the Rift Valley Province was prepared by the Engineers regarding the Soil and Water management aspects of the study.

Land misuse in these areas has resulted in a considerable amount of erosion, ranging from complete loss of top soil and deep gullies in some localities to minor amounts of erosion in others. The misuse has been unmanaged grazing, resulting in partial to complete removal of perennial vegetation, and cultivation of steep slopes without taking necessary soil conservation measures. Thus erosion is severe on the grazing areas as there is none or little vegetation to protect this soil during the high intensity rains common in the study area and the cultivated areas on slopes are extremely vulnerable to erosion if conservation is not practiced.

Streams which were at one time perennial, now flow only during and shortly after rain storms. The streams also carry high sediment loads which tends to fill existing reservoirs and cause pollution of the lakes and the ocean to which they flow.

The available meteorological and hydrological data is limited, which makes it difficult to plan soil and water management practices intelligently. There are only four complete meteorological stations in the study areas. Precipitation stations are fairly well distributed in Machakos, Embu and Kitui Districts, but there are only six within the boundaries of the study area in the Baringo District. The data collection is mainly in the high potential areas. Very little streamflow data is available except for the major streams.

Experiments have been conducted in the study area which show that with proper management the grazing areas can adequately carry more than the number now being grazed. One in Machakos District in 1949-50 demonstrated that with good management practices the area could carry as many as ten times more animals than it had formerly which indicates that with proper management the land could carry at least as many animals as there are now without deterioration of the land. Some special precautions may need to be taken during periods of prolonged drought.

Many people look on irrigation projects as a panacea for water and land problems. This is not the case. Irrigation projects in developing countries are more prone to failure than other kinds of projects. Of the several irrigation schemes in Kenya, it is reported that only one has any degree of success. To be successful an irrigation scheme must be well planned, designed and managed. This includes the resources, the engineering works, the management, and the training of the irrigators. The social aspects are also an important consideration. It is believed that the schemes in Kenya could become successful by changing some of the

social and management constraints on the schemes.

The extent of irrigation in this country will always be limited because of the availability of water. Management of this resource is very important to the country.

Domestic and livestock water supply is considered by most rural people to be most important need within the study area. The government is working hard to develop a supply for all the people. Much can be done to assist in this by aiding the rural people, particularly in remote areas, to collect and store their own water. This would be such things as roof catchments, rock catchments, sub-surface dams and small surface dams. It is not practical to reach all people in remote areas with a reticulated water supply.

The number of Kenyans trained in soil and water management is very limited. To prevent the extreme loss of soil and water before irrepairable damage is done, an accelerated program of training in soil and water is necessary. This includes those in top administrative positions in government, those in the Provinces and Districts as well as technicians and farmers in the fields. A viable extension staff with training in soil and water could give advice and training to farmers.

Soil and Water Management

1.1 Introduction

Soil and water are two of Kenya's most valuable natural resources. Without proper managementof these resources, the optimum agriculture production of the country cannot be realized. The management of soil and water must be planned and accomplished together, as that which is done with one effects that which must be done with the other. The primary objective of soil and water management is to keep the soil in place where it is formed and to retain the water on the land where it falls as precipitation. Water, except that which is evaporated or transpired and gets back into the atmosphere as vapor, is being pulled downward by the force of gravity. If this downward movement can be curtailed so that it does not move the soil with it, then the problems of soil movement, except that which is moved by the wind, are solved by the management of the water.

In a rainfed agriculture such as the marginal, semi-arid lands of Kenya, it is necessary to retain as much as possible of the precipitation in the soil to be available to the plants. The run-off must be controlled by tillage practices, vegetative cover, land use, mechanical structures, or other practices to direct it to where it can be utilized effectively without causing damage to the environment.

Continual development of the country will be influenced considerably by the way these resources are managed. Water is indispensible for the existance of plant and animal life, its quantity and quality in the atmosphere and the soil have a bearing on the amount and kind of life in an area. The total available water in Kenya is not a great amount. It is estimated that the total available water for irrigation over the whole country in terms of depth is less than 30 mm. By comparison the United States has more than 300 mm. available over the entire country. The objective of soil and water management is to make these resources available for utilization without waste for a high level of land and water use which can be continued for an indefinite period.

The Engineer group of the Marginal Lands Study Team has visited with those people concerned with soil and water management at all levels of government, at the University of Nairobi and other educational institutions, those in the private sector, and with farmers in the field to determine their attitudes and ideas regarding soil and water management. Most of the study area has also been visited to observe conditions as they are. The people at all levels realize the importance of doing something regarding soil and water management, and the help they need most is assistance from experienced technicians trained in this area. They are anxious to do something, but don't know the best way to accomplish that which needs to be done.

The little watersat the head of the catchment areas are of extreme importance. They create the big rivers and the

large bodies of water. If these waters are stored at the place where they fall by infiltration into the soil, in natural depressions, or in depressions made by man, then their movement to lower elevations will be slowed so that the rivers will not have as high a flood peak; they will flow longer after the rains occur and the water will be more accessible for use by plants and man. The first step in water management is to control the little waters at the head of the catchments.

1.1.1 Infiltration

Infiltration into the soil is of primary importance. If water is to be conserved in the soil and made available for plant use, it must first pass through the surface of the soil. If a high infiltration rate is maintained, less water will pass over the soil surface and soil erosion will be reduced. The infiltration rate in much of the study area is relatively low.

Duley (1939) points out that the reduction in the rate of intake of water through the surface is accomplished by the formation of a compact layer on the surface. This layer is a result of breakdown of structure due in part to the beating action of the raindrops and in part to the sorting action of the water flowing over the surface, filtering the fine soil particles around the larger ones to form a relatively impervious seal. The livestock tramping over an area also tend to reduce the intake rate of the soil.

Vegetative cover has considerable influence on infiltration rates. This cover may be grasses or other close growing vegetation as well as mulches. It has been shown that when infiltration rates are determined for soil protected by vegetation and the vegetation is removed, surface sealing occurs rapidly. (Schwab, et. al. 1966) Other factors such as slope, antecedent moisture, and water temperature have some effect on the infiltration rate, but these cannot be changed much by man. In general it may be said that the better the agricultural practices, the higher will be the rate of infiltration.

1.1.2 Soil Water

Soil is capable of holding a given amount of water against the force of gravity by means of capillary forces. The maximum amount of water a soil can hold in this way is known as its field capacity. In dry periods the amount of water in the soil will be reduced by evaporation and transpiration. As the amount of water becomes less and less, the suction exerted by the soil on the water becomes greater and greater, until it is so great that the plants are unable to extract the water from the soil as fast as the plants require the water. Then the plants begin to wilt. It is the difference in the amount of moisture at wilting and field capacity that is available for plant use. Plant growth will in general be an optimum if the soil moisture is replenished well before the wilting point is reached, as stress to the plant occurs when the soil moisture drops significantly below field

capacity.

Table 1 REPRESENTATIVE PHYSICAL PROPERTIES OF SOIL*

Soil Texture	Infiltration[1] Inches/hour	Total Pore Space %	Apparent Specific Gravity	Field Capacity % PW	Permanent Wilting % PW	Total Available Moisture[2] Inches per Foot
Sandy	2	38	1.65	9	4	1.0
Sandy Loam	1	43	1.50	14	6	1.4
Loam	0.5	47	1.40	22	10	2.0
Clay Loam	0.3	49	1.35	27	13	2.3
Silty Clay	0.1	51	1.30	31	15	2.5
Clay	0.2	53	1.25	35	17	2.7

[1]Intake rates vary greatly with soil structure and structural stability.

[2]Readily available moisture is approximately 75% of the total available moisture.

*From (Israelsen & Hansen 1962)

1.2 Climatology and Hydrology

This will be described in the sections of this report which deal with the two separate study areas, except for some of the aspects of climatology and hydrology which are common to both areas.

1.2.2 Temperatures

Mean temperatures in Kenyaare closely related to elevation above sea level. The East African Metecrological Department gives the following equation for the mean annual temperature; $T = 30.2 - 6.5 \times E$ (°C) where E is the elevation above mean sea level in thousands of meters. They also have derived equations for each of the months of the year. (East African Meteorological Department, 1970) Annual temperature variat-

ions are small.

1.2.3 Sunshine and Radiation

There are no reported observations of daily sunshine in the area. Woodhead (1968) prepared maps of Kenya showing the daily sunshine hours for each month. These vary from a low of 6.5 hours in July to a high of 9.5 hours in both January and February.

1.2.4 Winds

Wind runs are measured at most of the meteorological stations. The runs are highest in September and October and lowest in June and December. At least in the study area, the wind is not a major factor causing soil erosion.

1.2.5 Precipitation

The precipitation pattern shows a strong seasonal variation throughout the country. In the Eastern and Central area there are two rainy seasons. The long rains occuring during March through May and the short rains during October through December. April is generally the month having most rain, but there are many stations where the heaviest rains have been recorded in November. In the Western Rift Valley and Western areas the rainfall is highest during March through September and lowest during January and February.

The variations from year to year of rainfall are considerable and the time of beginning and end of the rainy periods are very erratic, especially in the drier areas. This makes it difficult to give a desirable planting date for crops.

1.2.6 Relative Humidity

This generally decreases with an increase in elevation and is higher where there is a vegetative cover and lower where there is none. It is always a maximum when the temperature is a minimum (morning), and a minimum when the temperature is a maximum (afternoon). In highly vegetated areas the maximum is between 60 and 70 percent. The minimum is about 40 percent.

1.2.7 Evaporation

Evaporation pans are used to estimate evaporation losses from natural surfaces. The pan evaporation is affected by many variables, including wind movement, pan diameter, water temperature, air pressure, depth of pan, and wind and wave action. Pan evaporation is converted to natural surface evaporation by using a coefficient which varies between 0.65 and 0.80. (Chow 1964)

Woodhead (1968) computed values of the Penman estimate of potential evaporation (E_o) for several locations in Kenya. The mean monthly and the mean annual evaporation rates are displayed in tabular form and on a series of maps.

Evaporation data are an essentail element in determination of crop water requirements, and upon the feasibility of irri-

gation projects. They are also essential to research and management of catchment areas. Agriculturalists and hydrologists have agreed that the Penman estimate of potential evaporation (Penman 1948) is the most suitable evaluation of evaporation for tropical East Africa.

Data for eighty stations are listed in Woodhead's report. These include the E_o in millimeters per day and E_o in millimeters per month. The effect of altitude on the annual evaporation estimate was established by Woodhead (1968) from the weighted regression; $E_o = 2422 - 0.358\ h$, where E_o is in millimeter per annum and h the altitude above mean sea level, in meters. Values of E_o of locations within the study area are given in Appendix Table.1

1.2.8 Evapotranspiration(ET)

This is the conversion to vapor and mixing with the atmosphere of the liquid water evaporated from the soil or soil surface and that transpired by the plants. Two different methods are used to get measurements of ET. The water balance method which include soil water depletion measurements and the use of lysimeters, and the empirical methods or empirical formulae. Because of the lack of data and the difficulty and time involved in getting ET by direct measurements, the use of empirical formulae is more common in planning of water development projects. Many formulae have been developed for determining ET which are based on meteorological data. These formulae give acceptable results when used in the conditions for which they were developed. The formulae are best suited to potential evapotranspiration (ETP). This is the amount of water evaporated and transpired from a growing, short full crop cover (usually grass) with a continuously adequate moisture supply. The ETP is related to irrigation requirements of other crops by crop coefficients which are based on actual water use data from field experiments.

The potential evaporation obtained by Woodhead (1968), using the Penman method and considered as the most suitable for use in tropical East Africa, is related to ETP by using a reduction coefficient of 0.8.

1.2.9 Streamflow

There are five drainage areas in Kenya. The area covered by this report is part of three of these areas. The Lake Baringo District and Kerio Valley is in Drainage Area No.2 which drains primarily into Lake Rudolph in the north with subdrainage basins discharging into a number of smaller lakes. The Machakos-Kitui-Embu Districts are Drainage Area No.3 (Athi River) and Drainage Area No.4 (Tana River). The Tana River is the largest river in Kenya.

The streams within the study area are ephemeral except parts of the Athi and the Tana with some of its major tributaries.

River gauging stations are maintained and operated by the Hydrology section of the Ministry of Water Development on most

of the major streams, but there are no records of streamflow on many of the smaller streams.

The development firm of Tippets, Abbot, McCarthy and Stratton (TAMS) has developed a computer model which gives the runoff of the entire country. They have prepared maps which show runoff isolines in millimeters per annum. Appendix 1 Table 2 of this report gives drainage basins areas and runoffs in mm for streams in the study areas.

1.2.10 Groundwater

A study of groundwater resources in the study area for the Marginal Lands Study has been made by a Hydrogeologist, George C. Taylor, Jr. Results of this study will be included with the final report of the Study Team. His findings are that the groundwater is of small quantity and no major irrigation development can be expected by use of groundwater.(Appendix 4)

1.2.11 Ecological Climatic Zones

At a Research Conference on Rangeland Productivity held in Kitale in June 1964, a committee was established to prepare definitions and categories of the main vegetative types of East Africa with reference to rangeland potential. In May 1965, the committee submitted its report to a second Research Conference which was approved by the conference.

The following zones are recommended by the committee:

I. Afro-alpine moorland and grassland, at high altitude above the forest line, of limited range use and low range potential.

II. Humid to dry sub-humid (moisture index not less than-10). Forests and derived grasslands and bushlands, with or without natural glades. The potential is for forestry or intensive agriculture. Areas at present under range-use require intensive management for optimum production. 1-2.5 hectare are usually required per stock unit.

III. Dry sub-humid to semi-arid (Moisture indices - 10 to -30). Land not of forest potential, carrying a variable vegetation cover, trees characteristic broad leaved, and the larger shrubs mostly evergreen. The agricultural potential is high, soil and topography permitting. Areas under range use are extensive and under intensive management. Their stock carrying capacity is high (less than 2 hectares per stock unit).

IV Semi-arid (moisture indices -30 to -50). Land of marginal agricultural potential, carrying as natural vegetation dry forms of woodland or equivalent bush-land. This is potentially productive range land, usually less than 4 hectares required per stock unit-limited mainly by encroachment of woody species. The grasslands are notably sensitive to severe grazing.

V. Arid (moisture indices -40 to -50). Land only locally suited to agriculture, woody vegetation being dominated by comminphora, Acacia and allied genera. Perennial grasses can dominate, but succumb readily if the range is managed harshly. More than 4 hectares is required per stock unit. Wildlife could constitute an alternative to domestic stock, particularly where dry thorn-bush predominates. Burning must be done with great caution, but can be highly effective in brush control.

VI Very arid (moisture indices -50 to -60). Rangeland of low potentail. The vegetation being dwarf shrub grassland or a very dry form of bushed grassland. The vegetation may be confined to runnels, depressions, and water courses with barren land between. Perennial grasses are localized within a predominantly annual grassland. Productivity is confined largely to unreliable seasonal flushes; and grazing systems must be flexible and based on nomadism. Wildlife is important, but the populations are restricted by the environment.

Woodhead (1968) presented a classification of East African Rangeland using a climatic index which quantifies the annual water balance. In this classification the rainfall has been compared with Penman's (1948) estimate of potential evaporation to derive an index which allowing for shortage of water in the profile might express the exploitable rainfall in terms which can be related to potential or actual vegetation. Total annual rainfall less total water surplus, representing the water available for evaporation or transpiration. is expressed as a precentage fraction of the annual total of potential evaporation to yield the available water index. Woodhead (1968) divided Zone VI of the Research Conference of May 1965 into Zones VI and VII in Table 2. The relation between ecological zone and available water index is given in this table.

Table 2

Ecological Zone	Vegetation Type	Available Water Index
I	Afro-alpine	Not delineated
II	Forest	61-100
III	Moist Woodland	46-60
IV	Dry Woodland	31-45
V	Dry thorn-bushland	12-30
VI	Semi-desert	5-11
VII	Desert	0-4

Table 3 RELATIONSHIP BETWEEN AVAILABLE WATER INDEX AND THE CLIMATIC INDEX

Climatic Index	Available Water Index
0 and above	75-100
-10	67-83
-20	60-67
-30	50
-40	33
-50	17
-60	0

The larger part of the study area is Zone IV with some in each of Zones III and V.

1.3 Soil Erosion

Although soil erosion problems in Kenya have been recognized for some time, changing land use patterns tend to accelerate the rates of erosion in some areas. High infiltration rates, which reduces surface run-off and soil erosion are features of well maintained forests. As the forest cover is being removed in many areas of Kenya, soil erosion is increasing because with the removal of the cover, the soil becomes unstable and moves down the slopes with the run-off water. Tree cover alone on forests does not give assurance that soil erosion will not occur. Removal of ground cover by grazing or fire will result in an increased rate of erosion even though the trees remain.

In semi-arid areas grassland may have large amounts of soil erosion. Native grass cover tends to be seasonal and at times provides little protection of the soil. Also unmanaged grazing is common in the semi-arid areas of Kenya. The resultant removal of cover intensifies the problem of soil erosion. The compaction of the surface by the grazing animals reduces the infiltration rate and increases the run-off and soil erosion.

Good management of land under crops with improved practices are the best measures to reduce erosion on cropland. Good management practices such as contour cultivation, strip cropping, grass strips, or building of terraces will break up the flow patterns and increase the infiltration rate. The proper use of fertilizers, the incorporation of organic matter, including crop residues into the soil, and also proper rotation of crops improve the soil structure and increase the infiltration rate which reduces the amount of surface run-off and the erosion of soil.

Clearing of steep slopes (above 12%) for crop cultivation without providing proper erosion control measures greatly accelerates the erosion rate on these slopes. Erosion control measures should be planned before any land is cleared for cultivation. Construction of these planned measures should be accomplished as soon as clearing is done, as large amounts of topsoil may be removed in a single storm of high intensity.

1.3.1 Soil Losses

The importance of soil loss is indicated by the effect of topsoil depth on crop yield as shown in Figure 1, the data for this curve were compiled from many areas.

Studies in New York by Free (1956) on paired run-off plots which compared up and downhill tillage with contour practice showed that crop yield differences varied significantly in favor of contouring each year, and after twelve years cumulative benefits resulted in a 21.3 percent increase for contouring.

The following table from Hudson (1971) indicates that farming practices which reduce soil erosion also increases crop yields. The reduction of 230 mm of runoff saved by the high yielding crop would certainly offset any additional water use by that crop.

Table 4 THE EFFECT OF CROP MANAGEMENT ON THE SOIL AND WATER LOSSES FROM MAIZE

Plot A		Plot B
Maize at medium level of production		Maize at high level of production
25,000 plants/ha	Plant Population	37,000 plants/ha
N 20 kg/ha	Fertilizer Application	N 100 kg/ha
P_2O_5 50 kg/ha		P_2O_5 80 kg/ha
Removed	Crop Residue	Ploughed in
5 ton/ha	Crop Yield	10 ton/ha
250 mm	Runoff	20 mm
12.3 ton/ha	Soil Loss	0.7 ton/ha

This would indicate that using agricultural practices which reduces soil loss also produces high yields merely because of those practices. The reduction in soil loss would also allow agriculture to be practiced much longer on the high yielding plots. It would be inevitable that eventually crops could not be grown at all because there would be no soil left.

Using the results from this experiment, the total soil loss to produce 100 tons of grain would be:

Table 5 SOIL LOST DURING PRODUCTION OF 100 TONS OF GRAIN

Medium level of yield		High level of yield
5 tons/ha	yield of crop	10 ton/ha
20 ha	area required	10 ha
246 tons	probable soil loss	7 tons

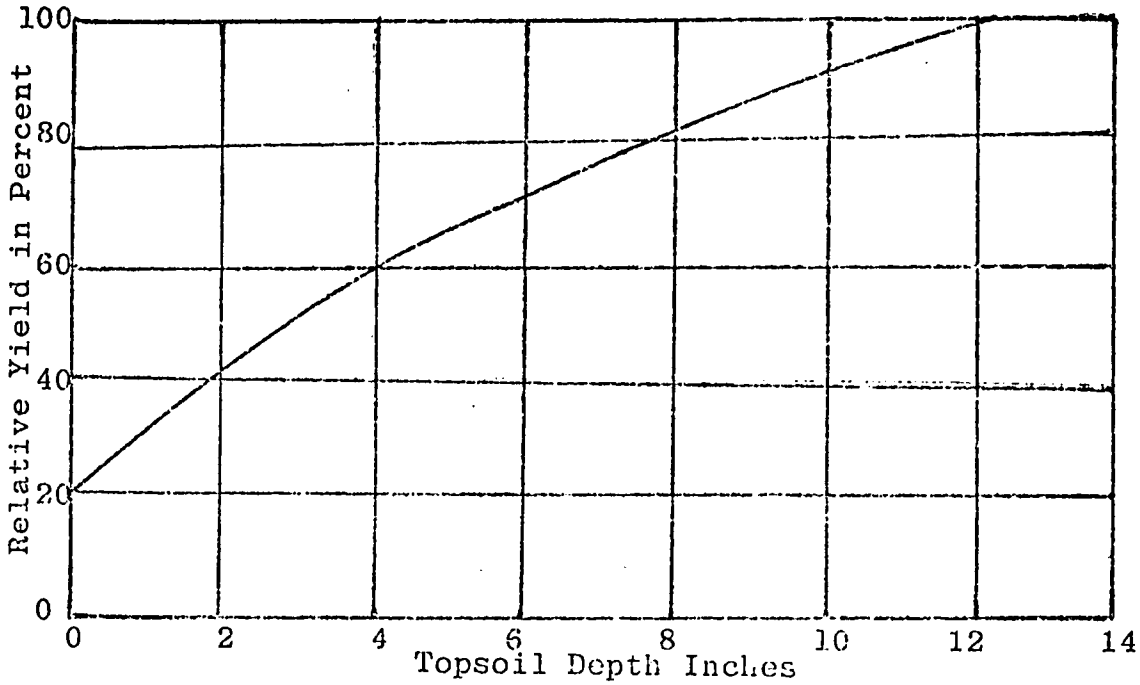


FIG. 1 Effect of Topsoil Depth on Crop Yield

Soil Loss measurements are obtained from small plots where rainfall simulators are used to produce storms of a given length and intensity. Soil loss measurements for the marginal lands of Kenya are not available. Suspended sediment load measurements were made on many rivers in Kenya and reported by Thomas Dunne in 1974. Measurements of the bed loads were not made. A project jointly funded by the Kenya government and the U.K. Ministry of Overseas Development to provide methods of assessing water resources, soil losses from small catchments, and silt loads of seasonal rivers has begun in the study area.

The Universal Soil Loss Equation (USLE), which was developed in the United States by Wischmeier et.al. (1958) is used to determine soil losses under various conditions. The basic equation is A = R x K x L x S x C x P where;

A is soil loss in short tons per acre

R is the rainfall erosivity index

K is the soil erodibility factor

L is the slope length factor

S is the slope factor

C is the crop management factor

Pis conservation practice factor

The rainfall erosivity index and the soil erodibility factors have not been determined for all parts of Kenya. Dr. Wenner has estimated the rainfall erosivity index (R)

to be 200 for the Eastern Province study area, and the Baringo-Kerio Valley.

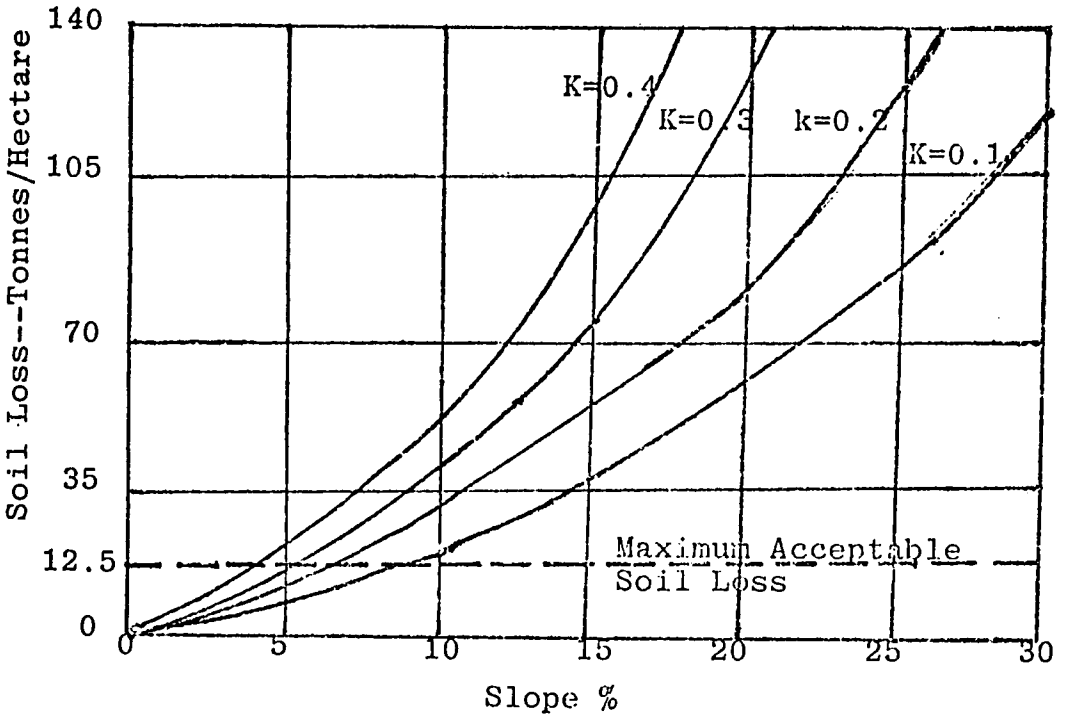


FIG.2 Soil Loss as Function of Slope and Soil Type

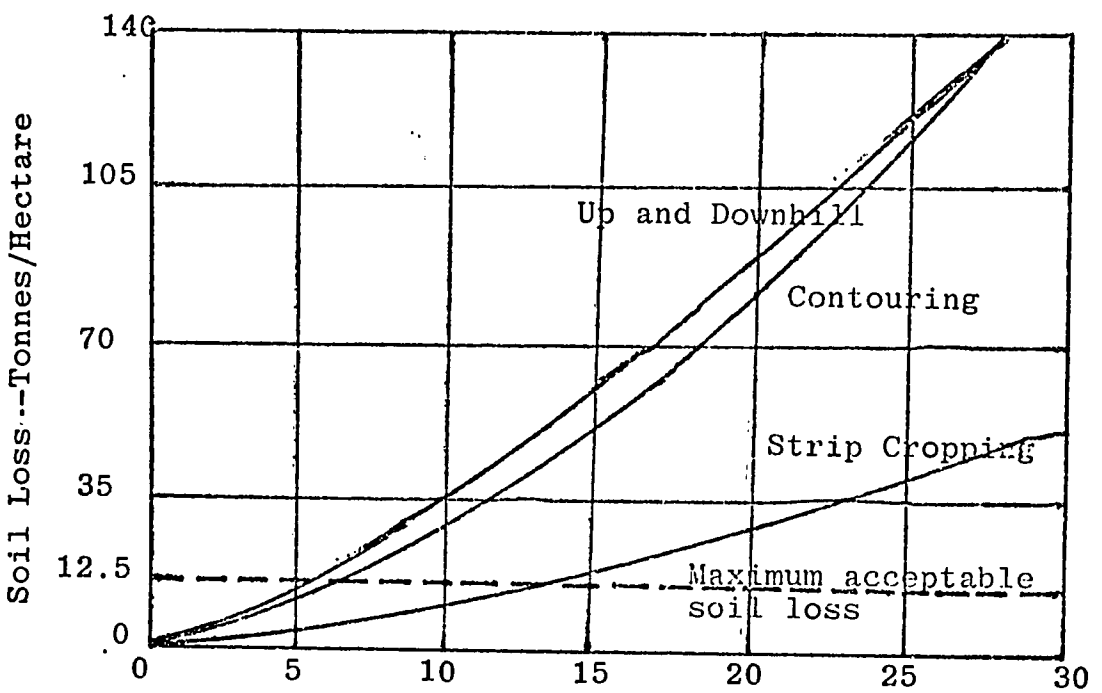


FIG. 3 Soil Loss as Function of Slope and Practice

The energy of moving water detaches and transports soil materials. The energy-intensity (EI) value measures total raindrop energy of a storm and its relation to the maximum 30 minute intensity. Soil losses are linearly proportional to the number of EI units

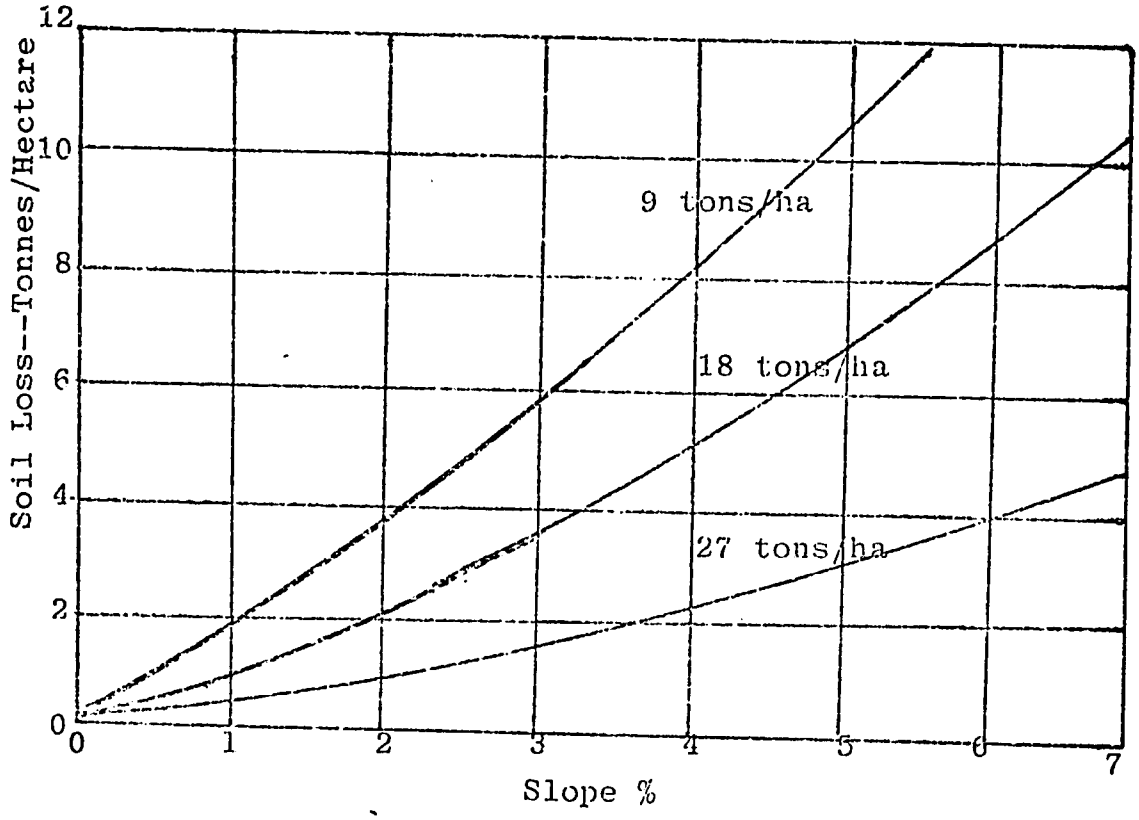


FIG. 4 Erosion for different levels of production of Maize

The capability of soil to resist erosion is a function of its physical and chemical properties. The most significant of these are texture, organic matter, structure, and permeability. In certain areas K values have been assigned to named kinds of soils. The assignment of K values has not been done in Kenya. The following values of general soil types are probably the best estimate to use here.

Sand and loamy sand	0.1
Sandy loam	0.25
Loam and silt loam	0.4
Clay loam	0.3
Clay	0.2

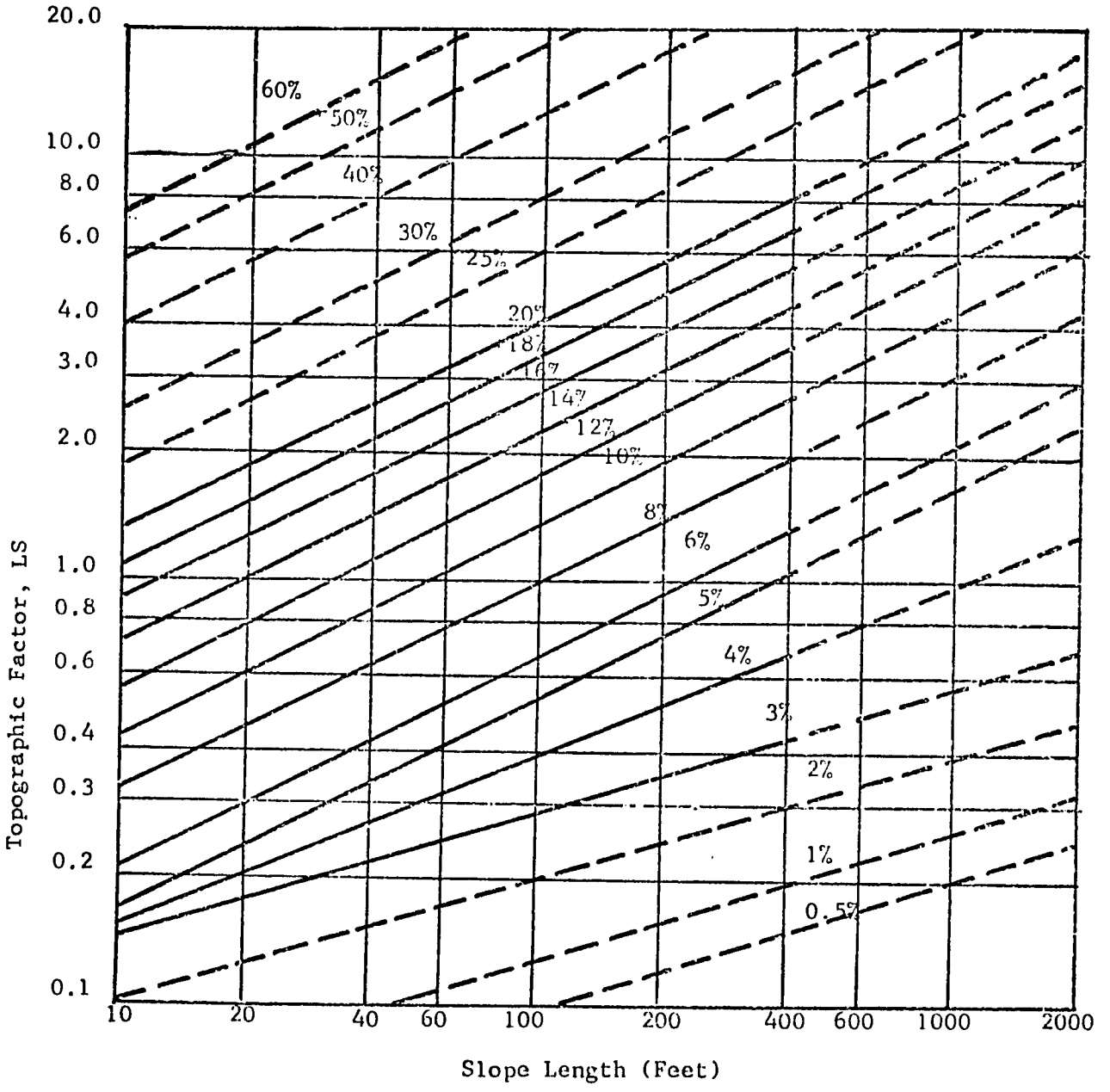


FIG. 5 Slope-Effect Chart (Topographic Factor, LS)*

* The dashed lines represent estimates for slope dimensions beyond the range of lengths and steepnesses for which data are available.

Soil loss is affected by both length and degree of slope. These factors are combined into a single factor LS which are shown in Figure 5 . Dashed lines on the chart for slopes less than 3%, greater than 20%, or longer than 400 feet are extrapolations and when using values from this area of the chart it may be necessary to make adjustments based on experience.

Table 6 "C" VALUES FOR PERMANENT PASTURE, RANGELAND, AND IDLE LAND

Vegetal Canopy			Cover That Contacts the Surfaces					
Type and Height of Raised Canopy	Canopy Cover %	Type	0	20	40	60	80	95-100
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht.)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
		G	.17	.10	.06	.031	.011	.033
Appreciable brush or brushes (2 m fall ht.)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht.)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

G - Cover at surface is grass or grasslike plants
W - Cover at surface is mostly broad leaf herbaceous plants

The C factor relates the effect of cover and management. The basic soil loss is the rate at which the area would erode if it were in continuous fallow. The factor C of the equation indicates the percentage of this soil loss which would occur if the surface were protected by a given combination of cover and management. The extension of the C factor to situations other than cropland is based on three different zones of influence: (a) the vegetative cover in contact with the soil surface; (b) canopy cover; and (c) effects at and beneath the surface (Wischmeier, 1971). Values of C for noncropped areas are shown in Table

Table 7 "C" FACTORS FOR WOODLAND

1/ Tree Canopy % of Area	2/ Forest Litter % of Area	3/ Undergrowth	"C" Factor
100-75	100-90	Managed 4 Unmanaged 4	.001 .003-.011
70-40	85-75	Managed Unmanaged	.002-004 .01-.04
35-20	70-40	Managed Unmanaged 5	.003-.009 .02-.09

1/ When tree canopy is less than 20%, the area will be considered as grassland, or cropland for estimating soil loss.

2/ Forest litter is assumed to be at least two inches deep over the percent ground surface area covered.

3/ Undergrowth is defined as shrubs, weeds, grasses, vines, etc., on the surface area not protected by forest litter. Usually found under canopy openings.

4/ Managed--grazing and fires are controlled.
Unmanaged--stands that are overgrazed or subjected to repeated burning.

5/ For unmanaged woodland with litter cover of less than 75%, C values should be derived by taking 0.7 of the appropriate values in Table . The factor of 0.7 adjusts for the much higher soil organix matter on permanent woodland.

The P factor of the equation accounts for control practices that reduce the erosion potential of the run-off by their influence on drainage patterns, run-off concentration, and run-off velocity. The P values are:

Land Slope %	P Values		
	Contouring	Contour Stripcropping	Contour Irrigated furrows
2.0 - 7.9	0.50	0.25	0.25
8.0 -12.9	0.60	0.30	0.30
13.0 -18.9	0.80	0.40	0.40
19.0 -24	0.90	0.45	0.45

The USLE can be used to predict soil loss by selecting the appropriate numerical value of each of the variables in the equation, or it can be used for selection of cropping or conservation practices. If the values of A are selected to

be equal to the maximum soil loss allowable, and the values of R, K and S are fixed for any given situation, then the combinations of the values of C and P can be made to determine various crop management or conservation practices which will give a soil loss equal to or less than the selected value of A.

Example of the use of the USLE to predict soil loss:

Cropland--Continuous maize with residue removed.

Cultivated up and down slope

Slope 8% Length 200 feet

R = 200

K = 0.37

LS = 1.4

C = 0.3

P = 1.0

A = 200 x 0.37 x 1.4 x 0.43 x 1.0 = 44.5 tons/acre/yr. soil loss

Cropland, same as above, but with rotation of wheat, meadow, corn, corn with residue left.

Contour strip cropped

R = 200
K = 0.37
LS = 1.4
C = 0.119
P = 0.3

A = 200 x 0.37 x 1.4 x 0.119 x 0.3 = 3.7 tons/acre/year

Pasture--Canopy of short brush--0.5 m fall height

Canopy cover 50%

Surface cover--grass and grasslike plants

Ground cover 80%

Slope 8% Length 200 ft.

R = 200

K = 0.37

LS = 1.4

C = 0.012

A = 200 x 0.37 x 1.4 x 0.012 = 1.24 Tons/acre/year

Pasture--Same as above except canopy cover decreased to 25%

with 4 m fall height

Ground cover increased to 95% for area not covered by canopy

R = 200

K = 0.37

LS = 1.4

C = 0.003

A = 200 x 0.37 x 1.4 x 0.003 = 0.31 Tons/acre/year

Forest--Area of tree canopy 30%

Area covered by litter 50%

Undergrowth--unmanaged

Slope 12% Length 100

R = 200

K = 0.32

LS = 1.8

C = 0.05

A = 200 x 0.32 x 1.8 x 0.05 = 5.8 Tons/Acre/Year

Forest--Same as above except

Canopy cover increased to 60%

Litter cover increased to 80%

Undergrowth--managed

R = 200

K = 0.32

LS = 1.8

C = 0.003

A = 200 x 0.32 x 1.8 x 0.003 = 0.35 Tons/Acre/Year

Table 8 SUMMARY OF ANNUAL SOIL LOSS FROM CALCULATIONS ABOVE - ASSUMING 200 HECTARES FOR EACH CONDITION

	Soil Loss Tonnes/Hectare		Soil Loss Tonnes/200 Hectare	
	Existing	Improved	Existing	Improved
Cropland	99.75	8.29	19950	1658
Pasture	2.78	0.70	559	140
Forest	13.00	0.78	2600	156
TOTAL			23109	1954

The above calculations and summary table illustrate the soil losses with various kinds of crop cover and management practices. Twelve tonnes per hectare is considered the maximum allowable loss of soil from a field with a deep soil if cropping is to be continued. Lesser amounts would be allowable on shallow soils. The totals in the two right hand columns give an indication of the amount of soil loss that could be expected from a catchment area of 600 hectares with 200 hectares each of cropland, pasture, and forest. The losses from the area as it existed originally are nearly 12 times the loss from the improved or managed area. The relative amounts of soil loss would also approximate the relative length of time to silt up a storage dam below the catchment area.

The following illustrates how the USLE can be used for making decisions regarding cropping or conservation practices.

R = 200

K = 0.2

L = 400 ft. Slope = 10%

C = 0.18

P = 0.6

Maximum allowable soil loss 6.75 tonnes/ha.

A = 200 x 6.2 x 2.8 x 0.18 x 0.6 = 12.1 Tons/Acre = 27.1 Tonnes/ha.

Conservation Practice	P Factor	C Factor	Soil Loss Tonnes/ha.	
(1) Strip cropping	0.3	0.18	13.56	Too high
(2) Terracing	0.12	0.18	5.42	Satisfactory
(3) Terracing	0.12	0.22 max.	6.75	Max. C value

Different combinations of cropping and conservation practices can be applied to obtain the maximum allowable soil loss.

Level of crop production and crop population density each has an effect on amounts of soil loss by erosion. However, this cannot be controlled because of being limited by the available moisture. Planting populations of greater density or fertilizing for higher yields may reduce yield, even to zero because of moisture depletion before the crop reaches maturity.

1.3.2 Grazing and Soil Erosion

Soil erosion control on the grazing lands of the study area is receiving little attention. The following statement is from the report of a study made in the Machakos area by the Departments of Sociology and Agricultural Engineering of the University of Nairobi. "Observations made on the grazing land indicated that erosion was a serious problem, particularly in the lower areas, that much land was bare, that degradation was taking place quite rapidly and that in contrast with the measures taken on cultivated land, very little was being done." Most of the activity relating to soil erosion control is being done on the cultivated lands as the loss of soil from these lands is more obvious than from the grazing areas. A considerable amount of soil is being lost from the grazing areas and remedial measures should be started immediately.

Much has been said regarding overstocking. It is not that the cattle greatly exceed the carrying capacity of the land, but it is that both the cattle and the land are poorly managed. With proper management, the land could probably support, except in extremely dry years, at least double the number of cattle now on the land. Of course, it would be necessary to alternate grazing areas or reduce the total number of cattle during the revegetation period, which will generally require two years.

Now would be an ideal time to begin a management control program. With the good vegetation which exists because of the favorable rains during the past year and the reduced numbers of cattle because of death losses during the preceding dry period, it seems that there would be less stress on grazing areas than at other times. A management program could begin in only part of the area, and as the vegetation is allowed to grow and produce feed, rather than being grazed to the ground continuously, the animals could be moved and progressively a management program could be instigated on all the grazing areas.

An experiment was begun in 1949 on what was knows as the Makaveti square mile in Machakos District. It covered only 32 acres which were divided into 64 half-acre paddocks. Various methods were used for restoring the cover from sub-soiling and ripping to simple enclusure. The first two years of the experiment 1949-50 produced the lowest total of rainfall for two successive years since records had been taken during the

preceding half-century. The 32 acres were opened to grazing from April 1951 onwards on land which before 1949 might have carried one beast to 12 hectares, and have maintained the animals in excellent condition at a rate of one to two beasts per hectare. The carrying capacity of the land was increased more than 10 times. If the same thing could be accomplished today, it would require only one-tenth of the grazing as now exists on the entire area. With all the animals moved onto nine-tenths of the grazing area with the good vegetative cover existing, they could probably get adequate feed. The remaining one-tenth could be restricted from grazing and a program of reseeding and rehabilitation accomplished so that this area could carry the entire animal population as well as is now being done, if the results were as favorable as that on the experimental area. A program to rehabilitate the other nine-tenths of the area could begin and theoretically on the basis of the Makaveti experiment, the total area in four years would have ten times the carrying capacity it now has. If it could adequately provide feed for twice the number of animals which it now does, it would be a great benefit to the area.

There is an area near Kapherere in the Baringo District where a farmer has for two years kept animals from grazing on five acres of his property. Cattle were allowed to graze in it beginning early this year. There are now 15 head of cattle grazing in the area. The grass is tall and thick, and with good management practices it will provide feed for this number of animals most of the year.

With a good vegetative cover, soil erosion will be minimized. The infiltration rate will be increased so more of the precipitation will be available for use by the plants and more feed will be produced. It may be desirable in some areas to use some mechanical methods of water control, such as; pasture furrows on the contour, small surface depressions, tied ridges, basin listing, or range pitting. Water spreading of flood waters where possible would be a benefit not only to obtain more plant growth from the irrigated areas, but would also reduce floods.

1.3.3 Soil Erosion Control Practices

Soil erosion control includes all practices applied to land that are effective in reducing flood run-off and controlling erosion. The choice of these practices depends largely on soil condition slope and hydrologic factors.

Much can be accomplished regarding soil erosion control by easy, inexpensive methods such as planting and cultivating on the contour, crop rotations, strip cropping, tillage practices, incorporation of organic residues into the soil, fertilizer application, and others. There will, however, be conditions where those methods mentioned above will not accomplish the needed control. Where this is the case it will be necessary to construct terraces, cut-off drains, waterways, and other conservation structures such as weirs, drops, chutes flumes or dams. In any case a very careful study of the

problem on a catchment basis must be made to determine the most practical and economical methods of soil erosion control. If mechanical structures are required, they should be used as a base to build on, and the cultivation, tillage and cropping practices should always be used regardless of other control measures.

1.4 Rural Water Supply

The Ministry of Water Development is responsible to the government for implementation of its policy that every citizen have access to a potable water supply by the year 2000. The current objective of the Ministry is to provide reticulated water supply systems in the rural areas. To provide reticulated supply to all rural residents is not practical, and programs to provide potable water to scattered segments of the rural population should be investigated. Various methods can be used for obtaining water for these programs such as; roof catchments, subsurface dams, boreholes, surface dams, rock catchments, and others. One of the main problems for the individual family with programs of this type is the storage facility necessary to store the water between rains. At the UNICEF-Village Technological Unit at Karen, they have examples and plans for construction of different kinds of storage units. Instruction could be given by the Extension Service to family members so that they can provide their own storage facilities.

The water supply program should be coordinated with other soil and water management programs. Proper soil and water management entails such things as soil and vegetative management to increase the infiltration rates of the soil. This increases the water storage in the soil, keeping the water near where it falls for a longer period of time. This levels out the flood peaks and causes the streams to flow for a longer period after each storm, which means the rivers are dry fewer days each year. This means that water is available at more places for longer periods of time. As soil conservation measures are taken, water drains off slower, also extending the period of stream flow. The increased soil moisture will encourage better vegetative growth, which will also slow the rate of runoff and increase the infiltration rate. As management practices are improved, some of the streams will again become perennial and springs which are now dry will again flow, and this supplying potable domestic and livestock water will not be nearly as difficult a task.

Many methods of water harvesting, even on a small scale, will be very helpful in achieving the goal as set by the government. More people, especially within the Extension Service need more training in soil and water management practices so that they can assist the rural population in this important task. The scarcer the water, the greater the need for technical and management skills.

1.4.1 Roof Catchments

Water collected from roofs of buildings at the family dwelling place and stored could provide water for domestic

use. Approximately 0.53 liters of water can be collected from one square meter of roof surface for each millimeter of rainfall. From a 50 square meter roof surface in an area with 500 mm rainfall a total of 13,250 liters of water could be collected. If this could be stored without loss thirty-six liters of water per day would be available. As this rainfall is distributed somewhat throughout the year, it is estimated that a storage of five cubic meters would be necessary.

1.4.2 Rock Catchments

There are many places where water could be collected from rock surfaces. All that would be necessary would be to direct the water from the rocks to a suitable storage facility. Often these rock catchment areas are on the hills so that if a piping system were provided, water could be taken by gravity pressure to several different places or directed to a central communal outlet.

1.4.3 Sub-Surface Dams

Sub-surface dams built on suitable sites of ephemeral river streams are inexpensive and easy to construct, suitable site is on a sandy river where there is a rock bar across the stream channel to form a base for the barrier. The barrier is built on the rock base and increased a small amount each season. The coarser the sand back of the barrier the greater is the storage capacity so the objective is to increase the height of the barrier enough each year so that the flow of the stream during flood stage tends to wash the smaller particles over the barrier and leave the larger particles upstream back of the barrier. Water in these dams is much cleaner than that in the surface dams as the water is filtered in the sand. Also the evaporation from them is a minimum as during the nonflow period of the river the water is below the surface of the sand.

1.4.4 Dams

Small dams to store water for domestic water are successful when they are properly constructed. Cautions should be observed in construction of these dams. Do not build them where there is a heavy silt load in the stream. When this is the case, the dam will soon fill with silt. Erosion control measures should be accomplished on the catchment area before dams are built. Care should be taken to provide adequate spillway capacity for the flood flows which can be expected. Design of each dam should be done by an individual who is competent in this kind of work.

1.4.5 Boreholes

The water table in the study area is relatively deep, 50 meters or more which makes the cost of drilling, equipment, and pumping rather high. For this reason very few boreholes are made for individuals. However, when the water supply is not high in salt content it is generally not necessary to provide a treatment plant for water from a borehole. This may be an additional expense for some other types of water

supply.

1.4.6 Water Harvesting

There are many possibilities of water harvesting methods which if used could be a great help in providing domestic and livestock water supplies. Most of these methods require very little technical knowledge to execute. Generally a demonstration or merely a suggestion of possibilities is all that is necessary to initiate the installation of small water harvesting projects. These could be of a size for only one family or for a group of families.

There is a government subsidy and a loan program which can be used to finance some of these types of programs. In some cases it is possible to get as much as 40% of the cost of these projects.

1.5 Irrigation and Drainage

Irrigation development in Kenya is limited by the amount of available water. The most important potential for development is in the Tana River Basin, and this is probably the only location in the country where land and water are both available for large scale development. There is a potential for development of approximately 100,000 hectares with the limiting factor being the water. (ALDEV 1963) This basin is representative of some of the problems associated with irrigation development. There is more irrigable land available that can be irrigated by the available water. The question is where is it most advantageous to use the water. In the upper basin the need for irrigation is more apparent as population pressures bring more people into the area, and there is greater need for intensive cultivation of the available land. However, the broken nature of the landscape and the fact that much of the land is already adjudicated, means that development in the upper basin will be restricted to small schemes because of the complications of layout on the existing pattern of land and land holdings. If this water which could be used for irrigation in the upper basin were allowed to flow to the lower basin instead and used for irrigation where large tracts of nonadjudicated land is available, a much larger and more viable scheme could be developed. Also the water could be used to produce electric power at the several hydroelectric plants between the upper and lower basins. In the upper basin, the existing community and the social infrastructure are an advantage in development of this area. While in the lower basin there is no problem of fitting a scheme to the pattern of land holding, but the lack of infrastructure and remoteness of the area create problems. Other items to be considered when deciding where it is best to develop are: quality of soil, comsumptive use of water, crops which can be grown, access to markets or processing plants, etc. These illustrations present some of the many problems which mustbe considered when planning irrigation development, especially in a country like Kenya where water is in short supply.

With the exception of the Tana River Basin, irrigation development will be on a relatively small scale, especially in the areas covered by this study. This is because of the

broken landscape and the small quantities of water available.

Irrigation development cannot be a major factor for a large increase of total agricultural production in Kenya, nor will it be instrumental in relieving the pressures of more land for more people. It is estimated that if the entire potential in the Tana River Basin were developed in the next 25 years, it would provide only enough increased land for 15% of the expected increase in population during that period. It is also estimated that the potential of the Tana River Basin is one-half of the total irrigation potential of the country.

Irrigation development is very costly and these developments are more prone to failure than other development projects. The failure is generally not because of technical deficiencies, but organizational problems. Many huge projects are built throughout the world with the best engineers and the most experienced personnel in planning, design, and construction of irrigation projects, but the potential is not achieved. This is generally because the headworks and main canal are operated by experienced people and the farm application of the water is left to chance, assuming that the farmer is capable of applying water efficiently for the optimum yield of crops. This is not the case, as the majority of irrigators are not trained in proper application of water even though they may have been irrigating for long periods of time. The philosophy of many irrigators is that, if a little water is good, a lot is better, which is not true.

The most efficient and optimum application of water is not known in this country, as the proper amounts and time of application need to be determined by research and investigation. The needed research has not been done here. Information gained from research done elsewhere can be applied to irrigation practices here, but for complete understanding of the problems, some research must be done in the locality being irrigated to relate the research done at other places to that of the local conditions.

Development of large irrigation schemes should be started only after being thoroughly investigated and carefully planned. The high incidence of failure of irrigation schemes requires that everything possible needs to be done to assure their success. Small irrigation schemes can be very helpful to increase productivity and assist the farmer. There are many opportunities to store and use small amounts of water to irrigate small areas where high value crops are grown. Areas as small as one-hundredth of a hectare could be a major factor in producing garden vegetables for family use, or even for sale, if water were available to irrigate it. With water available, crops could be grown the entire year to that three or four crops per year could be obtained from this land, and could provide the vegetables necessary for a family.

Water for these small areas could be made available in many ways, such as, collecting from roofs, run-off from small areas about the farm, building small dams or depressions to

collect and store water from small catchment areas, or pumping water from sandy river beds. Depending on conditions, it may be possible to provide irrigation water for much larger areas than that mentioned above, and any water which is stored for irrigation will be helpful in reducing flooding and soil erosion in addition to the benefits derived from irrigation.

If extension personnel were available to assist in planning and building small projects as those mentioned, the limited water resources of the country could be used to much better advantage and more people could be supported with the available land. The early projects built would be a demonstration of what might be accomplished and other would provide irrigation water for themselves.

1.5.1 Drainage

Irrigation and drainage are complementary practices. In most irrigated valleys, the higher lands are drained naturally as the water moves down to the lower portions of the valley. The water table is raised there which makes drainage necessary. From 20 to 30 percent of the irrigated lands need drainage to continue their productivity. The amount of drainage necessary is closely related to the irrigation efficiency in the area.

Drainage is the removal of excess water from the land surface, or ground water from below the surface. Removal of surface water prevents surface flooding or ponding so that crops will have favorable moisture conditions. Subsurface drainage lowers the water table so that the water does not interfere with root growth and development. Most soils in arid regions contain salts, and water used for irrigation also contains salts in varying amounts. High water tables cause salt concentrations within the root zone of plants which interferes with proper plant growth. Drainage lowers the water table and salts are removed from the soil with the water. Proper leaching and water removal will keep the salt balance of the soil favorable for optimum plant growth. Much of the drainage in irrigated areas is for salinity control.

Salt balance in a soil is very important where vegetation is grown. In arid regions where there is insufficient rainfall to move soil salts below the root zone, there will be an increase in salt concentrations in the upper portions of the soil. During the decade from 1929-39, more than 400,000 hectares of land in the United States was abondoned, most of it because of excess salts in the soil. By proper assessment and monitoring of salt concentrations in the soil and providing adequate drainage, these problems can be avoided.

There is a small private irrigation scheme on the northwest side of Lake Baringo which uses water from the lake for irrigation. It is reported that every two or three years, it is necessary to move to new land because of yield reduct-

ion due to excess salt in the soil. This excess salt comes with the water used for irrigation. The salt from the water remains in the soil as the water is evaporated or transpired. The problem may be either lack of drainage, which would remove some of the salts with the drainage water, or it may be that so little water is applied that most of the salt remains within the root zone of the plants. Application of sufficient water to move the salts below the root zone would solve the problem of moving to new ground. Moving may be a solution now, but cannot be continued as pressure for agricultural land will require that all available land be used productively.

Good irrigation practice reduces the need for drainage, but drainage must be considered as part of any irrigation scheme, and where necessary, the drainage system should be constructed as an integral part of the irrigation scheme.

1.5.2 Water Requirements

The crop water requirement, referred to as the consumptive use, is the depth of water necessary to supply the water loss of evapotranspiration. This is affected by the climatic conditions, by the crop characteristics, and local agricultural practices. To obtain optimum growth of the crop, it is essential that the crop needs be satisfied at all stages of growth. However, the effect of timing and duration of water shortages on some crops is very pronounced. Maize yields are reduced considerably when water shortages occur during the tasseling stage. If the shortage is of long durstion during this period, the yield could be reduced to zero. The yield reduction on sugar cane is much greater if water shortages occur during the period of active growth than if the shortages are during the late growth period. The critical stage of water shortage varies with different crops and even with different varieties of the same crop, but generally the most critical stage is during the flowering and seed development stages.

SOIL AND WATER MANAGEMENT
Embu--Kitui-Machakos

2.1 Location of Study Area

The Eastern Province study area is a block bounded by $0^{o}30'$ and $1^{o}00'$south latitude and $37^{o}30'$ and $38^{o}00'$ east longitude, and another block just south of this bounded by $1^{o}00'$ and $2^{o}00'$ south latitude and $37^{o}15'$ and $38^{o}30'$ east longitude. This includes 24 locations in Machakos District, 16 locations in Kitui District, and 3 locations in Embu District of the Eastern Province, Kenya. This is an area of approximately 18,450 Km^2.

2.2. Climatology and Hydrology

The Machakos, Kitui, Embu study area is influenced by two monsoon systems. The movement of air masses between the high pressure belts of the north and south hemispheres produces two rainy seasons a year. (Kaplan et.al. 1976)

From December to March the northeast monsoon is dominant with movement of dry air in a north easterly direction. There is very little precipitation during this period. From March to May the wind is from the east bringing moist air which produces the long rainy season. From June to September the southeast monsoon is prevailing and there is air subsidence which inhibits precipitation and brings low temperatures. There is almost no precipitation during this period. From September to November the wind is again from the east bringing rains from the end of November trhough December.

2.2.1 Meteorological Stations

There are three meteorological stations in the study area. The report from the station at Machakos includes: mean monthly maximum and minimum temperatures, relative humidity, rainfall, number of days of rain per month, mean daily radiation by months, mean monthly pan evaporation, and daily wind run by months. The report from the station at Kitui water supply includes the same data as the Machakos station report, and the report from the Katumani Agricultural Experiment Station includes the same data as the other stations, except that there is no report on pan evaporation. An evaporation pan is now installed at this station.

2.2.2 Temperatures

Mean monthly temperatures at Machakos Dam vary from $16.0^{o}C$ in July to $20.5^{o}C$ in March. At Kitui Dam the mean monthly temperatures vary from $18.1^{o}C$ in July to $20.4^{o}C$ in March. The Makinda meteorological station which is just outside the study area to the south had mean monthly temperatures varying from $20.1^{o}C$ in July to $24.6^{o}C$ in March. The meteorological station at Embu Mwea Experimental Station outside the study area on the northwest reported mean monthly temperatures which varied from $20.0^{o}C$ in July to $23.1^{o}C$ in March. The East African Meteorological Department has published equations for each month of the year from which temperatures can be calculated.

The only variable in these equations is altitude. Temperatures were calculated for several locations in the study area. The minimum temperature calculated for the study area was 16.0°C at Kilome, and the maximum calculated was 27.8°C at both Zombe and Voo locations in Kitui District.

2.2.3 Sunshine and Radiation

Records of radiation are available only at the meteorological stations in the study area. Radiation varied from a high of 627 Langleys per day at Machakos Dam in February to a low of 383 Langleys per day at Kitui Dam in July.

2.2.4 Winds

At Machakos and Kitui Dams, the wind runs have been measured without any reference to direction. At Machakos Dam the mean monthly wind run varied from 162 km per day in October to 90 km per day in June. At Kitui dam it varied from 186 km per day in September to 96 km per day in December.

2.2.5 Precipitation

Precipitation records were kept as early as 1904 at some of the stations in the study area. Observations were recorded in tenths of an inch through 1960, and beginning in 1962 they have been recorded in millimeters. Several of the stations have stopped operating and in some, the records are discontinuous. Precipitation amounts and frequency of occurance are very erratic in the three districts of the study area. Rainfall agriculture in the area is very uncertain, and irrigation, where possible, will be a means of increasing agricultural production.

Precipitation records were obtained from the East African Meteorological Department for 40 stations in Embu-Kitui-Machakos and 7 in Baringo-Kerio Valley. These stations with their mean monthly and mean annual precipitation amounts are shown in Appendix, Table 4. The period covered by most of these stations was from 1960-76. Mean monthly and mean annual rainfall was calculated for these stations. The highest mean was 1276 mm at Kitondo Forest Station in Machakos, and the lowest was 352 mm at Voo Dispensary Station in Kitui.

The rainfall pattern is very erratic with extreme variations in both the monthly and annual amounts of rainfall. The time of beginning of both the "long" and "short" rains is quite variable, making it difficult to determine planting dates when one can be assured of sufficient moisture to assure germination of the seeds and continual growth of the crop.

The highest monthly averages for the study area occur in April and November. The highest monthly rainfall for any of the stations was 965 mm at Mui Chief's Camp Station in Kitui. This was more than the mean annual rainfall of 796 mm for this station. In February and during June through September, there are long periods of rainless days. The monthly means for June through September are from 0-16 mm.

Rainfall of 75% probability of occurrence for these four months is zero at most of the stations.

2.2.6 Relative Humidity

The three meteorological stations are the only stations in the study area reporting relative humidity data.

The monthly mean relative humidity at Machakos Dam varied between 75 and 87 percent at 0900 hours and between 46 and 65 percent at 1500 hours. At Kitui Dam the variation was between 75 and 84 percent at 0900 hours and between 43 and 61 percent at 1500 hours. At Katumani experiment station the variation was between 72 and 87 percent at 0900 hours, and 44 and 67 percent at 1500 hours.

2.2.7 Evaporation

There are two stations within the study area which report mean monthly pan evaporation. The station at Machakos Dam reported a mean annual pan evaporation of 1727 mm for the period 1963-70. Monthly means at this station vary from a low of 91 mm for July to a high of 187 mm for October. The station at Kitu Dam reported a mean annual of 1935 mm for the period 1963-70 with a monthly low of 133 mm for June to a high of 198 mm for October.

2.2.8 Streamflow

The study area is drained by the Athi and the Tana Rivers. The Athi has a large drainage basin, but the low flow is below 0.5 cumecs during dry months of the year. Most of the streams which flow into it are ephemeral, generally becoming dry within one month after the end of the rainy season. The Tana is Kenya's largest river and drains the eastern flank of the Aberdares and the southern slopes of Mt. Kenya and the Nyamberri Range. Considerable irrigation potential has been identified on these rivers, particularly the Tana. Although much of the potential land areas have been identified as that on the lower reaches of the rivers outside of the study area, it is possible that some of the waters of these rivers can be used for irrigation within the sudy area.

Stream gauging is generally done only on the major streams consequently, very little or nothing is known regarding the flow of most of the tributaries to the main streams.

2.2.9 Sedimentation

An analysis of suspended sediment data from the Ministry of Water Development (Dunne 1974) indicates heavy suspended sediment loads in the order of 600 tonnes per Km^2 per annum in the Embu, Kitui and Machakos Districts. Bed load measurements are absent and in order to estimate the total sediment load or the rates of erosion, some indication is needed of the proportion of the total load made up by the bed load. Approximation for bed load discharge as a percentage of suspended sediment discharge vary from 25 to 15% (Land

and Borland 1951) depending on the characteristics of the suspended material. These estimates are only approximations and it is necessary to use indirect sources of data.

Two small dams in the study area provide useful estimates of the rate of sedimentation. Kalundu Dam, built in 1958 as a water supply reservoir for Kitui township was completely silted up by 1974. The average depositions of sediment represents a sediment yield of 733 tonnes/Km^2/annum. From an analysis of the trap efficiency of the reservoir it would suggest that the bed load was at least 50% of the total load. Results from a study of Muruba Dam in Machakos District indicates that the total sediment load was of the magnitude of 1500 tonnes/Km^2/annum. It would seem advisable that until more bed load measurements are obtained, that the rate of bed load transport be estimated to be of the same order as suspended sediment yield on small catchments in Basement Complex regions (Edwards 1977).

Data on suspended sediment yield in the study area (Dunne 1974) indicates yields generally greater than 500 Tonnes/Km^2/annum. Sediment delivery ratios of catchments this size indicate a rate of erosion from cultivated fields to be at least ten times this figure. This magnitude of soil erosion, 50 tonnes/ha/annum, would be about ten times the amount of erosion allowable without drastic reductions in crop yields. A soil loss of 10 tonnes/hectare/annum is considered the maximum acceptable on shallow soils.

A project jointly funded by the Kenya Government and the U.K. Ministry of Overseas Development to provide methods of assessing water resources which includes a study of silt loads of seasonal rivers has begun in the study area. When results of this study become available, a more accurate assessment of the sediment loads and rates of erosion can be made.

2.3 Soil Conservation Inventory

2.3.1 Application of Universal Soil Loss Equation:

2.3.1.1 Sheet Erosion:

An attempt was made to quantify the effect of sheet erosion by estimating the rate of soil loss from the study areas of Machakos, Kitui and Embu. The data collected by the soil scientists of the study team was used as far as possible. To estimate the soil loss from the Universal soil loss equation (discussed in section 1.3.1) it was assumed that the soil moisture was at field capacity. The actual rainfall factor taken being R=200. Reason for choosing this factor for the study area was that the estimated average for some representative stations in Kenya is 200 (Wenner 1977). By computing from the rain gauge charts from various stations the 130 Index (30 minute rainfall intensity index) was calculated for 10 stations (Wenner 1977). In a large area bounded by Voi Nairobi and Nanyuki the use of R=200 in the absence of any other reliable R is unavoidable at this stage.

The coefficients for the soil physical characteristics were obtained from the soil survey data. The twenty units were selected on the basis of available soil information, 50% of them had a coefficient of K=0.20. This is because the soil survey mapping indicates that the soils of the area are mostly clay. It has to be emphasized that the units used are estimates in the absence of direct sources of laboratory data. With reference to the universal soil loss equation (page 12), its application in the case of Machakos, Kitui and Embu soils is regarded suitable at this stage because the numerical value of the coefficients were obtained from the survey data and from rainfall charts already calculated (Wenner 1977). More complete information should be obtained to select the control practices best suited to the particular needs of each farm unit, soil units, or even catchment area units.

2.3.1.2 The R Factor:

Rainfall: is the most important factor in any erosion discussion. The amount and the intensity of rainfall are the two major properties for a rainfall to be called erosive. When a storm falls on a bare land it erodes the top soils, with some force. This force or energy referred to as Kinetic energy of the rain is termed as E. and the intensity in which it falls is given as I. There is then a formula R=E x I where R = Rainfall
E = Kinetic energy of that rain
I = the intensity (usually taken for a period of 30 minutes).

The R values are obtained from rainfall data, while the E values per inch or mm. of rain are expressed in foot-tons per acre. This can be converted into SI units if necessary. The I values are expressed in inches or milimeters per hour. The sum of computed EI values for a given time period is a numerical measure of the erosivity of all the rainfall within that period (Wischmeier et al 1967). It is through this computation that R values are obtained. R values for all parts of Kenya are not yet available. At present the R=200 has to be relied on. One of the difficulties that must be kept in mind is that very few measurements of this nature have been made at high rainfall intensities. The R=200 was made by an independent single worker and there is no way of telling how much this figure can be entirely relied upon. Different parts of Kenya have different types of rains of varying amount. It therefore may be timely to suggest that investigative work towards the goal of generating more R values for Kenya be initiated as soon as possible. The EI30 Index already discussed was developed for USA conditions and Hudson has however, warned that the use of EI30 Index for the countries with limited rainfall data may not be an advantage. He therefore suggests that the use of KE greater than 1 (see K factor discussion below) which can be used with less detailed rainfall records. (Hudson Chapter 4). This is a useful estimator of erosion if adopted for Kenya. KE greater than 1 simply means the total Kinetic Energy of the rain falling at fintensities of more than 1 inch per hour. If converted to SI units the intensity becomes 25mm/h.

The extension of the usefulness of the USLE to Baringo area will be hampered by the lack of basic information on the factors. It has to be appreciated that the numerical values for each factor may differ from one soil unit to the other and may therefore raise a question as to why all this similarity of figures has been adopted. There are certain limits where one cannot go beyond. It is also timely to raise the point that erosion index of 200 is rather low in the area under reference. When rainfall is inadequate in an area it follows that establishment of good vegetative cover will also be inadequate and will therefore result in soil erosion hazard being greater in the area.

2.3.1.3 The K Factor:

The K factor in the equation was given the value 0.20 in most cases, and it was then ascertained by field observation that the soil units had been grazed and kept free of vegetation for a period exceeding 2 years, but this exposure did not alter their clay content. The soil physical characteristics determined in the field were taken for allocating the K factor its place in the equation. This mechanically analysed method have given some indication of resistance to erosion found in different soils in the study area. Some aspect of erodibility of Kenya soils will be better known when the University of Nairobi Engineering Department publishes their

findings from their rainfall simulators (personal contact). The soil mechanical analysis in the field have determined some other values of K e.g. there are values of K=0.23, K=0.25 or K=0.19 the differences are, however rather insignificant where the erosion is concerned.

2.3.1.4.The length of Slope:

The length of slope has been given a uniform figure of 50m. This is because the slopes are qualitatively classified by the team's soil scientists or their quantitative values rather exaggerated to an extent which is not practicable. Experience has shown that most slopes in small holder farming areas of Machakos and Kitui are 50 meters long. It is considered that a selection of 50m. is good since such length is likely to have no interference from the top to the bottom, such as roads, ditches or other interfering structures.

The Slope percent was recorded from readings obtained from clinometres. This is fairly accurate. The slope length and the slope angle in degrees were combined to give a value of LS. The value was obtained from already prepared curves (Wenner, Hudson, Wischmeier). and recorded in the appropriate column. The Kenya Soil Survey Slope Classification is shown in table 9.

2.3.1.5 The C Factor:

The C factor in the equation is complicated. An attempt was made to combine field information and available literature to arrive at a tentatively accurate value. The C factor was calculated for a maize crop in the study for worst conditions shown in Table 10. The soil units in which the area is under permanent cultivation was found to be above 50%. In table 13 the bare land is given the worst conditions of erosion where no cover or management is practised and erosion figures ran to very high values. The residues from whatever harvest are assumed removed to be fed to animals. Even if left it is readily attacked by termites and destroyed. Under these conditions, the maize yields range from 4 to 7 bags per hectare. The following crop stages applied here were taken from USDA/SCS (Guide for erosion and sediment control 1975. Appendix C.) Under the worst conditions crop stage period is as follows: for Machakos, Kitui and Mbeere area of Embu District.

Crop stage period F - Turn plowing to seeding - Feb/March
Crop stage period I - Seedbed preparation to 1 month after planting March/April.
Crop stage period 2 - Establishment from 1-2 months -April/May
Crop stage period 3 - Growing cover 3rd month after seeding May/June
Crop stage period 4 - Stubble from harvest to ploughing

The period in the study area starts with the long rains which begins early March.

Table 9

Slopes are classified as follows:

Letter	Slope %	Average
A	0 - 2	1
B	2 - 5	3.5
C	5 - 8	6.5
D	8 -16	12.
E	16 -30	23.
F	30 -50	40.
G	50 -80	65.

The factor C in the USLE is a ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled continuous fallow. The factor measures the combined effect of all interrelated cover and management variables (W.H.Wischmeier et al 1967) An evaluation of coefficient C for a maize grown field in Machakos, Kitui and Embu was made and assumed that the field were under conventional tillage practice. The expected yields were taken to be 8 (720 kg) to 10 (900 kg) bags per hectare. When you compare the bags with American bushels you find that this yield is 20 to 25 bushels per ha. The reason for such comparison was because the American tables were used for calculating and relating the conditions in Machakos, Kitui and Embu and their yields were quoted in bushels per acre.

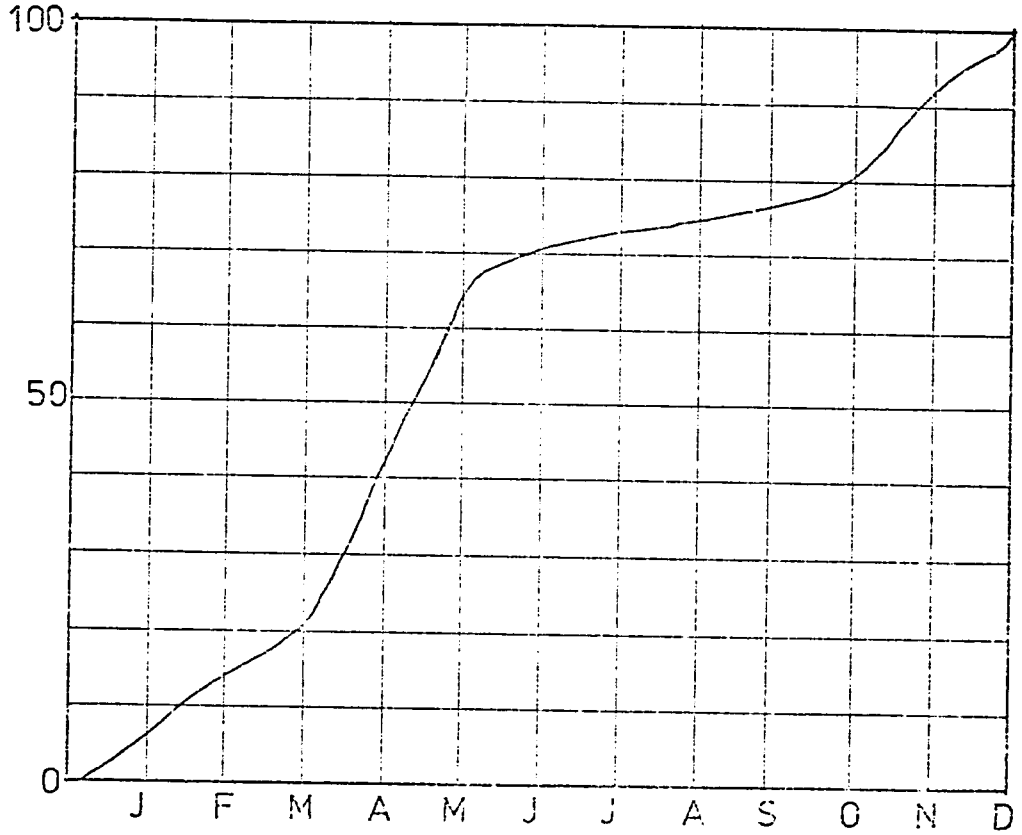
Table 10

Calculation of C factor for a maize crop

1 Crop	2 Dates	3 Reading from Curves in %	4 Crop stage Period	5 EI in Period %	6 Soil loss Ratio %	7 C Value Column 5&6
Maize	1feb to 1Mar.	14%	F	7	33	0.0231
Maize	2Mar to 1Apr.	21	1	13	48	0.0624
Maize	2Apr.to 1May	43	2	22	49	0.1078
Maize	2May to 1Jun.	65	3	21	35	0.0735
Maize	2Jun to 1Jul.	71	4	6	80	0.0480
Total C Value						0.3148

Figure 6

monthly cumulative percentage of annual erosivity



Months

1960 - 1972

Nairobi - Machakos - Kitui - Embu

The C factor for a maize crop in the study area is determined for five crop stage period column 2 in the table above which shows the actual dates when maize is grown. The percentages in column 3 in the table is read from Fig. 6 which shows the monthly cumulative percentage of annual erosivity for areas Nairobi, Machakos Kitui and Embu (afterWenner 1977) column 4 shows the crop stage period already discussed, column 5 shows the EI value in period obtained by the difference between the percentages at the beginning and at the end of period e.g. 14% at the beginning and 21% at the end gives 7%. This is the value entered in column 5. The soil loss ratio in column 6 are obtained from Table 2. Agricultural Handbook No. 282 USDA. Column 7 is the product of column 5 and 6.

The C factor for maize, sorghum and beans was again considered separately. In each case a crop was regarded as being grown in a particular zone. However, very little consideration was given to any of the zones as the data is yet to be made available for each zone. In general maize is grown fairly successfully in zone III and sorghum in zone IV while beans can be grown in any of the two zones. The three crops are discussed separately. Observation in the field has shown that maize and beans are interplanted. This practice can result to less soil loss from a given slope. This fact has not been considered. Consideration was given for crops which are grown as pure stands and the resulting figures are for these pure stands. Less attention was paid to particular varieties of crops, but Katumani variety of maize and "Mwezi Moja" variety of beans are what we have in mind. Serena is the variety of sorghum mostly favoured in many parts of Kenya, but no consideration was taken over sorghum while working out the soil loss ratios.

2.3.1.6 The P Factor:

The management P was given the value P=1. This is the value which assumes that the field is ploughed up and down the hill, without any contour farming, contour farming plus strip cropping, or rotation of crops, or even contour farming and terracing. In Machakos and Kitui and some parts of Embu the soil loss figures presented in the tables might not be true now since there is considerable conservation practices in the fields. The figures pertain to areas without an conservation practice.

Sorghum is drought resistant and can outyield maize in the drier parts of Machakos, Kitui and Embu. The table below is worked out to show the C factor in case of sorghum grown in the area. Sorghum is usually not intercropped with other crops in the region. It takes four months seeding to harvest. Sorghum requires a rainfall of at least 12-15 in (305 to 318mm.) during its growing period, and it is therefore the nearest crop to our R=200mm factor value used throughout the calculation in the equation.

Table 11 Calculation of C factor for a sorghum crop

1 Crop	2 Dates	3 Readings from curves *	4 Crop stage period	5 El in period	6 Soil ratio * %	7 C Col.5 Col.6 *
Sorghum	1Jan-1Apr.	21	F	7	70	0.0490
	2Apr-1May	44	1	23	76	0.1748
	2May-1Jun	65	2	21	64	0.1344
	2Jun-1Jul	71	3	6	38	0.0228
	2Jul-1Aug	73	4	2	65	0.1300
						0.5110

* The description of columns 3 to 7 are similar to those of a maize crop after Table 10

The table below was worked for the beans in the same area. To get the soil loss ratio for particular crop stage periods, peanut and soya bean values were obtained from the table and then averaged. The average between these two legumes were considered to be closely related to "Mwezi Moja" bean-variety which is grown in the study area. No figures were worked for cowpeas. The canopy of cowpeas have almost the same behaviour as that of beans. The condition of growth for cow-peas is fundamentally the same as those of beans.

Table 12 Calculation of C factor for a bean crop

1 Crop	2 Dates	3* Readings from curves	4* Crop stage period	5* El in period	6* Soil loss ration	7* Col.5 xCol.6
Beans	1Feb-2Mar	14	F	1	49	0.0049
	2Mar-1Apr	21	1	7	62	0.0434
	2Apr-1May	44	2	23	55	0.1265
	2May-1Jun	65	3	21	32	0.0672
	2Jun-1Jul	71	4	6	54	0.2420

* The description of columns 3 to 7 are similar to those of a maize crop after Table 10.

Table 13 CALCULATION OF SOIL LOSS USING UNIVERSAL SOIL LOSS EQUATION

Soil Mapping Unit	R	K	LS	P	L	S	BARE GROUND C	BARE GROUND Soil loss ton/acre/yr*	MAIZE C	MAIZE Soil loss ton/acre/yr*	SORGHUM C	SORGHUM Soil loss ton/acre/yr*	BEANS OR COWPEAS C	BEANS OR COWPEAS Soil loss ton/acre/yr*
Columns 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
MBr/DF	200	0.20	9.9	1	50	29	0.7	277	0.3148	125	0.5110	202	0.242	96
MQl/DF	200	0.20	9.9	1	50	29	0.7	277	0.3148	125	0.5110	202	0.242	96
PIC/AB	200	0.20	0.4	1	50	2.5	0.7	11	0.3148	5	0.5110	8	0.242	4
PFr/AB	200	0.20	0.4	1	50	2.5	0.7	11	0.3148	5	0.5110	8	0.242	4
PIr/AB	200	0.20	0.4	1	50	2.5	0.7	11	0.3148	5	0.5110	8	0.242	4
UU3/CD	200	0.23	2.0	1	50	10.5	0.7	64	0.3148	29	0.5110	47	0.242	22
UQl/BC	200	0.23	0.8	1	50	5	0.7	26	0.3148	12	0.5110	19	0.242	9
UUC/BC	200	0.20	0.8	1	50	5	0.7	22	0.3148	10	0.5110	16	0.242	8
UUC1/BC	200	0.25	0.8	1	50	5	0.7	28	0.3148	13	0.5110	20	0.242	10
UNr1/BC	200	0.20	0.8	1	50	5	0.7	22	0.3148	10	0.5110	16	0.242	8
UNr2/BD	200	0.20	1.6	1	50	9	0.7	45	0.3148	20	0.5110	33	0.242	15
ULr2/BC	200	0.23	0.8	1	50	5	0.7	26	0.3148	13	0.5110	19	0.242	9
UFD/AC	200	0.20	0.5	1	50	4	0.7	14	0.3148	6	0.5110	10	0.242	5
HQR/DF	200	0.23	9.9	1	50	29	0.7	319	0.3148	143	0.5110	233	0.242	110
HNr2/DE	200	0.22	5.0	1	50	19	0.7	154	0.3148	69	0.5110	112	0.242	53
MNr/DG	200	NO DATA: THE SLOPES ARE TOO STEEP							-	-	-	-	-	-
MQ2/DF	200	0.15	9.9	1	50	29	0.7	208	0.3148	93	0.5110	152	0.242	72
PFb/AD	200	0.25	1.3	1	50	8	0.7	46	0.3148	20	0.5110	33	0.242	16
AXb/A	200	0.23	0.06	1	50	1	0.7	2.0	0.3148	1	0.5110	1	0.242	1
UFr/BC	200	0.20	0.8	1	50	5	0.7	22	0.3148	10	0.5110	16	0.242	8

* Short ton

R = rainfall erosivity index
K = soil erodibility factor
L = slope length factor
S = slope factor
C = crop management factor
P = conservation practice factor

2.3.2 EMBU STUDY AREA

The study area in Embu district concentrates on Mbere area which comprises two divisions. Siakago division in the northern part and Gachoka division in the south. These two divisions had received some conservation attention only when the Special Rural Development Programme carried on soil and water conservation works. Field visits revealed that the soil erosion process in these area has not reached such an alarming stage as that of Machakos, Kitui or Baringo areas. The present agricultural staff have been introducing conservation measures such as grass strips. It was found at Muchonoke that one farmer had started practising erosion control measures. A gully 3 ft. wide which had started to form was controlled by a thin grass strip. It was pointed out that the grass strip should be approximately 2 meters wide. In Muchonoke area the farmers are just starting opening up land for cultivation. Soil Conservation measures should be done first when the land is still virgin and when natural vegetation can be left as to conserve the soil. For tillage practices, the Mbeere inhabitants use mainly ox-drawn ploughs jembes and pangas for clearing up. The farms are small holdings of about 4.1 ha (10 acres).

A visit to a farm near Muchonoke primary school revealed that the old terraces there had stabilized except where there were paths or where the animals had trodden. On the bench terraces a variety of healthy crops were grown- maize, beans, millet, mango trees and banana trees. It is evident that the farm management in this part can raise yields in terms of harvest per ha. Information was obtained that the grass strips which were very effective in stabilizing the farms visited in the area which were planted in 1973. After 5 years. of growth they were more effective in controlling soil erosion on slopes of 5 to 10% than would expensive structure. One farm on which erosion has been brought under control by the use of grass strips could be used for demonstration.

The grass strips should be laid to follow the contour line. It is found in Embu that where this is not the case the water broke through and eroded the soil on the lower sides of the slope. An example of this was seen in the farm mentioned.

2.3.2.1 Cut Off Drains:

In Gachoka division several cut off drains have been dug already. No proper information was given as to why they were constructed in September 1977. The ready answer was that funds were available. It was also found that no provision had been made for the discharge for any of these cut offs. It was found that in less than 6 months at least two of those cut offs had broken out and gullies were beginning to form. The extension staff who lay out the conservation structures must know that a water way has to be provided to conduct the water from cut off drains safely down the slope to a natural depression or water course. If this is not done a cut off drain should not be constructed as it intensifies soil erosion. The grass strips in Siakago division should be made popular also in Gachoka division. The ten different farmers who were visited and questioned on the grass strips felt very good about them. They not only were preventing soil erosion but providing forage for cattle.

2.3.2.2 On-going activities:

1. There are six main soil conservation projects in the area and more will be started when these six are finished Two areas in Mbeere division:

   (i) Gakanga - Itira in Nthawa location
   (ii) Kanyaga in Nthawa location

   In Gachoka division the DDC has recommended the following areas in Mbeti and Mavuria locations:

   (i) Rupingazi Valley Slopes - in Mbeti location
   (ii) Kirima Slopes in Mavuria location
   (iii) Riachina in Mavuria location
   (iv) Ngarira - Gichiche in Mavuria location

2. Land adjudication has been done in some of the locations and the people are happy with these adjudications. Four areas were demarcated on a clan basis while ten other areas have been earmarked as adjudication sections.

3. There is much shifting cultivation going on now and the people who are engaged in this practice do not want adjudication. Shift cultivators are not conservation conscious.

4. Some adjudication done, may have been carried out on uneconomical units. Some of the areas (perhaps should be left for ranching because of the soil type, either it is too shallow rocky or the slopes are too steep- or a combination of both for farming.

2.3.2.3 <u>Conclusions on Soil and Water Management in Embu-Mbere Area</u>

1. There is very little soil conservation activity in Embu Mbere area. There are no local groups such as Mwethya

in Kitui and Machakos and the people seem to have never had any contact with the soil conservation station at Ruiru. This station is supposed to be serving Embu area.

2. The training of extension staff seems inadequate, as evidenced by the layout of cut off drains which do not discharge their water into proper drainage channels.

3. Land registration is slow, many people do not like it and there are land disputes pending.

4. Ishiara Scheme to the north of the study area has failed to meet its goal because of four problems which should be looked into:
   (a) the scheme is a practical failure because of lack of technical know-how.
   (b) water is not used effectively
   (c) disputes among the irrigation farmers
   (d) salinity problem

5. Overgrazing is becoming evident but has not yet become universal. It should be checked early.

2.3.3 Time spent on constructing new terraces (An example taken from Machakos District

According to records held by the District Agricultural Office, the whole district has 3000 Mwethya groups with a membership of 150,000 people and 40% of this number i.e. 60,000 members are engaged in constructing new terraces. Different slopes are allocated the number of members engaged in constructing new terraces as follows:

Table 14

Constructing new terraces Slope in %	% of 60,000 members	Actual number of members
0-2	5	3,000
5-15	40	24,000
15-25	25	15,000
25-35	20	12,000
More than 35	10	6,000
TOTAL	100	60,000

There are 90,000 Mwethya group members who are left to carry out the repairs on the already constructed terraces. This is 60% of the districts' membership of 150,000 members who form the 3000 Mwethya groups in the district. Each Mwethya group works twice (2) in a week. Each time the group works for 6 hours a day therefore 2 x 6 = 12 hours of work per week. If we multiply this weekly hourage with 4 weeks we get the number of hours per month per Mwethya group.

Table 15

Repairs to Old Terraces

Slope in %	% of 90,000 members	Actual Number of members
0-2	5	4,500
5-15	40	26,000
15-25	25	22,500
25-35	20	18,000
More than 35	10	9,000
	100	90,000

The following table shows the output in hours per Mwethya group. Each slope angle has been allocated its share of members who participate in the work for that particular slope angle.

Time Spent on New Terraces

Table 16

Slope angle %	Hrs per month	No of Members	Total hrs.per month
0-2	48	3,000	144,000
2-15	48	24,000	1,152,000
15-25	48	15,000	720,000
25-35	48	12,000	576,000
-35	48	5,000	238,000
TOTAL		60,000	2,830,000

Table 17

Time spent on Repairing Old Terraces

Slope angle %	Hrs per month	No.of members	Total hourage
0-2	48	4,500	216,000
2-15	48	36,000	1,728,000
15-25	48	22,500	1,080,000
25-35	48	18,000	864,000
-35	48	9,000	432,000
TOTAL		90,000	4,320,000

Finally we see that - 60,000 members x 48 hours per month will spend 2,880,000 hours in constructing new terraces and tha, 90,000 members x 48 hours per month will spend 4,320,000 hours repairing old terraces. In Machakos alone. Mwethya groups spend a total of 7,200,000 hours on terrace work per month.

Terrace repairs and construction is heavy physical work. If the workers are termed unskilled then their gazetted wage rate is Ksh.1.25 per hour (see Kenya Gazette Supplement No. 42 of 1/4/77.

Frequently people will not work for the hourly rate of Ksh. 1.25 and the figures shown here are only as indicators of how much is the output by the Mwethya group members. Individual unskilled workers ask to be paid Ksh. 2 per hour for similar job. Assuming 4 months of Mwethya group activity per year, its shilling value in Machakos is $1.25 \times 4 \times 7.2 \times 10^6$ = shs. 36 per year.

2.3.4 GULLY EROSION

The Universal soil loss equation already discussed attempts to predict splash, sheet and rill erosion from arable land, but does not consider the gully erosion, streambank erosion or erosion from non-arable land within the catchment.

Gully erosion which comes after sheet and rill erosion occurs in three ways.

i. where runoff of a slope increases sufficiently in volume or velocity to cut deep incisious (FAO No.7 81 Rome 1965)

ii. where concentrated water flows long enough in the same channel to develop deep incisions.

iii. they may develop in unchecked rills or they may develop in natural depressions of the land surface where runoff water accumulates.

All these conditions appear in the study areas.

The gullies found in Eastern study area are a mixture of V and U shaped. Their shapes depending largely on the resistance of the subsoil on which they occur. The depths are also varied ranging from one metre to 6m. deep. The width of gullies also vary. The larger widths ranging from a few metres to about 15m. wide. The length of the gullies are variable dependent on the slope and also whether the gullies are wearing backwards up the slope.

Table 18 presents the current status of the soil erosion in the two study areas. All the forms are grouped together in these tables.

The soil mapping units were categorised as follows:

0-1 No erosion
1-2 Sheet erosion alone
2-3 Sheet and rill erosion
2-5 Sheet, rill and gully erosion

TABLE 18

The Current Sheet rill and gully erosion in Machakos, Kitui and EMBU

ECO. Zone	Mapping Unit	Hectares	Soil erosion rating	Type
II	HQb/EF	1200	2,3,4,	Sheet; rill, gu
II	MQ1/DF	4844	2	Slight sheet
II	MQ_2/DF	10522	5	gullies
II	UFr3/EC	993	3	Sheet
Total		17559		
III	HNr_1/DE	3500	2	sheet
III	HQb/EF	15948	5	gully
III	MBr/DF	1614	2 - 4	sheet - gullies
III	MQ1/DF	16236	2 to 3	sheet
III	MQ2/DF	17995	4 - 5	gully
III	UTr/BC	1650	0	0
III	UFr_2/BC	4970	3	sheet
III	UIr_1/BC	2310	1	sheet
III	UNr_1/BC	22031	2	sheet
III	UNr_1/BC	4030	2	sheet
III	UU1/BC	4600	3	sheet & rill
III	UU_3/BC	745	3	sheet & rill
III	UU_3/C	840	3	sheet & rill
III	UUC1/BC	2111	2	sheet & rill
III	UUC_2/CD	1700	2 - 4	sheet to gully
III	UU_1/BC	1958	2	sheet
Total		103168		
IV	RNR1/DE	350	3 - 4	sheet & gully
IV	HNr_2/DE	10370	2 - 4	sheet & gully
IV	HQb/EF	32686	2 - 4	sheet & gully
IV	LID/A	242	0	0
IV	LIC/AB	2350	1	sheet
IV	MNb/EG	5096	2 - 4	sheet & gully
IV	MQ1/DF	9813	2 - 3	sheet & gully
IV	MQ_2/DF	6413	5	severe gully
IV	PIC/AB	11894	2	sheet & rill
IV	PIr/AB	2289	0	0
IV	UPd/AB	3516	0	0
IV	UPd/AC	1179	0	0
IV	UFr1/BC	2765	3 - 4	rill
IV	UFr2/BC	3102	2 - 3	sheet
IV	UFr_2/C	1055	2 - 4	rills - gullies
IV	UFr_3/AB	7552	1 - 2	sheet
IV	UFr_3/BC	709	2 - 3	sheet - rills
IV	UIr_1/BC	4054	0	0
IV	UIr_2/AB	13354	0	0
IV	UIr_2/CD	5869	0	0
IV	UNr_1/AB	3172	1 - 2	sheet
IV	UNr_1/BC	51879	1 - 2	sheet
IV	UNr_1/C	850	2 - 3	sheet - rill
IV	UNr_1/CD	12093	2 - 3	sheet - rill
IV	UNr_2/BD	25217	2 - 3	sheet - rill
IV	UQ_1/BC	17128	1 - 2	sheet
IV	UQ_1/C	1243	1 - 2	sheet
IV	UQ_2/AB	869	1 - 2	sheet
IV	UQ_2/BC	3416	1 - 2	sheet
IV	UU_1/BC	32244	0	0
IV	UU_2/BC	30332	1 - 2	sheet
IV	UU_2/C	404	2 - 3	sheet & rill

Table 18 continued

ECO. Zone	Mapping Unit	Hectares	Soil erosion rating	Type
IV	UU_2/CD	9407	2 - 3	sheet & rill
IV	UU_3/BC	3727	3 - 4	sheet & gully
IV	UU_3/C	1892	3 - 4	sheet & gully
IV	UUC_1/AB	2310	2 - 3	sheet & rill
IV	UUC1/AB	6708	2 - 3	sheet & rill
IV	UUC1/BC	3726	1 - 2	sheet & rill
IV	UUC1/DE	7761	2 - 4	sheet & rill
IV	UUC_2/BC	9281	2 - 4	sheet & rill
IV	UUC_2/C	6281	2 - 4	sheet & rill
IV	UU2/CD	32045	2 - 5	sheet rill & gully
IV	VXG/EF	13092	2 - 5	sheet rill & gully
IV	Total	462762		
V	AX1/AB	35295	0 - 1	No - erosion
V	FXb/BD	14963	2 - 4	sheet - gully
V	HNr_2/DE	8189	2 - 5	sheet & gully
V	HQ$_2$/DF	39256	2 - 4	sheet & gully
V	LIC/AC	37655	0 - 1	No erosion
V	LID/A	7515	0	
V	MNr/DG	11892	2 - 4	sheet - gully
V	MQ_2/DF	10565	2 - 5	sheet-rill gully
V	PFb/A	27494	0 - 1	No erosion
V	PP_2/A	133847	2 - 4	sheet & gully
V	PIC/AB	3652	2 - 3	sheet & rill
V	UFC/AC	14347	2 - 3	sheet & rill
V	UFD/AB	37734	0	0
V	UFd/AC	11862	2 - 3	sheet & rill
V	UFr_1/BC	7883	0	0
V	UFr_1/B	1155	2 - 3	sheet & rill
V	UFr_3/BC	169010	2 - 3	sheet & rill
V	UFr_3/C	11739	2 - 5	gully
V	UFr_4/C	17005	2 - 4	sheet & rill
V	UFr_6/CD	15515	4	gully
V	ULb/D	1551	1 - 2	sheet
V	UNr_1/BC	84003	1 - 2	sheet
V	UNr_1/C	2358	2 - 3	sheet - rill
V	UNr_2/BD	7886	2 - 3	sheet-rill
V	UQ_1/A	9968	2	sheet
V	UQ_1/BC	20606	2 - 4	sheet-gully
V	UQ_1/CD	482	1 - 2	sheet
V	UQ_2/AB	9154	1 - 2	sheet
V	UQ_2/BC	1007	1 - 2	sheet
V	UQ_2/CD	3937	1 - 2	sheet
V	UQ_2/E	284	1 - 3	sheet & rill
V	UU_1/AB	7452	0	0
V	UU_1/BC	28390	1 - 2	sheet
V	UU_1/C	3975	1 - 3	sheet & rill
V.	UU_2/AB	47797	1 - 2	sheet
V	UU_2/BC	72983	2 - 3	sheet & rill
V	UU_2/C	2514	1 - 2	sheet
V	UU_2/CD	5065	1 - 2	sheet
V	UU_3/BC	2173	3 - 4	sheet & gully
V	UU_3/C	4472	3 - 4	sheet & gully
V	UU_3/CD	4968	2 - 4	sheet & rill
V	UU_3/DE	7701	2 - 4	sheet & rill
V	UUC_1/AB	75270	2 - 4	do
V	UUC_1/BC	50574	2 - 4	do
V	UUC_1/C	14285	2 - 4	sheet & rill

Table 18 continued

Eco.Zone	Mapping Unit	Hectares	Soil Erosion ratings	Type
V	UUC_2/AB	2298	2 - 4	sheet & rill
V	UUC_2/BC	10559	2 - 4	sheet & rill
V	UUC_2/C	8266	2 - 3	sheet & rill
V	UUC_2/D	90115	2 - 3	sheet & rill
V	VXV/BE	5010	2 - 5	sheet,rill & gully
V	Total	1220222		
VI	PFb/A	7500	0 - 1	no erosion
VI	PFn/A	25781	2 - 3	sheet & gilly
VI	UU_1/BC	1801	2 - 3	sheet & rill
VI	TOTAL	35082		

TOTAL ALL ZONES 1,837,800

The Kenya Soil Survey System of rating for soil erosion was followed when categorising the eroded areas in the particular mapping units. The areas are shown in the map. The gullied areas require gully treatment. Parts of Baringo/ Kerio Valley where gullying has advanced has produced another shape of landscape on which farm machinery will be difficult to use.

National effort is required for controlling the gullies in addition to individual efforts, since gully control is one of the most costly of all erosion control measures. It is however never too late to do something.

The problems of overgrazing have been already mentioned, mainly in relation to sheet and rill erosion. If a catchment gets a reduction in the density of vegetation through overgrazing then the runoff water gains an increased velocity with the risk of beginning gully erosion. This is the case of Baringo study area as has already been mentioned.

Tables 19and 20 show the extent of gully erosion hazard in Machakos, Kitui, Embu, Baringo and Kerio Valley areas. The soil mapping units have been grouped together and their hectarage calculated. A total of 467,686 ha. is gullied in Machakos, Kitui and Embu area. This represents 25.45% of the whole area. It means that 25% of the area is in need of gully treatment measures. In Baringo and Kerio Valley, the gullied area is 275,691 ha. which is 55% of the whole area requiring gully treatment measures.

TABLE 19

GULLY EROSION IN MACHAKOS, KITUI AND EMBU AREA

Mapping Unit	Area in ha.
HQb/EF	1,200
MQ2/DF	10,522
HQb/EF	15,948
MBI/DF	1,614
MQ2/DF	17,995
UUC2	1,700
HNr1/DE	350
HNr2/DE	10,370
HQb/EF	32,686
MNr/DG	55,962
MQI/DF	9,813
MQ2/DF	6,413
UFr2/C	1,055
UU3/BC	3,727
UU3/C	1,892
UU2/CD	32,045
VXC/BF	13,002
FXr/BD	14,968
HNr2/DE	8,139
HQb/EF	39,266
MNr/DG	11,992
MQ2/DF	10,869
PFr/A	133,847
UQ1/BC	20,606
UU3/BC	2,173
UU3/C	4,472
VXC/BF	5,010
TOTAL	467,686

TABLE 20

GULLY EROSION IN BARINGO AND KERIO VALLEY AREA

MF/EF	15,813
FXC/BD	59,125
MIb/EE	23,813
AXI	42,063
AX2	44,063
LIr/AB	11,938
UIb/BC	78,876
TOTAL	275,691

2.4 Rural Water Supplies and Water Conservation

2.4.1 Rural Water Supplies

It is the objective of the Government through the Ministry of Water Development to supply every citizen with potable water by the year 2,000. At present it is estimated that only 13% of the rural population is served by water supplies of varying degree of service. The M.O.W.D. through the rural water supply program RWS, the minor urban water supply program MUWS, the self help and DDC projects are all set with one goal in mind that of alleviating water problems where women spend most of their time carrying water over long distances.

The 1978 population of the study area covered by the three districts is estimated to be around 683,000, 330,000 and 79,000 for Machakos, Kitui and Embu respectively. Of the above population the number of people served by water is about 88,760, 42,900 and 10,290 respectively for the three areas, i.e, that there is a potable water supply within 5 km.

Since the RWS program was started in 1970 Machakos and Kitui have had 5 projects and 3 projects completed respectively i.e. a population of about 10,000 for Machakos and 4,000 for Kitui. In Embu, the special Rural Development Program (SRDP) has constructed two projects, Ena and Ishiara and the estimated population served by these projects is about 3,500 people.

The next RWS program IV estimates the number of people to benefit in the study area as around 40,000 and 10,000 for Machakos and Kitui areas respectively. No projects have been approved for Embu district, within the study area.

The MUWS program which started in 1974 included the construction of 42 water supplies in the minor urban areas of the country. These urban areas have no water supplies at present or the water supplies currently in operation are inadequate and below the required standards. The objective of the program is to provide to these growing urban areas water of the required standards.

In the project area, the urban centres covered by the project's first phase are Kitui, Machakos, Kangundo-Tala and Mwingi. The first phase was expected to be completed within five years but considerable escalation in costs of construction and materials affected the budget for the projects resulting in delays while more funds were being sought. The completion of the projects may therefore be delayed for some further 4 years or more.

The next phase of the program which may not be implemented until after the 1980's proposes projects such as Mbooni, Nunguni, Makueni, Masii, Athi River, Sultan Hamud, Kibwezi, Kalawa and Masinga in Machakos; Katse, Mutomo for Kitui; and and Ishiara and Siakago for Embu.

It is apparent that the goal set for the turn of the

century for the rural water supply will never be realised through the RWS program only. However, this has been realised and self help projects aided by DDC and other organizations e.g. CARE, Missionaries and Donor agencies has done a lot towards meeting this target. Their programs are directed toward assisting self help projects.

Some of these projects e.g. Wango (Karaba in Mwea(Embu) Mutune - Kitui etc. are quite successful.

The idea of piped water appears to be the accepted fashion of any water supplies within the rural population and the tendency is to shun any other form of water development. But extensive water projects take years to plan and implement and small projects based on roof catchments, dams, subsurface dams, rock catchments and development of springs should be emphasised. There are some quite successful small projects in the study area e/g the Ngomeni and Yambyu rock catchments (Kitui), the Kerie (Kiangombe hills, Embu), and Kiteta (Mbooni - Machakos) water supplies based from springs.

There are other potential areas which could be developed e.g. the Kareroma rock catchment in Embu, Evurori location which extends for more than 3 ha.

The Mola-Yandume springs in Nuu location Kitui district could serve a useful purpose if they were developed.

2.4.2 Water Conservation

This is undoubtedly the highest priority need in the study area of the three districts. The lack of permanent rivers and the unreliability of the ground water resources necessitates the need to conserve water.

Though Embu district has quite a number of permanent river e.g. Ena, Thuchi, Rupingazi, Kapingazi and Tana, the study area is quite like Machakos and Kitui, the rivers being quite remote and would require a lot of financial inputs for the area to benefit from these rivers.

Water conservation, in the form of construction of large surface dams, water holes etc. has been going on since the ALDEV period and also through the dams construction units of MOWD the soil conservation service, MOA and the National Youth Service.

Records to date indicate that Machakos and Kitui have had about 826 and 313 dams respectively for each district. However, most of these dams have been broken down or washed away. The rest which are remaining are reckoned to have their capacities reduced by 50% each year through sitting. Studies made on sediments carried by streams (Dunno 1974, MOWD. Publication) indicate heavy suspended sediment loads of the order of 600 tonnes/Km^2 for Embu, Machakos and Kitui. This figure is only approximate and the magnitude of the bedload has not been indicated.

The Kalundu Dam in Kitui district, built in 1958 and

completely silted up in 1974 indicates an average yield of sediments of about 733 tonnes/Km^2. Another dam is Machakos Maruba dam indicates sediment yields twice that of Kalundu.

Water conservation in Embu district was not intensified as in the other two study areas, but the need to conserve water within the project area is as important and necessary as in the Kitui and Machakos areas.

The land use in Embu is not as badly managed as in the other areas but nevertheless the population pressure is undoubtedly building up.

Water conservation should be carried on a watershed/catchment basis starting at the top. This should not be carried out in isolation but other activities as well e.g. controlled livestock grazing, reseeding of pastures, soil conservation, afforestation etc. should precede or run concurrently with water conservation. The dams construction units of the MOWD is not adequate to serve all the areas in the country and such units need to be increased. Subsurface dams should be encouraged and run alongside dam construction activities on the same basis and any other form of water harvesting.

2.5 Irrigation and Drainage

The topography in the Embu-Kitui-Machakos area is such that major irrigation projects are not practical in most of the area. The rivers have cut deep which leaves much of the land with slopes too steep for successful irrigation except by over-head methods. It would require canals of considerable length to distribute the water in many of the areas. There are a few areas where the topography is suitable for irrigation development, and investigations should be made regarding the availability of a water supply for these.

The water supply is limited in the area, and there are areas outside the study area where the topography is more favorable. Careful investigations need to be made regarding the location of water use.

With the exception of a few potential sites which will be mentioned later, the major irrigation potential is the use of water on small projects, such as the irrigation of a few hectares or that of a small garden plot or even a single fruit tree. Development of these small projects will require extension personnel who can assist individual farmers or small groups of farmers to plan and develop the water supply as well as assistance in principles of water application to the land to be able to obtain optimum production increase with the limited amount of available water. Extension workers with expertise in water development and irrigation practices are not available. Too often an irrigation project fails because the water user is not trained in proper water application.

Considerable research and investigation is necessary to determine best methods of water use under existing climatic, soil, and crop conditions in a given location. Even where large projects are possible, the first phase should be on a small scale so that best methods of water application are determined early to avoid mistakes as the development of the project progresses.

2.5.1 Small Projects

The greatest benefit of irrigation in most of the study area can be obtained from a very large number of small projects, developed generally on an individual farm or a small drainage basin. First efforts should be to increase the infiltration rate. By doing this more of the precipitation will be available for use by the plants. With this accomplished, the plants will produce better and more regularly if irrigation is not available and where it is used less water will need to be applied by irrigation.

In soil and water management it is necessary to keep as much of the water where it falls as is practical. To accomplish this, small storage facilities need to be built near the head of the catchment basins. Planning and design of these storage units should be such that the water when needed can be utilized for irrigation. The emptying of the storage facility by spreading the water on the land makes it possible to store a larger percentage of the next rainstorm.

Utilization of the small storage facilities, including the soil reservoir, on all portions of a catchment area will greatly reduce the peak flood flows and tend to cause the rivers to flow for a longer period after the storm. Some of them will eventually become perennial streams with proper management practices.

Examination of daily precipitation records for some of the rain gauge stations in the study area even during the rainy season show that there are periods of two weeks or more without an appreciable amount of precipitation. When this is the case, water from the small storage facilities mentioned above would be very beneficial in increasing crop production.

2.5.2 Use of Runoff Water

Using runoff water to produce crops on lands which receive as little as 100 mm annual precipitation has been practiced for more than 3000 years. Ancient farmers in the Middle East cleared hillsides to increase runoff water and built rock walls on the contours to collect it. Similar systems have allowed agricultural civilizations to survive in desert regions. Using runoff water by methods similar to that mentioned could enhance agriculture in the semi-arid areas of Kenya.

Runoff water from noncropped areas directed to cropped areas can increase the soil moisture storage around the crops. This extra soil moisture may be the difference between some production or complete crop failure. Chief Wilson of the Kateta Location in Machakos District has a grove of approximate 1200 orange trees. Moisture from natural precipitation is generally not sufficient for optimum production of these trees. The trees are spaced farther apart than is necessary in an irrigated grove. He is preparing the land around each of these trees so that the water from the fringe areas is directed to an area occupied by the tree roots. Basins are constructed around each tree to collect and store the water so there is no runoff. As the trees are young, with the first production last year and the water harvesting is just beginning, it has been impossible to observe results from this project. It would seem, however, that nothing but good results can come from this type of activity. This system could be used on any number of trees. Again it is mentioned that flood flow peaks are reduced. Soil erosion is reduced to a minimum, and additional water is made available to the trees probably increasing production.

By dividing watersheds into small catchment areas which would allow the runoff to be controlled and directed to areas where the water would be spread over cultivated fields; crops could be grown on these fields. If the fields were prepared with channels and terraces to direct the water uniformly over the fields, an irrigation would be accomplished with each rainstorm. A careful design would be required for this type of system to prevent excessive runoff and erosion from storms of high intensity.

Another system is where flood waters are deliberately diverted from their natural channel and spread over adjacent flood plains or detained in small dams for later use in irrigation. Again a careful design and layout are necessary to prevent damage by flood waters.

By using methods such as those mentioned and similar ones, crops can be made to grow in areas which are otherwise too dry to mature a crop. Yields from many cultivated lands in Kenya's marginal area can be materially increased without istallation of costly irrigation projects, and it will lower the risk of crop failure.

Runoff agriculture requires a deep soil that can store considerable water between rains. It will work best for deep-rooted crops such as trees and shrubs which extend their roots into a larger volume of soil so they are less dependent on frequent rainfall. As modern experience is limited in irrigation from runoff areas as mentioned, it is necessary that considerable research and investigation be made to determine the extent of these practices. Specific site prerequisites are necessary to be able to practice irrigation by these runoff methods. Investigation needs to be done by persons experienced in this to determine suitable locations. In many cases the farmer could develop his own runoff scheme with assistance from those with experience.

2.5.3 Ishiara Scheme

In Embu District near the town of Ishiara there is an irrigation scheme obtaining water from the Thuchi river. This scheme was initiated in the early 50's by the African Land Development Program (ALDEV). This scheme was successfully operated for several years. The scheme consists of a total of 28 ha and each farmer has 0.8 ha for cultivation. With political change in the early sixties, the running of the scheme was transferred to the Embu County Council. The County Council or the agricultural extension staff did not have the technical and managerial competence for operation of the scheme. In 1968, the Ministry of Water Development reconstructed this intake and did repair work on the canal system.

Because of lack of interest and management, the effectiveness of the scheme has grown downhill recently. The scheme was visited in February 1978. Very little of the area had crops growing which were adequately cared for. Much of the area has been planted, but apparently nothing had been done with the land since planting. The technical assistant who is in charge of the scheme, reported that only 10 of the 37 settlers on the scheme were taking care of their crops. It was further reported that the location chief gave no help or encouragement to the scheme. The Technical Assistant stated that he has no power and cannot control the management. The farmers will not clean nor maintain the canal. The farmers do not pay for the use of the water or the land, and apparently do not think they have an economic stake in the success of this system.

Water is being misused. An approximation of the amount

of water flowing into the canal at the head was made. With normal seepage and canal losses there should have been sufficient to irrigate an area three times the size of the scheme. Water was allowed to run for long periods of time and lower portions are being water-logged. It is very likely that if corrective measures are not soon taken the land will become useless unless expensive correction measures are taken. The soil is good. The lay of the land is good, and there is adequate water to expand the scheme to several times its present size. There is also good irrigable land available for such expansion.

The Tana River Development Authority has made a preliminary feasibility study of the scheme (TRDA 1978). They are recommending rehabilitation of the present scheme and increasing the size to 140 ha., half of which would be north of the Thuchi River in Meru District.

Before this or any other irrigation scheme is developed, a very careful study of the causes of failure should be made so as to avoid such failures in the future. The Ishiara Scheme may be an exception, but it apparently does not provide anything to the economy of Kenya and is a big expense to the country. There is no advantage to spend large amounts of capital to develop schemes of this type.

2.5.4 Eastern Kitui Potential

Near the eastern boundry of our study area in Kitui there are large areas of irrigable land, possibly as much as 100,000 hectares. The soil is suitable. The topography is right for irrigation. If water is available, extensive irrigation development could be accomplished in this area. The principal rivers in this area are the Ikoo and the Tiua. The Ministry of Water Development reports that they have no records of streamflow quantities on either of these rivers. If there are suitable sites for dams and storage reservoir on these streams, the area could be developed for irrigation to the limit of the water supply.

It would be desirable to phase the development of an area such as this by starting with very small areas, a few hectares, to conduct research investigations to determine suitability of different crops, cropping patterns, amount of water necessary, economics, and others.

2.5.5 Other Projects

Work has begun on the Masinga dam in Embu District. This will form a large reservoir on the Tana River for river regulation, power generation, and possibly some irrigation in the upper Tana basin. There are also sites for reservoirs for water storage being investigated by TAMS on the Athi River and more studies should be made to determine if there might be storage sites and water resources available for irrigation development. Although it has been stated that irrigation cannot be an important factor in agriculture in Kenya, it is important that all the water which is available for this be

determined and developed. It has been stated that a better living can be provided for a family from 2 hectares of irrigated land than from 200 hectares of rough pasture in a 625 mm rainfall area.

An analysis of the water needs should be made for each project site. In Kenya this is done by using the potential evaporation derived by Woodhead, converting this to potential evaportranspiration by multiplying by 0.8 and subtracting from this value the dependable precipitation, usually at the 75% probability level. An example of this is shown in Table 3 of the Appendix for the Ishiara scheme. During the early phase of development, an education and training program should be part of the program. The number of projects necessary in soil and water management requires skilled manpower far greater than is available in Kenya, both in numbers and level of training. In the three stages of an irrigation project, the planning, construction, and operation, the first two may be done by expatriates or international contractors, but the operation phase of a project is best handled by local staff. Expatriate staff are not desirable during this phase for several reasons. They are difficult to obtain in sufficient numbers. It may be difficult to get personnel who will live in the project areas. They may be unavailable during times of international crisis, or their presence may discourage the training and promotion of local personnel. If local staff were brought onto the project at the beginning of the planning and design stage, they could be trained somewhat in the technical aspects of operation of irrigation systems. This would reduce the dependence on expatriate personnel.

The training should be at all levels, technicians, engineers, managers, etc. Some who have had formal academic training could get on-the-job training by working with trained personnel on the project. Others who need more academic training beyond that available in Kenya could be given scholarships for additional overseas training. Training of local personnel is one of the most important aspects of projects in any phase of soil and water management.

SOIL AND WATER MANAGEMENT
Baringo-Kerio Valley

3.1 Location of Study Area

The Baringo-Kerio Valley study area is bounded by 0°15' and 0°45' north latitude and 35°30' and 36°15' east longitude. This includes all or part of 12 locations in the Baringo District, and 2 locations and part of another in the Keriyo-Maraquet District. The District headquarters are at Kabarnet for Baringo and at Iten for Keriyo-Maraquet. The main populations centers for these districts are at Marigat and Tamback respectively.

3.2 Climatology and Hydrology

There is only one meteorological station in this study area and only seven raingauge stations with a record of more than three years. Several raingauge stations were established recently and records of three years were obtained from the meteorological department. Records of the other seven stations were also obtained from them.

The Tugen Hills go through the west central portion of the study area. They have an elevation which rises to more than 2500 meters. West of these hills is the Kerio Valley with the elevation drops to below 1000 meters at Lake Baringo. Temperatures at the Marigat meteorological station are reported to have a mean maximum of 33.7°C in February and 30.4°C in July for high and low maximums. The mean minimum varied from a low of 15.9°C in September to a high of 18.0°C in April. The temperatures at the higher elevations would be below these amounts. Reported relative humidity at this same station varied from 68% to 53% at 0900 and from 42% to 29% at 1500.

The mean annual evaporation from a type A pan was 2576 mm with a mean of 248 mm in March, being the highest monthly mean and 189 mm in July for the lowest monthly mean.

The rainfall varies with the elevation. The mean annual at Perkerrairrigation near Lake Baringo being 663 mm and the mean annual at Katimoke Forest Station 1503 mm.

The precipitation in Baringo-Kerio Valley is mostly from April to August, with January and February being the driest months.

3.2.1 Surface Water

There are several perennial streams in the study area, Perkerra, Molo, Sandai, Kerio, and OI Arable. There may be others, but there are no gauging stations reported on any of the others so there is no record of them. The Perkerra and Molo flow into Lake Baringo. The Sandai flows into Lake Begoria, while the Kerio flows beyond the study area into Lake Turkana. Quantities of flow for these streams are reported in Table

Lake Baringo is in the northeast portion of the study area and Lake Begoria, a salt water lake is in the southwest. Part of this lake is outside of the study area. Between these two lakes is a series of swamps which very likely at one time was a fresh water lake, connecting Lake Baringo and Lake Begoria, making only one large Lake in the area.

3.3 SOIL CONSERVATION IN BARINGO - KERIO VALLEY STUDY AREA

Soil Conservation measures are needed to ensure that land is utilized sufficiently to produce some food for the inhabitants of a given area. Baringo and Kerio Valley in the Rift Valley can be managed such that land produces enough for the local inhabitants. This review is to present in outline what is happening to Baringo and Kerio Valley related to soil management and conservation.

3.3.1 The Soil Conservation Situation in Baringo:

According to latest reports from the District headquarters, Baringo District enjoyed some financial help from the district development committee to carry on some soil conservation work from 1974 to 1975. There are no records to indicate how much terracing or other conservation works were undertaken. However, terraces were measured out and constructed to conserve the soil. Water holes were also dug. The construction work in 1975 was done by the soil conservation service, Nakuru which released the machinery for construction of water holes. Nakuru soil conservation service renders paid assistance to farmers, institutions and to Government bodies requiring their service, but they are not expected to continue working any where unless an assurance of payment for services is made. From 1975 to 1976 (one hundred and seven water holes were constructed in Southern division where the farmers have title deeds. The figures below present what was done.

Total - (measured laid out) - terraces

1975	1974
46,713.46 m.	27,242.76 m.
i.e. about 47 km.	about 28 km.

These figures suggest very low output for a district with severe erosion. It should be noted that the figures presented represent high potential areas of the district with remarkable neglect in the grazing area towards the eastern side and the lake region.

In soil conservation as in other related agricultural practices, a stock unit is an animal whose weight is 1000 lb. i.e. 454.5 kg. live weight. If then, we have in range areas goats weighing an average of 200 lbs. (90.7 kg.) each, it would follow that 5 goats in areas surounding Lake Baringo would be one stock unit. One stock unit requires 10 acres (4.05 ha.) in this area. Soil Conservation measures, therefore, would be effective after realization of the recommendations on revegetation and reseeding programmes contained in the livestock report which is dealing with the carrying capacity of the land. Animal ownership of unproductive animals for prestige on the land should be discouraged through the chiefs meetings. The DDC members should also be involved in this campaign.

3.3.2 The Geographical Zones in Baringo:-

The Study area in Baringo and Kerio Valley occupies the low zones, medium zone the high zone and the Kerio Valley itself.

3.3.2.1 The Low Zone: Is characterized by an altitude ranging from 914 m. to 1524 m. above the sea level. The rainfall ranges from 508 mm. to 762.0 mm. and therefore in the region of semi arid land. The area is also the seat of Lake Baringo, Perkerra Irrigation Scheme and half of Lake Bogoria with its hot springs. North of Lake Baringo the area is hot and rocky and thorn bushes are predominately the natural vegetation. This area is suitable for properly managed large grazing blocks. There is remarkable soil and water loss in the north that can be remedied by incorporating proper water and land management. Proper stocking rate can be attained in this region by adopting methods recommended by the livestock section of this report. All the excessive bulls should be sold or slaughtered. All the barren females should also be removed and new grazing methods introduced at once. To avoid raw eroding areas from expanding the cattle dips should be sufficiently distributed. Raw eroding areas are also likely to develop from watering points. They should be evenly distributed in this northern part. Erosion around Marigat which neighbours the Perkerra Irrigation Scheme is disastrous. Here, the concentration of population living permanently in the same land exerts constantly heavy pressure. Rotational grazing by fencing off the badly eroded areas and allowing them to return to natural vegetation cover seems to be the best solution. The Provincial administration and the agricultural staff based at Marigat can ensure that land usage rules are adhered to around this area. The low zone is also well watered from the high zone and this could account for the extent of erosion in this area. Photos 1-4 show how erosion has taken place around Saber on the Chemogut river valley. The animals are permanently here and devour anything that tends to grown. A rough estimate of the erosion hazard indicates that 56% of the range land (3,612 sq.km.) is badly eroded. All forms of erosion are present, sheet rill and gully. Thirty six percent of this area requires rehabilitation. The grazing land has been categorized as follows:-

(1) High potential range land which occupies 8% of the total grazing land. This may also be found in the Kerio Valley. There is usually no soil erosion in this area except where land is opened up for cotton growing as is the case of Kerio Valley. Here erosion is now evident.

(2) Ol-Arabal area lies south east of lake Baringo and extends to Oleimatashu Swamp on the Perkerra River. This is a good area and has not been overstocked. The population is high and the area is level. The erosion is minimal. During the last 10 years the Tugens who practice shifting

agriculture have caused the deterioration of this land. With careful management this area can support most of agricultural practices. There are a few conservation structures that are required if proper management of land is to be practised.

(3) Churo Area (North East of study area)

This is a very high potential grazing land, the people want to divide this land into small agricultural units. There is very little erosion in this area because of the vast vegetative cover. The area adjoins with the study area to the north east. Tangulbei region is in the study area. The Tangulbei Dam built by ALDEV does not dry up for long periods. The water is clear, in this dam an indication of good ground cover from the catchment. Near the Tangulbei dam is a bore hole whose information is contained in the water section in the report. The grazing area in Baringo is 8,612 sq. km. and 36% of this area is basically occupying east Pokot Land. There are two locations, Tirioko location and Kibkwo location which are outside the northern study boundary. Korosi location was looked into and it was concluded that it is good for rehabilitation. There is absence of serious erosion but as a measure to reduce runoff, pasture furrows can be constructed where runoff seems to be high. Pasture furrows are open drains which follow the contact and which are close together. They are good for conserving the water

Fig. 5

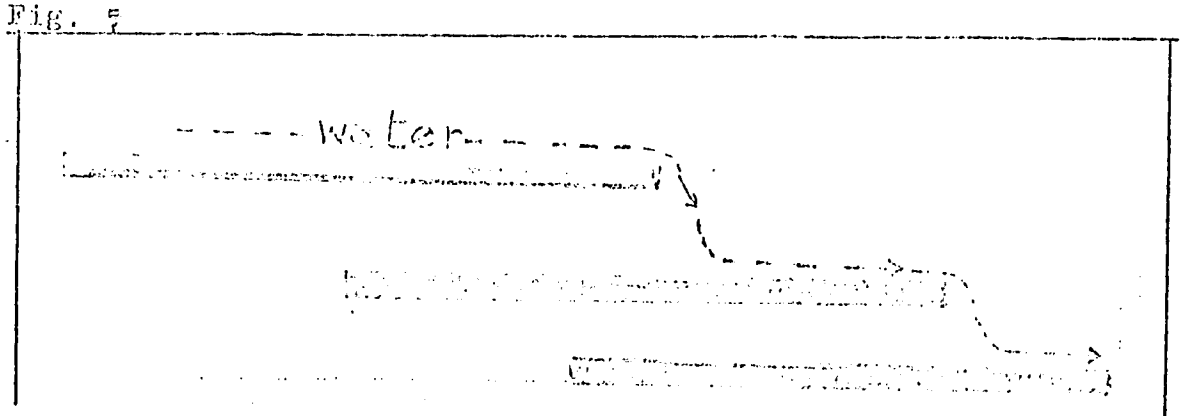


DIAGRAM OF PASTURE FURROW DRAINS

This system of water conservation can then be followed by reseeding programmes. This conservation practise is already being practised successfully in Turkana district, whose conditions are close to those in Baringo. Grass cover establishes well from the conserved moisture.

3.3.2.2 Medium Zone:

One ascends from low zone to the west of the Lake to what is a plateau with nearly level slopes 1-5%. Most of the top soil has been washed away leaving the fertility very low. This area requires rehabilitation. Where the ground changes in topography there is serious erosion. The rainfall is about 762 mm. getting higher as one goes west reaching a maximum of 1016 mm.

The slope changes with the climb from 5-12% and the agricultural practise is mainly grazing (see photo 2 with goats at the background around Sabor area). This area should be the principal focus for erosion and denudation rehabilitation. It is the area from which the sedimentary materials are transported to the low land and eventual silting of Lake Baringo. Along the gullies the water table is very low (see the ground water section).

3.3.2.3 The Highlands:-

Kabarnet the headquarters of Baringo district is situated on this land. It is high (1829-2741m.above sea level) with remnants of indigenous forests. The rainfall is 1016 - 1270 mm. per year. Large areas have been opened up for arable agriculture and grazing is also practised. The DDC funds have been concentrated in this part and several soil conservation structures have been built. On the areas where ALDEV had done some work, the bench terraces have stabilized. It was however observed that a cut off drain was being constructed where there was no need. Cut off drains should be constructed only after careful investigation has been carried out. The embankment material should not allow seepage which may eventually break the walls of the embankment in time of a high storm. The cut off drain should be visited regularly to see its effectiveness. Poorly constructed drains are more disastrous than when the land is left bare. In the case of this particular cut off drain, the soils below had stabilized because the ALDEV terraces had stabilized and the farmers had been harvesting maize crops from the terraces. The banks were stabilized with the Kikuyu grass (pennisetum clandestium) which does very well in this highland region of Baringo District. The local inhabitants are the Tugen tribesmen and they have had their land adjudicated.

This accounts for the careful usage of the land found in this area. Some comments on the impact of land adjudication to soil conservation and land use are made in the earlier report (midpoint review p. 4-37). These comments are favourably fit for Machakos, Kitui and Embu areas. Baringo is different because the ethnic group is also different (see report No.6,"Human Resources and Social Characteristics".) The principles behind land adjudication and its impact on the land use are the same for all the areas. The Tugen hills however, presents the visitor with the qualities of proper land use enhanced by land ownership.

3.3.3 Soil Erosion Situation.

The areas discussed in the preceding paragraphs have each their share of erosion problem. One area on the way between the main road to Lake Baringo and Kabarnet was carefully looked at. Some at the local inhabitants believe that the severe erosion happens due to the will of God. It is God who brings rain and that rain washes down the soil. Soil erosion on the road to Sabor 9-15% slope

to go to Baringo part was looked into. It is imperative that an agreed code of land use by established and adhered to as quickly as possible in order that the rational use of land resource may be regulated and the present wasteful exploitation be avoided.

It is suggested that a small demonstration plot be set up on the land of a cooperating farmer. Fence it off, remove all the animals and put in gully rehabilitation structures. Use it for both demonstration and research, i.e. to determine its rate of rehabilitation.

3.4 Rural Water Supplies and Water Conservation

3.4.1 Rural Water Supplies

The existing water supply projects of the study area within the district are all located on the high potential areas i.e. either on areas around the Tugen hills or around the Keiyo Marakwet escarpment. The Kerio Valley and the lowlands bordering Lake Baringo have no water supplies which are existing. This is probably due to the fact that permanent settlement in the lower areas is taking place recently as a result of the high population pressure from the hills. Water supplies exist in Karbanet, Karbatonjo, (Baringo District) and Tambach and Iten (Keiyo Marakwet District). These water supplies are not adequately meeting the demands of the people, due to inadequacy of the source or the quality of the water system. Iten and Karbanet are among the projects under argumentation under the minor urban water supply program (MUWS).

The next RWS program proposes a number of projects which are listed below. These include Kabluk in the Kerio Valley where rapid settlement is taking place and Kampi Ya Samaki on the western shores of Lake Baringo.

Marigat, classified as a local rural centre has been proposed in the next phase of the MUWS program.

The self help and DDC water projects within the study area of the district are not playing an important role in the rural water supply program as in the Machakos, Kitui-Embu areas probably due to the semi-nomadic nature of the people.

Table 21 Proposed Rural Water Supplies: Baringo District

Project Name and District	POP 1977	Water demand M^2/Day	Source	Estimated Cost. K.Shs.
Ratat	1200	$40m^3$	Pekerra River	1.2 million
Chepsigot-Biretwo (Keiyo/Marakwet	6500	260	Torole River	4 million
Lekwa (Keiyo Marakwet	2000	$80m^2$	Spring	1.2million
Kapkong Tenges-Sacho (Baringo)	1500	60	Springs	2.5million
Kabluk	4500		Springs	
Kampiya	82		Source not confirmed	1.2million

Soil Erosion caused by overgrazing in the Lake Baringo Area

3.4.2 Water Conservation

Very little has been going on in the past to conserve water. The soil conservation unit, MOA has been constructing small dams for individual farmers in S. Baringo District around Eldama Ravine but this is outside the project area. The dam construction unit (MOWD) has not been involved in any projects in the area.

However, the need to conserve water is great both for domestic, livestock and irrigation. In Kerio Valley, the success and expansion of the Barwesa irrigation scheme will require the regulation of the Yeptos river by construction of dams.

The land around Lake Kamnarok is suitable for irrigation and at present, the lake is being drained into the Kerio river by a channel. The importance of conserving the lake water for multipurpose use need not be emphasised.

The need to conserve the water on the Pekerra is apparent, the future expansion of the Pekerra irrigation project being dependent on availability of more water from the river. Reports made earlier had made recommendations for damming the Pekerra catchment is badly eroded and is continuing to be eroded such that any dams constructed would soon silt up or be washed away. Other rivers like the Ndau and the Molo could be regulated to make water available throughout the year. The Lake Baringo lowlands (Njemps flats) are highly suitable for irrigation, and water from these rivers would serve a useful purpose.

Water from Lake Baringo is dubious as to its use for irrigation as the quality of the water is deteriorating and its existence threatened. Continued deposition of silt into the lake results in the lake getting shallower and thus increasing the rate of evaporation. For the lake to survive and for any success to any water conservation projects within the area, the soils need to be stabilized first by controlled grazing, reseeding of pastures, proper tillage practices and afforestation. In some of the ephemeral streams like the Ndau, subsurface dams and weirs should be constructed where conditions permit. The various springs emerging from the Tugen hills and Keiyo escarpment should be protected and water supplies developed from these springs.

3.5 Irrigation and Drainage

There are several irrigation schemes in this area. As early as 1883 a report (ALDEV 1967) was made of Njemps irrigation systems near Marigat based on the use of water from the Perkerra River. The river changed its course by 1918 and the irrigation was discontinued. Proposals were made to restore a scheme in the same region, but nothing was done until 1952. The Perkerra irrigation scheme was developed with a total of about 560 hectares. Today only about 370 hectares are cultivated. Other schemes are the Barawesa in the Kerio Valley, the Loboi and the Sandai to the north and west of Lake Bogoria. The latter two are relatively small, but have been in existance for some time. On the northwest side of Lake Baringo there is a private irrigation project of about 10 hectares. Water for this project is pumped from Lake Baringo, and part of the area is irrigated by the trickle method. The project is moved to a new location every two or three years because of salt accumulation in the soil. At the time the project was visited there seemed to be very small amounts of water applied, especially where trickle irrigation was used. This would encourage accumulation of salts within the root zone of the soil. Larger applications of water would leach the salts below the root zone, and with proper leaching and drainage, irrigation could probably be accomplished continuously. The situation does indicate, however, that the lake water contains large amounts of salt, and if this water is used for irrigation it should be investigated to determine the amount of leaching and drainage which would be necessary to continue an irrigation program indefinitely in the same area.

Members of the study team attended a meeting held at Kabarnet on February 23, 1978 where the possibility of several irrigation projects were discussed. Provincial agricultural and development officers were there, as well as many district officers from the Baringo and Keriyo-Maraquet Districts. Representatives were also there from Ministry of Water Development, Ministry of Agriculture, and Kenya Soil Survey in Nairobi. Several proposed projects were presented by Mr. Mosny of the Irrigation Department of the Ministry of Water Development. The feasibility of these proposals was discussed by the group, and the potential for several medium-sized projects in the area appears to be good.

3.5.1 Irrigation Potential in Baringo-Kerio Valley

Several sites in the Baringo-Kerio Valley area have potential for irrigation development. None of these would be large projects, but there appears to be good soil and water available. These sites should be further investigated. A brief description and location of them is given below.

Sandai River--In an area bounded by the Weseges Range on the east, Lake Bogoria on the south and the Rogite Range to the west, there is a large tract of irrigable land. It would be possible to irrigate portions of this area with water from the Sandai river. The river flows into the Kisibor swamp

which drains into Lake Bogoria. It has been proposed that a control weir be constructed on the Sandai so that water could be diverted to the Kisibor swamp or Loboi swamp. A bund and a dam built on the Kisibor swamp would increase the storage capacity of the swamp. The dam would be designed so that if necessary, fresh water from the river could flow to Lake Bogoria, otherwise, the entire flow could be stored in the two swamps and the water used for irrigation.

Loboi--This is a small scheme where only a few hectare are being irrigated at the present time. There is unused water in the Loboi River which could be used to increase the size of this scheme. Irrigation has been practical in the area for some time so the people are familiar with irrigation practices and its potential. Probably with some technical assistance, the scheme could be expanded by the people themselves.

Lake Baringo--There is a large area of irrigable land north of Marigat and east of Lake Baringo, 1000 hectares or more which could be irrigated by pumping water from the lake. Apparently, the lake water is relatively high in salt content, as Mr. Leaky has a problem of salt build up in the soil where he uses the lake water for irrigation. This should be investigated and adequate provisions made for leaching and drainage of the salts if a project is begun here. Pumping costs may also be a factor.

There is a good possibility of a sprinkle irrigation system on this project. The water being pumped could be delivered at a pressure high enough to operate sprinkle heads. The cost of providing the increased pressue should be more than offset by the smaller amount of water used because of higher efficiencies obtainable with sprinkle systems. If a sprinkler system is used, it should be well designed, and technical help should be available to assist in operation of the system.

Ndau River--There is an irrigation scheme near Lake Baringo, 10 or 15 km. north of Marigat which is irrigated with water from the Ndau River. It contains about 200 ha. operated by 380 individuals. Water is diverted from the river by using a temporary diversion canal. Flood waters fill the canal with mud and rocks and it is impossible to put in another one until the water goes down again. Water cannot be diverted from the river during this period. Because of this there are often long periods of time when water cannot be obtained for irrigation. To improve this scheme, it would only be necessary to build a permanent diversion structure so that water would be available for the crops when necessary. If sufficient water is available, the size of the scheme could be increased as there is irrigable land in the area not being used for cropping. The project would be improved considerably if water application methods were improved. Technical assistance is needed, especially regarding the timing and quantity of water application.

Barwesa--About 75 hectares are now being irrigated with water from the Yeptos River. The canal and diversion works

have been neglected, and rehabilitation is necessary. There is sufficient irrigable land in the area for enlargement of the scheme, providing there is water available. Cotton is the principal crop grown on the scheme. The distance from Barwesa to Kibos, the nearest ginnery is more than 200 km. This is a long distance to haul bulk cotton, and it seems that another crop be investigated at least until there is sufficient acreage of cotton in the area to justify a cotton gin there.

Lake Kamnarok--The lake drains in to the Kerio River. The outlet could be dammed,raising the lake level. The increased volume stored in the lake could be used to irrigate land on the east bank of the river. Approximately 5,000,000 M^3 could be stored in the lake and used to irrigate 600 ha.

Perkerra--This scheme has been operating for several years. There are 560 ha in the scheme, but only 360 ha now being cultivated. Lack of water during the dry season is one reason given for not cultivating the entire area. The other reason given is that the selection committee will not approve applicants from other tribes as settlers on the land, and they cannot get more settlers. There are at least two solutions to the first reason. Water is turned out of the canal from 1800 in the afternoon until 0430 in the morning. This is so they do not have to irrigate in the dark. No other place is known where night irrigation is not practiced where irrigation water is from the natural flow of the river without a storage reservoir. If night irrigation cannot be practiced, a night storage reservoir could be built which could provide for a larger stream during the day. The second reason given is a tribal problem, and apparently must be solved before any success can be achieved on large irrigation schemes involving settlement.

It has been suggested that storage on the Perkerra would be a solution to the shortage of water during the period of low flow. It would be impractical to build a storage reservoir on this river until the soil erosion in the catchment area is reduced considerably. If nothing were done regarding the soil erosion, the reservoir would fill with silt in a very short time. It has been reported that there is an excellent site for a reservoir at the confluence of the Perkerra and the Emining Rivers. This should be investigated and if feasible, plans made for a dam where the soil in the catchment area is stabilized.

Other areas not mentioned here probably have potential for irrigation development, and if all those mentioned and others not known were developed, the area could support a much larger population that now lives there.

In any irrigation development it is very important that a sufficient number of personnel be available to operate and manage the project. Also it is necessary that assistance is available to the irrigator regarding irrigation practices.

4.1 Recommendations

1. Proper soil and water management is very important to Kenya. Much of the valuable soil is being eroded and carried by streams to places where it has no value, or may even be a hazard in some places. Water is being lost in rapid runoff and is causing damage by flooding. To conserve these valuable resources, and reverse the present trend, many persons trained in soil and water management are needed. There are very few Kenyans with this kind of training and the country cannot or should not depend on expatriates to do this job.

   An extensive training program should be established to provide Kenyan personnel to do the necessary work in soil and water management. This training should be for administrators who will direct the program, for the designers and planners of development activities, for technicians doing the work in the field, and for extension staff who can work with farmers to give them assistance in operation, management and maintenance of soil and water conservation practices. The training should be both academic and on the job experience with experts in the various disciplines of soil and water management.

   The University of Nairobi, Agricultural Engineering Department is increasing their offerings in soil and water. Egerton College is also planning an expanded program in this area. These programs will assist greatly to provide the necessary training. However, it is desirable that qualified persons should have the opportunities to go abroad to receive training beyond the Bachelors level. These people should be selected from those who already have degrees from the University of Nairobi, either in Agricultural or Civil Engineering. Some who already have degrees may also benefit by going abroad for on the job training where soil and water work is being done.

   Technicians working in the field also need extension training in soil and water management. This can probably be provided by the proposed program at Egerton College, although it will be at least two years before many of those with this training will be available. The extension staff should also have specialized training in soil and water, a two to six week course is not sufficient for this. One year of specialized training should be the minimum for both the technicians and extension workers.

   An individual with advanced training and experience should be located in each district to direct the soil and water management there.

2. A project of development should be an integrated one which includes experts in all disciplines necessary

for complete development of an area. As it is necessary to do soil and water planning and development on an entire catchment basin, it is desirable that the project area be a catchment basin or several basins, depending on the desired size of the project area. A map of the catchment basins of the study area is included with this report. The experts in the various disciplines should very carefully coordinate their work to provide a project which would be a model which could be followed in other areas. The phasing of the project should be such that the beginning of development will cover an area small enough to ensure success in the early phases. Also lack of data may require trial and error methods rather than recognized design procedures be used in the early stages of development. Information gathered during the early phase of a project can be a valuable resource to use in a continuing development program.

The project from the beginning, even in the planning and design phases, if possible, should include on the job training of Kenyans. This should be very carefully coordinated to obtain the maximum benefit of this valuable source of training at all levels of operation.

3. Vegetative cover is an important aspect in soil and water management. The Livestock and Range Management Specialists have already mentioned a program of livestock and grazing management, including reseeding and mechanical practices, which if practiced will allow for a vegetative cover to assist in soil and water management. The programs recommended by them should probably be the first step in a soil and water management program. Vegetative cover protects the soil from rain drop splash, retards the velocity of the water flowing over the surface and increases the infiltration rate. These are all important aspects of a soil and water management program.

4. Water harvesting, even on a small scale, can be very important in soil and water management. Small individual harvesting schemes can provide domestic and livestock water as well as water for supplemental irrigation. Harvesting may consist of collecting water from roofs or rock catchments, from non-cropped areas and directed to cropped areas, or stored for any future use. The major problem when water is to be stored is the storage facility. Plans should be made available to the individual for these facilities. Technical assistance will be necessary for both harvesting methods and storage facilities. Adequate training of extension personnel who can give this assistance will be important to the water harvesting activity.

5. Though recommendation (2) requires water conservation to be done as part of integrated catchment/watershed development, there are already a number of dams which have been designed within the Ministry of Water Development but have not been constructed due to lack of machinery, there being only one dam construction unit to cover the whole country. In areas where soils have been stabilized, dams can be constructed and at least 1 dam construction unit would probably be required per district together with the manpower to run it.

APPENDICES

Appendix 1 Tables

Appendix 2 Bibliographic References

Appendix 3 Contacts

Appendix 4 Ground Water Reconnaissance of the Machakos-Kitui and Baringo-Kerio Study Areas, Kenya, by George C. Taylor, Jr. Hydrogeologist

Appendix 1

Table 1

POTENTIAL EVAPORATION E_o (Woodhead)

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	ALTITUDE METERS
Kitui Dam	170	176	185	160	148	128	123	154	173	189	157	153	1916	1090
Machakos Dam	179	176	186	156	142	123	113	118	150	179	159	157	1838	1570
Katumani	181	165	166	136	145	126	116	125	153	171	136	170	1790	1600
Embu Kathiga	220	210	210	183	159	114	144	142	195	203	180	182	2142	1250
Kitui Ag. Off.	189	191	200	169	168	152	149	162	183	203	163	167	2096	1180
Machakos Sch.	190	174	182	151	140	129	128	140	169	180	158	166	1907	1680
Makindu	175	179	182	160	151	139	139	153	179	191	154	149	1951	998
Eldoret Ag. Res.	191	168	196	163	159	138	124	124	150	179	165	156	1913	2200
Rumuruti	160	159	174	143	160	140	135	144	162	162	139	139	1817	1770
Marigat	203	195	212	187	190	173	167	182	193	199	182	189	2272	1000

Appendix

Table 2

STREAMFLOW AND RAINFALL ON SELECTED BASINS IN STUDY AREA

Basin Code	Stream	Basin Area Km^2	Mean Annual Rainfall mm	Mean Annual Runoff mm	Runoff Rainfall Ratio
2C	Kerio	17,774	450	53	0.12
2EB	Waseges	780	865	45	0.05
2EC	Rongau	821	947	112	0.12
2EE	Perkerra	569	936	71	0.08
2EG	Molo	1,665	870	117	0.13
2EH	Ndou	603	792	53	0.07
3AA	Mbagathi	773	742	105	0.14
3BB	Nairobi	255	1148	255	0.22
3DA	Athi	821	810	90	0.11
3DB	Athi	793	815	48	0.06
3F	Athi	14,382	515	30	0.06
4BG	Tana	470	900	140	0.16
4CC	Thika	981	920	135	0.15
4EC	Ena	661	1085	284	0.26
4ED	Tana	3,088	698	75	0.11
4G	Tana	53,835	465	21	0.05
4H	Tiva	20,103	482	24	0.05

Appendix
Table 3

ESTIMATED IRRIGATION REQUIREMENTS FOR ISHIARA SCHEME

Month	Potential Evaporation mm (1)	Net Water Requirement ETP mm (2)	Effective Rainfall mm 75% Prob.	Net Irrigation Requirement mm	Gross Irrigation Requirement (3)		
					(mm)	litres/sec	M^3
Jan	220	176	1	175	350	82	220,000
Feb	210	168	0	168	336	33	213,000
Mar	210	168	91	77	154	36	960,000
Apr	183	146	113	33	66	16	41,000
May	159	127	13	114	228	54	145,000
Jun	114	91	0	91	182	44	114,000
Jul	144	115	0	115	230	54	145,000
Aug	142	114	0	114	228	54	145,000
Sep	195	156	0	156	312	76	197,000
Oct	203	162	30	132	264	62	166,000
Nov	180	144	118	26	52	13	34,000
Dec	182	146	23	123	246	58	155,000
TOTAL	2142	1912	389	1523	3046	--	1,671,000

(1) Figures for Kiritiri Chiefs Camp near Ishiara
(2) 80% Potential Evaporation
(3) Assumes 50% application efficiency

Appendix
Table 4

Mean Monthly and Annual Precipitation - Embu-Kitui-Machakos mm

Station	Index No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Machakos D.O	91.37010	64	44	140	187	67	12	10	7	15	60	210	124	939
2. Kangundo D.O	91.37020	55	39	158	219	62	8	6	4	6	82	237	114	988
3. Matiliku	91.37028	50	46	111	203	56	17	3	2	6	56	180	103	826
4. Donyo Sabuk	91.37054	49	30	118	211	83	16	10	6	12	84	237	154	1010
5. Kabaa Cath. Miss.	91.37058	38	37	95	158	50	10	4	6	14	67	179	81	744
6. Nakabete	91.37071	44	31	75	126	46	9	4	4	8	42	180	85	653
7. Kampi ya Mawe	91.37075	36	32	80	140	42	14	2	5	6	42	164	103	664
8. Yatta B2 Vet. Dep.	91.37076	20	12	65	139	31	59	2	4	9	48	206	62	655
9. Katumani*	91.37089	42	34	74	132	58	11	5	3	9	39	168	76	650
10. Kilome	91.37091	58	45	134	251	112	25	11	8	22	105	247	78	1095
11. Kyusyani	91.37092	23	32	80	181	41	13	1	4	7	46	216	94	738
12. Mutogani	91.37094	22	38	105	180	36	5	2	3	9	71	235	77	785
13. Mbooni Forest	91.37099	91	57	144	246	78	18	6	5	11	100	300	149	1206
14. Kitondo Forest	91.37101	65	70	121	248	93	22	16	28	30	115	318	152	1276
15. Yatta Furrow	91.3703	42	29	108	215	77	19	7	7	12	55	184	57	812
16. Uuni Forest	91.37105	45	47	90	215	56	22	4	3	11	70	222	64	845
17. Kitui Ag. Off.	91.37800	30	42	170	229	37	25	1	7	13	96	346	114	1116
18. Mutomo	91.38001	34	32	75	176	47	5	3	2	11	64	342	172	961
19. Sec. Sch. Kitui	91.38002	32	40	132	167	54	6	00	6	13	86	311	126	974
20. Zombe Ag. Sta	91.38004	25	20	94	118	17	2	0	1	7	48	249	92	673
21. Migwani	91.38005	7	32	81	201	25	3	1	3	9	74	252	99	776
22. Kanziku	91.38006	18	29	88	106	19	2	0	2	8	32	214	108	624
23. Voo dispensary	91.38007	14	12	76	125	15	2	0	3	4	47	163	91	552
24. Mui Chief's Camp	91.38008	24	22	102	157	28	4	2	3	6	55	282	111	796
25. Mutha Ch. Camp	91.38010	26	21	66	125	14	1	1	4	10	34	206	89	598
26. Mutito Ch. Camp	91.38012	25	25	84	131	25	2	2	3	5	64	275	105	745
27. Machakos Dam*	91.37098	45	57	115	178	37	11	4	4	6	47	183	91	798
28. Kitui Dam*	91.38014	35	41	133	225	50	6	1	4	14	60	298	101	963
29. Ngoliba Scheme	91.37121	36	17	79	264	65	30	14	8	21	71	153	49	805
30. Makuli Forest	91.37106	49	56	98	234	110	30	25	22	38	78	230	105	1075

* Meteorological Station

Table 4

cont.

Station	Index No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
31. Tiva Market	91.37096	17	38	85	112	44	3	0	2	4	32	183	77	597
32. Konza Ranch	91.37112	18	12	57	137	47	11	4	00	8	28	95	45	463
33. Ikanga Ch. Camp	91.38013	22	34	83	115	19	2	1	2	5	51	219	80	632
34. Nzani Forest	91.37100	58	43	113	244	90	28	13	15	24	95	262	156	1135
35. Kiambere Mkt.	90.37135	36	26	96	174	53	14	1	2	9	65	203	73	762
36. Kindaruma	90.37146	25	25	87	159	49	9	1	2	10	39	180	42	579
37. Kiritiri Ch.Camp	90.37039	28	31	121	252	71	9	5	6	7	81	186	79	862
38. Siakago	90.37132	32	37	145	355	101	10	5	4	8	125	255	84	1161
39. Murinduko	90.37103	22	37	87	244	145	21	27	22	18	105	185	44	957
40. Ena Tobacco Fac.	90.37164	33	43	121	298	111	9	8	5	14	106	259	66	1072

Appendix

Table 5

Mean Monthly and Annual Precipitation - Baringo and Kerio Valley (mm)

Station	Index No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Perkerra	89.36053	24	20	4[illegible]	83	88	73	105	96	45	36	45	15	663
2. Tenges for Nursery	89.35176	44	40	71	139	191	153	216	233	78	75	79	36	1355
3. Katimok Forest	89.35177	62	30	84	164	219	172	204	250	77	79	127	35	1503
4. Iten Sec. Sch.	89.35178	30	45	68	184	185	92	119	124	83	112	166	36	1243
5. Kabarnet Tengulbei	89.36019	23	29	62	93	150	55	79	106	70	33	72	23	795
6. Kabarnet Hot Springs	89.36026	35	29	49	96	102	54	96	88	38	56	61	16	720
7. Snake Farm	89.36067	27	22	40	85	85	70	102	100	40	26	65	22	684

APPENDIX 2

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APPENDIX 4

GROUND WATER RECONNAISSANCE OF THE MACHAKOS-KITUI AND BARINGO-KERIO STUDY AREAS KENYA

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PREPARED AS A CONTRIBUTION TO THE
MARGINAL/SEMI-ARID LANDS PRE-INVESTMENT STUDY
CONSORTIUM FOR INTERNATIONAL DEVELOPMENT

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2.	--Map of the Baringo-Kerio study area showing the location of boreholes.	49a

1.0 Summary

1. Extractable ground water is available in small quantities from boreholes tapping Precambrian basement rocks in about 85% of the Machakos-Kitui study area and about 6% of the Baringo-Kerio area. These boreholes must be carefully sited, if they are to be successful, that is, to yield more than about 6 l/min (0.36 m^3/hr). The average successful borehole in these rocks yields about 42 l/min (2.52 m^3/hr) with a specific capacity of about 1.7 l/min/m (0.1 m^3/hr/m).

2. In about 15% of the Machakos-Kitui area and 94% of the Baringo-Kerio area ground water is contained in Tertiary and Quaternary volcanic rocks. Although yields from boreholes in these rocks are highly variable from place to place, failures are much less common than in the basement rocks. The average successful borehole in these rocks yields about 95 l/min (5.7 m^3/hr) with a specific capacity of about 3.3 l/min/m (0.2 m^3hr/m).

3. Underflow conduits in sandy alluvial deposits along ephemeral stream channels are important sources of water in the Machakos-Kitui area. These conduits are tapped by many temporary water holes, by subsurface dams, and, in places, by protected concrete-curbed wells. Along the larger ephemeral streams the conduits provide viable water supplies to wells and subsurface dams during normal dry seasons. The yields of these, however, may fall off 50% or more during protracted dry periods. There is scope for more extended development of such conduits throughout the study area.

4. High-level springs in the escarpments and hilly tracts of the Baringo-Kerio area have been developed to a limited extent by protected spring captations and the flows delivered by gravity pipelines to points of use on lower ground. There is scope for much more extensive water-supply development of this type in the Baringo-Kerio area, and to a much more limited extent in the Machakos-Kitui area.

5. The chemical quality of the ground water in the Machakos-Kitui area is generally good, and waters from boreholes are satisfactory for human and animal consumption and probably for irrigation. The dissolved solids content ranges from about 230 to 1,775 mg/l with a mean of about 800 mg/l. The fluoride content ranges from 0 to 6.7 mg/l with a mean of 1.4 mg/l. With a few exceptions, the nitrate content appears to be less than 1.0 mg/l. There are very few data available on the chemical quality of ground water in the Baringo-Kerio area. Most of the waters from springs, wells and boreholes are reported to be potable with total dissolved solids probably less than 1,000 mg/l. High fluoride, however, is likely to be a common problem.

6. Ground water is not available in either the Machakos-Kitui or Baringo-Kerio study area for large or even moderate scale irrigation projects. Small supplies are available, however, at

many places and could be developed (a) by pumping from boreholes, (b) by pumping or gravity pipelines from subsurface dams, and (c) by gravity pipelines from high-level spring captations. The quantities available from small individual developments of this type could effectively irrigate areas of one acre (0.4 ha) or somewhat more of vegetable gardens and/or tree crops. Owing to the limited quantities available from potential sources (other than perennial streams or lakes) in the two study areas and the need to reduce or eliminate transit losses, irrigation supplies should preferably be delivered to cultivated plots by pipeline rather than by open canals (furrows).

7. Borehole water supplies, in general, should be given priority consideration, in development planning for village and town (municipal) water supply. Borehole water is normally free of pathogenic bacteria and requires little or no treatment before use. Protected high-level spring captations, if properly managed, can also provide water of high sanitary quality. Most surface-water sources require treatment, which may be expensive, if adequate sanitary quality is to be assured.

2.0 Introduction

This report, which forms a part of the Marginal/Semi-Arid Lands Pre-Investment Study, presents the results of a reconnaissance evaluation of the ground-water resources of the Machakos-Kitui and Baringo-Kerio study areas and their potential for further development for domestic, livestock, urban and small irrigation supplies. This evaluation, carried out during February-March 1978, was based on study of available aerial photography, satellite imagery, topographic and geologic maps and reports, borehole and streamflow records and other hydrogeologic data. In addition brief field observations were made by the writer of the geological and physical features of the study areas and of their relationships to the availability of ground water. Study materials examined during the present consultancy are listed in the "References" of this report.

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3.0 Machakos-Kitui study area

3.1 Location and extent: The Machakos-Kitui study area comprises a main rectangular block lying between 1°00' to 2°00' S. latitude and 37°15' and 38°30' E. longitude and also a smaller block, immediately to the north, lying between 0°30' and 1°00' S. latitude and 37°30' E. and 38°00' E. longitude. The maximum extent from east to west is about 140 km and from north to south about 165 km. The study area covers about 18,425 km^2 and includes parts of the Machakos, Kitui and Embu Districts in south-central Kenya. Machakos and Kitui, headquarters of their respective districts, are the principal population centers in the study area.

3.2 Topography and drainage: Topographically, the study area can be divided into (1) western region of high isolated inselbergs and clusters of hills and short ridges interspersed with dissected bench lands; (2) the narrow flat-topped ridge of the Yatta Plateau which extends southeast across the entire central region; and (3) an eastern region of lower hills, ridges and broad lowlands which open eastward into a low southward and eastward sloping plain. In the western region, which lies largely in the Machakos District, a number of large inselberg hill masses rise to altitudes ranging from 1,600 to more than 2,000 m above sea level and 400 to 600 m above surrounding bench lands. The larger streams are commonly incised 100 to 200 m below the level of the bench lands, which apparently are remnants of the pre-Miocene peneplain described by Pulfrey (reference Q).

The Yatta Plateau, as described by Schoeman (reference M), now forms the divide between the Athi River and the Tiva River drainage systems. The plateau, which has a virtually level summit some 5 to 15 km wide, extends from near the Ol Doinyo Sapuk inselberg southeast entirely across the study area for some 275 km to the Galana Valley east of Tsavo. The average slope of the plateau summit, is about 2.27 m/km to the southeast. The present channel of the Athi River, which follows a course close to the southwest margin of the plateau, is incised some 140 to 160 m below the plateau summit.

The eastern region, which lies mostly in the Kitui and Embu Districts, is generally lower than the western region. Scattered hilly tracts and inselberg knobs and ridges rise to altitudes of 1,150 to 1,450 m above sea level and 450 to 650 m above broad intervening lowlands of the pre-Miocene peneplain. The easternmost part of the study area, which is a southward and eastward sloping continuation of this peneplain, is generally less than 550 m above sea level.

The principal drainage systems of the study area are those of the Athi, Tana, Tiva and Thua Rivers, but only the Athi and Tana carry perennial flows. The Athi, whose headwater tributaries rise in the high rainfall areas near Nairobi and on the southern slopes of the Nyandarua Range, enters the study area in the northwest near Ol Doinyo Sapuk inselberg. Draining virtually all the western region of the study area, the Athi follows a southeasterly course parallel to and immediately southwest of the Yatta Plateau. The principal tributaries of the Athi within the western region are the Eyumo and Kaiti Rivers, both of which

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are ephemeral (seasonal) streams.

The Tana River, which is the largest and most important stream in Kenya, rises on the eastern slopes of Mt. Kenya and flows northeast across the northern block of the study area. The Thika River, an important perennial tributary of the Tana, also flows across the northwest sector of the study area. Rising in the eastern region are two large ephemeral streams the Katulani and the Kithioko which drain north to the Tana. The Tiva River and its tributaries, all of which are ephemeral, drain southward across the peneplain lowlands lying east of the Yatta Plateau. The eastern part of the study area is drained eastward to the lower course of the Tana River by way of the ephemeral Thua River and its tributaries.

3.3 Rainfall and evaporation: As is true of much of Kenya, rainfall in the Machakos-Kitui area is concentrated in two seasons, one beginning in March and extending into June (the long rains) and the other beginning in October and extending into January (the short rains). February and June through September are commonly the driest periods in the year. Precipitation, however, is characterized by extreme variability both areally and seasonally as well as from year to year. Also, owing to orographic effects the higher hill masses commonly receive more rainfall than intervening lower areas (reference C). The highest rainfall in the study area occurs in the Mbooni and Mua-Iveti Hills of Machakos District where the annual average ranges from 1,000 to 1,200 mm at altitudes exceeding 1,800 m. Also in the vicinity of Ol Doinyo Sapuk (altitude 2,144 m) average rainfall exceeds 900 mm annually and in the northwestern part of the northern block on the slopes of Mt. Kenya average annual rainfall is greater than 1,000 mm. Average annual rainfall in much of the western region, in the Yatta Plateau, in the Tiva River drainage basin, and in the central and southeastern parts of the northern block ranges from 600 to 800 mm. East of the Tiva River basin in the Kitui area, annual average rainfall increases to the range of 800 to 1,000 mm but then declines eastward to less than 600 mm in the easternmost part of the study area (reference F, fig. 4a).

Potential evaporation ranges from about 1,600 to 1,800 mm annually in the Mbooni and Mua-Iveti Hills. In most of the western region, in the northwestern part of the northern block, and in the Kitui area it ranges from about 1,800 to 2,000 mm annually. The potential evaporation elsewhere in the study area is from about 2,000 to 2,200 mm per year (reference F, fig. 4b).

3.4 Surface water: The only fully perennial streams in the Machakos-Kitui study area are the Athi, the Tana and its principal tributaries, the Thika and Thiba. Other streams are ephemeral (seasonal) and carry surface flows only during the rainy seasons and for a few weeks thereafter. The larger of these ephemeral streams are considered to be sources of permanent supply during the dry seasons, as water can usually

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be obtained by digging in the sandy river beds, even after surface flow has ceased.

The mean annual discharge of the Athi River, based on records obtained prior to 1972, was 23.0 m^3/sec at gauging station 3DA2 which is located near Fourteen Falls north of Ol Doinyo Sapuk Hill in the northwest sector of the study area. The mean low-flow discharge (95% flow duration) was 3.1 m^3/sec at this station. At Kamburu Bridge (gauging station 4ED3) on the Tana River in the northern block of the study area the mean annual discharge was 107.0 m^3/sec and the mean low-flow discharge was 31.0 m^3/sec (95% flow duration). This station measures the flow contributions of the Thika and Thiba Rivers as well as of the headwaters of the mainstem Tana. (reference A, maps nos. 6 and 7).

The mean annual runoff, in l/sec/km^2, is from 15 to more than 30 in the Thiba and upper Tana watersheds, from 10 to 30 in the Thika watershed, and from 1.0 to 20 in the upper Athi. Elsewhere in the study area mean annual runoff is less than 1.0 l/sec/km^2, virtually all of which occurs during the rainy seasons or shortly thereafter (reference A, map no. 5).

3.4.1 Surface-water storage: Several types of surface-water storage are utilized in the study area. Natural depressions, locally called pans or waterholes, are widely distributed in areas of fairly level terrain, with clayey and silty soils. They may be formed initially by wind deflation and then enlarged by some hand excavation and/or by the trampling of animals. Generally, such pans are broad and shallow and contain water for no more than a few weeks after rainfall ceases. Dalolos are natural depressions in stream channels which hold water for short periods following ephemeral runoff. Earth dams are constructed across relatively deep and narrow stream channels, where soil and foundation conditions are favorable. Suitable sites for earth dams can be found in most of the study area, except for the lower and flatter parts of the eastern region. Rock catchments are also utilized at sites where the runoff from rocky tors or inselbergs can be collected behind dams or weirs constructed across drainageways on footslopes. Suitable sites for rock catchments can be found around the footslopes of many of the isolated hill masses of the study area, notably in the eastern region. Subsurface dams also are presently utilized in many places in the study area to collect stream underflow in subsurface storage. There is scope for much wider use of subsurface dams for water conservation.

As of 1962 some 52 large earth dams had been constructed in Machakos District and 75 in Kitui District for a total of 127 (reference D, p. 252). Of this number about half are located in the study area. These dams, constructed by earth-moving machinery, had initial storage capacities which averaged about 45,460 m^3 each. There were also some 269 smaller earth dams in Machakos District and 416 in Kitui District. Of the total

of 685 about half are located in the present study area. The smaller earth dams, constructed mostly by hand labor with some animal drawn scoops, generally, had initial capacities of less than 10,000 m^3. (Those dams with less than 10,000 m^3 capacity have generally been considered "seasonal" while those of larger capacity have been considered "permanent".) Since 1962 new earth dams have been constructed. At the same time many older dams have fallen into disrepair or their reservoirs have filled with silt. At present there are several hundred earth dams in the study area. The initial reservoir capacities of about 75% of these were less than 10,000 m^3, 20% ranged from 10,000 to 20,000 m^3, and 5% exceeded 20,000 m^3. The cost of desilting a reservoir is on the average about twice the cost of new construction per unit volume of water storage provided. Thus, where the capacity reduction due to silting exceeds about half the initial storage volume it is usually cheaper to construct a new dam downstream and to leave the upper older dam as a silt trap. Only where there is no alternative downstream dam site should desilting of an existing reservoir be considered. The cost of an earth dam and reservoir is chiefly a function of the amount of earth which has to be moved. Costs now range from about Ksh 13 to 20 per m^3. Storage efficiency can be judged on the ratio of the amount of earth which has to be moved per volume of water stored. Least efficient (and most costly) in some small excavated reservoirs is a 1:1 ratio. About the maximum efficiency obtainable is 1:15.

In many places in the study area there are large masses of bare rock (tors or inselbergs) which may rise 50 to 200 m or more above the surrounding peneplain. These have been utilized since the early 1950's for water harvesting projects to collect and store water in rock catchments. Construction of these catchments generally involves building low but carefully aligned masonry walls or "garlands" around the edge of the rock mass so as to catch the bulk of the rain water falling on it and to guide this water into a storage tank built at the foot of the rock mass or in some cases at a convenient point on the rock itself. Storage has often been achieved most efficiently by cleaning out deep pockets of weathered rock material, which may be 5 to 10 m deep with a virtually impervious base. Dams of concrete or masonry 4.5 to 6 m high have then been constructed to create deep, narrow reservoirs with minimal potential evaporation and siltation losses. Alternatively, in more open storage sites, earth dams with concrete core walls and spillways have been built. Such dams have been raised to heights of 7 to 8 m with core walls extending 8 to 9 m below ground level to reach solid rock and form an effective seal. Rock catchments have been built in the study area with initial storage capacities ranging from less than 10,000 m^3 to as much as 70,000 m^3. About one hectare of rock catchment area has been considered sufficient for 1,205 m^3 of reservoir storage in low rainfall areas, that is, less than about 600 mm average annually. In higher rainfall areas, of course, relatively small catchment areas can provide relatively large volumes of runoff for reservoir storage. As

of 1962 there were reported to be 3 rock catchments in Machakos District and 24 in Kitui District with about half the total in the study area. Since then more have been constructed, but the total number now extant in the study area is not known at this writing (reference D, p. 250-251).

Another type of water retention and storage facility which has been increasingly utilized in Kenya since the early 1950's is the subsurface dam (reference D, p. 249-250). These structures depend first on the availability of extensive deposits of coarse quartz sand such as are commonly found in the larger ephemeral streams (sand rivers) of Machakos and Kitui Districts, and second on the presence of a rock ledge across the stream channel. The principle is simply the retardation and accumulation of the underflow which moves through the sand. By constructing a concrete or masonry barrier (subsurface dam) at a rock ledge across a sand river, water-saturated sand collects behind the barrier and eventually underflow is forced to the surface and spills over the barrier, which has now become a weir. Initially, the barrier needs to be no higher than the original sand surface but it needs to be well-footed in the underlying bedrock. Each year during dry periods it can be raised 50 cm or so by adding a new course of concrete or masonry on top of the barrier, thereby providing space for collection of more sand on its upstream side from successive floods. By giving careful attention to the height of each course which is added, only the coarse bed-load sand of the stream accumulates behind the barrier, and the finer sand and silt are carried over the top during floods. The coarser the sand the greater is its storage and water-yielding capacity. Subsurface dams on the larger sand rivers can be expected to have yields ranging from 25 to 100 m^3/d during normal dry seasons. Considerably larger yields could be expected during the rainy seasons. There were as of 1962 some 226 subsurface dams in Machakos District and 35 in Kitui District with about half the total in the present study area. Additional subsurface dams have been constructed in the area in more recent years.

3.4.2 Surface-water utilization: With the exception of the Kamburu, Seven Forks and Kindaruma hydropower dams on the Tana River in the northern block of the study area and the Yatta Furrow irrigation project which depends on a diversion from the Thika River, most existing surface-water storage facilities in the study area have been constructed to provide water supply for urban, rural and livestock use and some limited supplemental irrigation. They also serve to regulate runoff for enhancing ground-water recharge and for erosion control.

Earth dams have been the most favored method of storing surface water in the study area, because they are considered to be most cost-effective in terms of the quantity of water which can be stored per unit initial construction cost. They are, however, vulnerable to rapid siltation in many places and must be periodically cleaned, if they are to remain viable. Most earth dams in the area, if they are not periodically desilted, can be

expected to have a useful reservoir life of less than 15 years. (In some cases reservoir life may be less than 10 years. The reservoir behind the earth dam at Kitui, for example, is reported to have silted up in a period of about 6 years.) In recent years subsurface dams have been increasingly favored for water storage, because they are subject to minimal evaporation losses and have relative low susceptibility to siltation, while at the same time they provide a filtered water supply of better sanitary quality than that available from an earth dam. Rock catchments also can generally be expected to have considerably lower rates of evaporation and siltation than earth dams (reference D, p. 246-260).

To assure the viability of a surface-water storage facility it must also be protected against direct depredation by people and livestock. This can involve protection of facility by fencing and/or provision of an effective means for drawing off water without giving direct access to the facility by the human and animal population. In some parts of the study area water is drawn off by a gravity pipeline leading to a watering point at which a concrete tank and cattle trough is installed. The tank is kept continuously full from the pipeline and is controlled by a ball float valve. For general community and livestock use tanks of about 4.5 to 45 m^3 capacity have been used. Elsewhere in the study area water supplies have been developed for villages and towns located on higher ground by pumping from the large permanent streams, from earth dams, or from subsurface dams on sand rivers and lifting the water through pipelines to elevated tanks for distribution to local watering points. Some pipelines, such as that supplying Mutomo, are as much as 17 km long. This pipeline takes its water by pumping from a subsurface dam on the Tiva River southwest of the town. Mutha is also served by a pipeline with an intake on the ephemeral Thua River about 17 km to the northeast of the town. Water supplies from both these sand river subsurface dams are supplemented by supplies from boreholes.

3.5 Hydrogeology: There are three groups of rocks in the Machakos-Kitui study area which store and yield ground water to wells, boreholes and springs. The most important and extensive of these groups are metamorphosed sedimentary and igneous rocks of Precambrian age. They include crystalline limestones, quartzites, muscovite schists, and hornblende gneisses as well as migmatized gneisses and granites. Together with amphibolites, pyroxenites, pegmatites and other intrusive rocks, they form a basement complex that lies beneath a thin veneer of soils and alluvium in some 85% of the study area, or protrudes through the veneer in rocky tors, rounded bare rock inselbergs or elongated hills and ridges (reference K, L, M and N).

Tertiary and Quaternary volcanic rocks occur in the Yatta Plateau and in the northwestern part of the northern block of the study area. Altogether, these rocks lie at or near the

surface in about 15% of the study areas. The Yatta Plateau is directly underlain by one or more flows of phonolite lava resting directly on rocks of the basement complex. These flows with an aggregate thickness of about 6 to 15 m and of presumed Miocene age apparently filled an ancestral valley of the Athi River and displaced the river southwestward to its present position. Also during pre-Miocene time a widespread peneplain was developed by erosional levelling of basement complex rocks. This peneplain, now dissected by downcutting of streams, is represented by bench lands in the western region of the study area and by more the extensive erosional plains of the eastern region. Also numerous erosional residuals, in isolated hills and ridges of resistant rock, now rise above the peneplain surface. Younger volcanic rocks of presumed Quaternary age and resting on rocks of the basement complex are present in the northwest part of the northern block. These volcanic rocks include flows of phonolitic trachyte from the Mt. Kenya lava field to the west and also a narrow band of olivine basalt which closely follows the course of the Thiba River (references M and Q).

Alluvial deposits of sand with some silt and clay of late Pleistocene to Holocene age occur along most of the larger streams. In some places, as for example, in the lower reach of the Kaiti River and in the reach of the Athi River downstream from the junction of the Athi the alluvium is as much as 10 m thick. In most places in the study area, however, the alluvium in stream channels is no more than a few meters thick over bedrock. Probably 90% of the study area has a soil cover ranging from a few centimeters to several meters thick. Virtually all the soils are of residual origin developed by deep weathering of the underlying parent bedrock. Such soils are commonly of low natural fertility requiring applications of animal manures and other fertilizers for satisfactory crop growth.

3.5.1 Water in the Basement Complex rocks: Among all the rock groups, the Precambrian basement complex is the most extensive in the study area. The metamorphic and igneous rocks of the basement complex are not inherently permeable nor do they contain extensive and productive aquifers. Rather, extractable ground water occurs chiefly in relatively small "cells" where the mantle of weathered rock may be 50 to 100 m thick and the underlying fracture systems in the fresh rock are relatively open and closely spaced. These cells generally occur in areas of low-lying topography near stream channels and separated from one another by non-productive zones of massive unweathered rock with relatively widely spaced fractures. Such non-productive zones must be avoided in the siting of boreholes. On the other hand, selection of favorable sites depends on the sound application of geologic criteria coupled in most cases with geophysical exploration. Even with careful siting, however, some failures can and do occur, because the degree of permeability of the weathered zone and of the underlying fracture system is a fortuitous element that controls the individual yields of

boreholes. The cut-off yield for a successful borehole in Kenya has generally been set at about 6 l/min (0.36 m^3/hr) and a borehole yielding less has generally been considered a failure. If borehole sites in the Precambrian basement terrain are selected randomly the failure rate can be as high as 30 to 40%, but if sites are selected after careful geological and geophysical analysis the failure rate can be reduced to 15 to 20% or even less.

Some 90% of the 174 boreholes of record in the study area tap water in rocks of the Precambrian basement complex. The mean yield from boreholes in these rocks is about 76 l/min (4.56 m^3/hr.) About 75% of these boreholes yield 106 l/min (6.36 m^3/hr) or less; 50% yield 42 l/min (2.52 m^3/hr) or less; and 25% yield 10 l/min (0.6 m^3/hr) or less. The mean specific capacity (yield in liters per minute or cubic meters per hour per meter of drawdown) among these boreholes is about 28 l/min/m (1.68 m^3/hr/m). About 75% of these boreholes have specific capacities of 5 l/min/m (0.3 m^3/hr/m) or less; 50% have 1.7 l/min/m (0.1 m^3/hr/m) or less; and 25% have 0.5 l/min/m (0.03 m^3/hr/m) or less. The highest yield reported from a borehole tapping water in basement complex rocks in the study area was 284 l/min (17 m^3/hr) at borehole C-401 drilled in January 1946 at long. 37°21'E. lat. 1°17'S. near Kangundo (table 1). This borehole, 6 inches in diameter, was drilled to a depth of 34 m. Water was struck at 27 m and rose to a static level near the land surface (references R and S).

Among the boreholes tapping water in the basement complex rocks, the mean depth is 93 m. About 75% are less than 122 m deep; 50% are less than 91 m deep; and 25% are less than 56 m deep. The mean depth to water (rest level) below land-surface datum is about 32.3 m in these boreholes. In about 75% of the boreholes the rest level is 43 m or less; in 50% it is 25 m or less; and in 25% it is 11 m or less. The deepest producing borehole in the basement rocks of the study area is C-3760 finished in July 1971 at long. 37°36' E., lat. 1°05'S. about 2.5 km north of Kwandani. This borehole 6 inches in diameter and 198 m deep struck water at a depth of 61 m which rose to a rest level 28 m below land surface. The borehole produced only 5 l/min (0.3 m^3/hr) with a drawdown of 77.4 m for a specific capacity of 0.1 l/min/m (0.006 m^3/hr/m) (reference R). Hydrologic data for boreholes in the Machakos-Kitui area extracted from the Ministry of Water Development's BOROP (Borehole data output) data storage bank are given in table 1. Geologic logs for typical boreholes tapping ground water in rocks of the Precambrian basement complex are given in table 2.

The ground water in the weathered and fractured cells of basement complex rocks is virtually all ultimately derived from local recharge, chiefly by natural infiltration from streams but also by direct rainfall penetration. Also the quantities of water which can be extracted from individual boreholes are relatively small. As indicated in the previous discussion the average borehole tapping water in the basement complex rocks yields about

42 l/min (2.52 m^3/hr) with a specific capacity of about 1.7 l/min/m (0.1 m^3/hr/m). Moreover, borehole yields are subject to considerable seasonal and annual fluctuation owing to variations in recharge and ground-water levels. Although there is no systematic monitoring of ground-water levels and borehole discharge in the study area, individual borehole yields during normal dry periods are reported to fall off as much as 25% from wet season yields and as much as 50% following deficient rains. During exceptional droughts the less productive boreholes may fail entirely.

3.5.2 Water in the Volcanic Rocks: Rocks of volcanic origin resting on older basement complex rocks directly underlie the land surface in about 15% of the study area. Ground water in the volcanic rocks occurs chiefly in scoriaceous and fragmental zones between lava flows and in places along the contacts of these flows with underlying rocks of the basement complex. Among the 174 boreholes of record in the study area some 10% tap water in Tertiary and Quaternary volcanic rocks. Although some boreholes in the volcanic rocks produce only meager yields, absolute failures are much less common than in the basement complex rocks. Nevertheless yields from individual boreholes in the volcanic rocks are highly variable from place to place owing to lateral discontinuities in the permeable zones. Also the total thickness of volcanic rocks in the study area is considerably less than in areas to the west and north. Among 14 boreholes tapping water in volcanic rocks in the study area initial yields ranged from 1 to 240 l/min with a mean of 32 l/min (1.92 m^3/hr). Thus on the average, yields from boreholes in the volcanic rocks in the study area seem to be roughly comparable to those from the basement complex rocks. Elsewhere in Kenya, however, borehole yields from volcanic rocks are, on the average, more than twice as great as those from rocks of the basement complex (reference 8). The depths of the boreholes in the volcanic rocks of the study area range from 64 to 178 m with a mean of 107 m (table 1).

The ground water in the volcanic rocks is considerably less subject to the vagaries of rainfall and local recharge than that in the basement complex rocks. The water-bearing zones are generally more extensive than the ground-water cells in the basement complex rocks and consequently can store more water and yield it to boreholes over longer periods of time. Also in the study area much of the volcanic rock terrain lies where rainfall is 800 mm or more with favorable conditions for recharge.

3.5.3 Water in the Alluvial Deposits: Along most of the larger ephemeral streams of the study area are channel deposits of unconsolidated sand with some silt and clay. The deposits along most streams are no more than a few meters thick, but in some places they attain thicknesses of as much as 10 m. These channel deposits form important underflow conduits which are directly recharged by surface runoff during the wet seasons. During dry periods the underflow conduits also receive discharging

ground water from subsurface springs draining from the basement complex and volcanic rocks. The underflow moves slowly downstream in the sand rivers where it can be tapped by shallow dug wells no more than a few meters deep or trapped in artificially thickened sand reservoirs behind subsurface dams. Such underflow conduits are well-developed along the larger ephemeral (seasonal) streams such as the Eysemo, the Kaiti and their tributaries in the Athi River basin, the Tiva River and its larger tributaries, and the Thua, the Ikoo Rivers and their tributaries in the eastern part of the study area. The underflow conduits in the study area are tapped by many temporary waterholes and, in places, by protected concrete-curbed dug wells which are used most intensively during dry periods. Also they are developed by 250 or more subsurface dams, and the water is drawn off by gravity or pumping for rural, village and livestock water supply and some limited minor irrigation. The underflow conduits provide viable water supplies during average dry periods, but the yields of wells and subsurface dams are reported to fall off 50% or more during periods of protracted deficient rains or drought.

3.5.4 Chemical quality of ground water: Chemical analyses, some partial and some complete, for some 89 boreholes are given in tables A.1.2 and A.1.b of the Ministry of Water Development report, "Hydrology of the Machakos District--a Reconnaissance Report" (reference C). Among the analyses are those for waters from 21 boreholes in the study area. These analyses indicate total dissolved solids ranging from 231 to 1,775 mg/l with a mean of about 800 mg/l. The fluoride content of the waters ranges from 0 to 6.7 mg/l with a mean of 1.4 mg/l. Nitrates are generally present in less than 1 mg/l. Water from borehole C-1485 is reported to contain 30 mg/l of nitrate. The waters with lower total solids appear to be of calcium-magnesium bicarbonate type with the sodium chloride content increasing somewhat in waters with higher total solids. The waters from the boreholes generally appear to be suitable for human and animal consumption. Additional more definitive analyses would be desirable to assess the suitability of the borehole waters for irrigation.

3.5.5 Ground water utilization: Some 90% of the existing boreholes in the study area are 6 inches (152 mm) in diameter and most of rest are 4 inches (102 mm), 8 inches (204 mm) or 10 inches (254 mm) in diameter. Virtually, all boreholes tapping water in the basement complex rocks are finished with a surface string of mild steel casing through the weathered or fractured rock, but the lower part is uncased (open hole). About 90% of the boreholes in the volcanic rocks are also finished open hole. The length of the surface casing string may range from as little as 3 m to as much as 102 m, but the average in the study area is about 31 m. About 10% of the boreholes tapping water in the volcanic rocks are finished with slotted pipe either with or without gravel packing. The slotted pipe is apparently set opposite the loose scoriaceous and/or fragmental zones that may tend to cave or collapse in an open hole.

The majority of boreholes in the study area have been constructed by traditional percussion drilling. It is reported, however, that during the past 5 years or so down-the-hole air hammer drilling rigs have been used to construct some boreholes in the study area. This drilling method is much more rapid and efficient for drilling large numbers of boreholes in the hard rock terrains, but some of this advantage is offset by higher capital costs for equipment as well as continuing costs for operation and maintenance.

About 41% of the 174 boreholes of record in the study area are privately owned and are known to be used mostly for domestic and livestock water supply and occasional irrigation of small gardens and/or tree crops. About 8.6% of the boreholes are used chiefly for irrigation and of this percentage 5.8% are privately-owned and 2.8% are government-owned. About 38% (66 boreholes) of the total (174 boreholes) are used for village and town (public) water supply. Of this number the Ministry of Water Development operates the pumps and maintains 24 boreholes for rural water supply and 8 boreholes for urban supply. The rest are operated and maintained by other governmental agencies. For the remaining boreholes of record in the study area the use and ownership are curently unknown.

No reliable estimates are available of total ground-water use in the study area nor of the various categories of use for rural, livestock, urban and irrigation supply. Total use is probably relatively small, however, and probably of the order of 5 to 10 thousand cubic meters per day. Judging from borehole distribution the most intensive ground-water extraction from existing boreholes is in the southwest corner of the study area near the Nairobi-Mombasa highway; in the Mavoye-Muumander area also on the western side of the study area; in the vicinity of Machakos town; in the Kitui-Kangundo-Tala area of Machakos District; and in the vicinity of Kitui town. These areas would merit attention for potential problems of local overdevelopment. Elsewhere in the study area existing boreholes are generally spaced 2 km or more apart so that interference between boreholes is not likely to be a problem in the near future.

Owing to the nature of the terrain, captation of high-level springs and delivery of water by gravity through pipelines to population centers on lower ground is feasible at only relatively few places in the study area. A spring on Kiangombe Hill (el. 1,804 m) is developed and the flow delivered by a gravity pipeline 11 km long to the town of of Kerie in Embu District. Also the towns of Mutiti and Nuu in the Kitui District are served by gravity water supplies from high-level spring captations in neighboring hills.

3.6 Conclusions:

1. Extractable ground water is widely available in small quantities from rocks of the Precambrian basement complex in about 85% of the Machakos-Kitui study area. The boreholes sites in these rocks must be carefully selected if the boreholes are

to be successful, that is, to yield more than about 6 l/min (0.36 m^3hr). The average successful borehole in these rocks yields about 42 l/min (2.52 m^3/hr) with a specific capacity of about 1.7 l/min/m (0.1 m^3/hr/m).

2. In about 15% of the study area extractable ground water is contained in Tertiary and Quaternary volcanic rocks. Because they are relatively thin, these rocks yield water to individual boreholes in about the same quantity as the basement rocks, that is, at an average of about 32 l/min (1.92 m^3/hr). Although yields obtained from boreholes in the volcanic rocks are highly variable from place to place, failures are much less common than in the basement rocks.

3. The underflow conduits in sandy alluvial deposits along ephemeral stream channels are important sources of water which are tapped by many temporary waterholes, by subsurface dams, and, in places, by protected concrete-curbed dug wells. Along the larger ephemeral streams these conduits provide viable water supplies to wells and subsurface dams during normal dry seasons. The yields of these, however, may fall off 50% or more during protracted dry periods.

4. There are apparently only limited data available on the chemical quality of water from boreholes in the study area. These data indicate that total dissolved solids range from about 230 to 1,775 mg/l with a mean of about 800 mg/l. The fluoride content ranges from 0 to 6.7 mg/l with a mean of 1.4 mg/l. With a few exceptions the nitrate content appears to be generally less than 1 mg/l. The waters from boreholes are generally acceptable for human and animal consumption. Although most of the borehole waters appear to be suitable for irrigation, additional more definitive analyses would be desirable to assess any potential hazards for irrigation use.

5. Ground water is not available in the study area for large or even moderate scale irrigation projects. Small supplies are available, however, at many places and could be developed by pumping from boreholes which individually could effectively irrigate areas of the order of 1 acre (0.4 ha) or more of vegetable garden and/or tree crops. Also water supplies for small-scale irrigation, of the same order of magnitude, could be developed from protected concrete-curbed dug wells and subsurface dams and the water lifted by pumping to cultivated plots on higher ground. Or in some places water could be delivered by gravity pipelines (possibly of plastic) from subsurface dams to sidehill plantings of irrigated tree crops. Owing to the limited quantities of water available from potential sources (other than perennial streams) in the study area and the need to reduce or eliminate transit losses, irrigation supplies should preferably be delivered to cultivated plots by pipelines rather than by open canals (furrows).

6. Borehole water supplies, in general, should be given priority

consideration, in development planning, for village and town water supply. Borehole water is normally free of pathogenic organisms and requires little or no treatment before use. Water from most surface sources requires treatment, which may be expensive, if adequate sanitary quality is to be assured. Water supplies from protected concrete-curbed wells and subsurface dams may also normally be expected to provide water of better sanitary quality than that from open earth dams and reservoirs.

7. Wherever feasible new boreholes in the Precambrian basement rocks should be sited near earth dams and reservoirs or near subsurface dams, which may provide beneficial recharge to the ground-water cells in basement complex rocks tapped by the boreholes. Or boreholes should be located in the vicinity of streams which can provide natural recharge to the cells. Readily available local recharge serves to maintain borehole yields at higher rates than might be possible otherwise. Such joint supplies, that is, boreholes-cum-earth dams or boreholes-cum-subsurface dams would insure a measure of protection against the inevitable contingencies of protracted rainfall deficiency or drought, which characterize the study area.

8. At a few places in the study area high-level springs have been developed by protected captation boxes and the flow delivered by gravity pipeline to populated centers on lower ground. This type of water supply has considerable merit. Other than initial costs for captation boxes around spring heads and pipelines, maintenance costs can be relatively low. Although high-level springs do not appear to be common in the study area, efforts should be made to locate and identify those which have adequate and dependable flows so that they can be appropriately developed. Also in places it may be possible to develop combined water supplies using both high-level springs and boreholes in the same area for increasing the available water supply. The most viable high-level springs are likely to be found in the hilly areas of higher rainfall, that is, more than about 900 mm.

9. Although there has already been extensive construction of subsurface dams and rock catchments there is scope for considerably wider use of these structures for local water supply in the study area. As part of general water development planning it would be highly desirable to identify specific potential sites for such structures based on study of available aerial photography, and local topographic and geologic conditions together with on-site field inspections and surveys to develop cost estimates for construction. This work could be done either departmentally or through contract.

10. Throughout the study area, as well as elsewhere in Kenya, there is an urgent need for a program of systematic and periodic monitoring of existing water-development facilities including earth dams, subsurface dams, rock catchments, spring captations and boreholes. Although it may not be possible to monitor all

such facilities regularly with available personnel resources, it would seem feasible to select a representative number, say 10%, of those existing and to monitor them on a periodic basis. Only the more important facilities could be selected and should be chosen so as to achieve an appropriate coverage in the various climatic and geographic zones of Kenya. First, for existing surface-water facilities, relevant data on initial construction details should be compiled and entered in a computer program such as that now available in the Ministry of Water Development BOROP countrywide program for basic borehole data. Second, a field program needs to be established to collect periodically hydrologic data on such relevant parameters as current reservoir levels, available storage, water quality and siltation rates at surface-water facilities and water-level, water-quality and pumpage data at boreholes. At a later stage these data could be set up in computer programs for easy retrieval by the concerned data users.

3.7 Recommendations:

1. The number of boreholes in the Machakos-Kitui study area could, at least, be doubled over the number now extant, provided new boreholes are properly spaced (average 1 to 2 km apart) and sited with respect to existing boreholes. (There are presently some 174 boreholes of record in the study area.)

2. There are now existing proposals for water-development projects in the western region of the study area, that is, the Machakos District, as a part of an Integrated Regional Development Programme prepared by the Kenyan Government for funding by the European Economic Community (EEC). Together with essential soil, water conservation and erosion control works the program proposes, among other works, the construction of some 80 new earth dams, 20 water-harvesting schemes using specially treated catchment surfaces, and 200 subsurface dams, as well as rehabilitation of some 13 existing dams. These proposals apparently make no provision for siting, construction and equipping of boreholes (reference I). Provision for borehole development and utilization, it is believed, should form an integral part of overall water development in the area for rural and livestock water supply and supplemental irrigation. Boreholes, of course, provide the best potential source of sanitary water supply for the human population. In areas remote from other potential water sources, such as earth dams or subsurface dams, boreholes may be the <u>only</u> available sources of water supply. Also in areas where soil erosion has not been controlled and earth dams are not likely to be viable, boreholes may provide alternative choices for water supply.

3. As an adjunct to and in conjunction with the above cited program (item 2), it is recommended that consideration be given to donor agency financial support of a project for the siting, construction and equipping of approximately 200 boreholes in the Machakos-Kitui study area with the Ministry of Water

Development as the counterpart agency. Also, for effective water development and management, planning for the siting of new boreholes should be taken up concurrently with that for new earth dams, subsurface dams and rock catchments. With this approach the relative advantages of each type of water source can be optimized in any given locality for provision of potable water for the human population as well as basic water supply for livestock and for supplemental irrigation.

4. Prior to initiation of construction it would be essential to develop a detailed plan for appropriate borehole development and utilization in the study area taking into account the considerations mentioned above (item 3), local hydrogeological conditions, and local socio-economic conditions, such as the acceptance of the water supply by the local water users and their willingness to support at least part of operation and maintenance costs. All new borehole sites would be chosen first, after careful consideration of geologic and geophysical criteria based on local surveys and second, after careful analysis of the probable viability of a borehole water supply in the local socio-economic milieu. This Phase I of a borehole development program could be carried out over a 2-year period by the Ministry of Water Development (MWD) with the assistance of a senior hydrogeologist advisor under a donor agency contract. During this 2-year period the advisor would guide local geological and geophysical surveys essential for borehole siting by MWD personnel and socio-economic surveys for borehole utilization. He would also assist in the procurement of casing and drilling equipment for borehole construction; of pumps, piping and tanks for local water distribution; and a 5-year supply of spare parts--all with donor agency financing.

5. During Phase II the advisory staff would be increased by an additional hydrogeologist and a well-drilling advisor for a total donor agency contract staff of three advisors. The Phase II activities would be carried out over a 3-year period for an overall project duration of 5 years. The senior hydrogeologist would serve as project chief and would be responsible for coordinating borehole construction activities with other water-development projects of the Ministry of Water Development in the study area. The second hydrogeologist would be responsible for guiding geological and engineering personnel of the MWD in the field operations of drilling and logging of the boreholes, conducting pumping tests, collection of water samples and in the preparation of technical reports describing and interpreting the results of borehole construction activities. The well drilling advisor would be responsible for the operation and maintenance of borehole drilling equipment provided under the project, the training of drilling crews provided by the MWD, the construction and casing of boreholes, and the installation of pumps. The MWD would assume responsibility for construction and maintenance of delivery of pipelines, storage tanks, and other distribution facilities as well as drilling equipment provided under the project.

6. The gross cost of the proposed $US input into borehole development project outlined above is estimated to be of the order of US $3,000,000 in 1978 dollars. If a 6% inflation factor is added, the gross cost over 5-year term could reach $4,000,000.

4.0 Baringo-Kerio study area

4.1 Location and extent: The Baringo-Kerio study area lies in parts of the Elgeyo-Marakwet and Baringo Districts of the Rift Valley Province. It comprises a rectangular block lying between 35°30' and 36°15' E. longitude and 0°15' and 0°45' N. latitude covering an area of about 4,546 km^2 in west-central Kenya. The maximum extent from east to west is about 82 km and from north to south about 55 km. Kabarnet, the district headquarters of Baringo District, Marigat and Tambach are the principal population centers in the study area.

4.2 Topography and drainage: The study area, which lies athwart the main Rift Valley includes the following physical divisions from west to east: (1) the Uasin Gishu Plateau; (2) the Elgeyo Escarpment; (3) the Kerio Valley; (4) the Tugen Hills; (5) the Lake Baringo basin on the floor of the Rift Valley proper, and (6) the Laikipia and Ngelesha Escarpments on the edge of the Rumuruti Plateau to the east. Drainage on the Uasin Gishu Plateau is southwestward to Lake Victoria, the divide lying along the lip of the Elgeyo Escarpment except where it passes west of the Sion River. This stream drains into the Kerio Valley at Biretwo dropping over a lava precipice at the top of the escarpment in Torok Fall, whose height exceeds 300 m. Altitudes along the divide range from 2,600 to more than 2,750 m above sea level. East of this divide the escarpment drains directly to the Kerio River by way of 25 or more short spring-fed tapering streams and to the southeast and south by way of Kinwaror, Kiptunel and other headwater tributaries of the Kerio.

The Kerio Valley, which drains north to Lake Turkana by way of the Kerio River, lies some 1,500 m below the lip of the Elgeyo Escarpment and 900 to 1,200 m below the crest of the Tugen Hills. The valley, which ranges from about 4 to 12 km wide, slopes evenly northward across the study area from an altitude of about 1,525 m in the south to 1,065 m in the north. The Kerio River, which is perennial in the study area, draws most of its flow from high rainfall areas (1,150 to 1,250 mm) to the east, south and west of the valley. In the southern part of the valley the river has cut down through a cover of alluvial deposits and into underlying bedrock. At Cherbloch Bridge, for example, the road crosses the river at a gorge which is less than 6 m wide but more than 18 m above the river level. About 20 km north of Cherbloch Bridge is Lake Kamnarok. This lake lies in an alcove in young lava flows which have blocked local drainage of streams flowing westward from the Tugen Hills.

East of the Kerio Valley are a series of northerly trending ridges, the Tugen Hills, whose crest rises to some 2,285 to 2,440 m above sea level. The high rainfall (1,150 to 1,250 mm) area along the crest of these hills gives rise to 30 or more small spring-fed tapering streams which are perennial in their

upper reaches but in their lower courses become ephemeral when the surface flows seep underground or evaporate. From the drainage divide along the crest these streams drain both east to the Lake Baringo basin and west to the Kerio Valley.

The Lake Baringo basin in the eastern part of the study area lies between the Tugen Hills on the west and the Laikipia and Ngelesha Escarpments on the east. Lake Borgoria (altitude 990 m) and Lake Baringo (altitude 971m), which form the sumps for the surface drainage of the region, were at one time interconnected. Lake Borgoria, however, is now blocked at its north end by large alluvial fan deposited by the Waseges River where it debouches from its gorge into the Baringo-Borgoria lowland. Lake Borgoria, whose only perennial tributary is the Waseges River, contains water whose salt content ranges from 12,595 mg/l at its north end to 63,600 mg/l (about twice the content of sea water) at the south end (reference V, table III). Lake Baringo receives the inflows of four perennial streams along its southern periphery. These are the Perkerra River, which is the largest, and also the Molo, Loboi and Ol Arabel Rivers. The water from Lake Baringo is nominally fresh, at present, although there are some reports of recent deterioration in the chemical quality. Doubtless the quality would fluctuate seasonally and annually depending on the balance of inflows from precipitation and streams as against evaporation. (The lake has no surface outlet.) Data on the water quality of the inflowing streams are not available, but the water from all is nominally fresh, that is with a total dissolved solids content probably less than 1,000 mg/l.

East of the Lake Baringo basin the land rises steeply in a series of three escarpments to the Rumuruti Plateau, whose altitude ranges from 1,980 to 2,500 m. The Waseges, Ol Arabel and Mukutan Rivers, all perennial, rise in high rainfall (1,000 to 1,250 mm) areas on this plateau and drain west and northwest. The Waseges empties into Lake Borgoria and the Ol Arabel and Mukutan into Lake Baringo.

4.3 Rainfall: In the Baringo-Kerio study area some rainfall occurs, on the average, in every month of the year. Rainfall is most concentrated, however, during the period April through August with August commonly the wettest month of the year. January and February are commonly the driest months. Rainfall distribution and intensity are largely controlled by altitude. Along the lip of the Elgeyo Escarpment, along the crest of the Tugen Hills and on the Rumuruti Plateau annual rainfall ranges from 1,150 to more than 1,250 mm. In the Kerio Valley floor and in the Baringo-Borgoria lowland of the Lake Baringo basin rainfall ranges from 900 to less than 650 mm annually. At altitudes greater than about 1,500 m rainfall is sufficient to sustain perennial streams, but at lower altitudes only the largest rivers and their main tributaries carry water throughout the year.

4.4 Surface water: Within the study area the chief perennial streams are the Kerio, Perkerra, Molo, Waseges, Loboi, Ol Arabel and Mukutan Rivers. Of these only the first four are regularly gauged. A summary of the runoff characteristics of these streams based on data through 1972 and taken from reference A (Appendix A, p. 3) is given below:

Stream	Station no.	Catchment area (km^2)	Mean Annual Runoff		95% Duration Runoff	
			m^3/sec	l/sec/km^2	m^3/sec	l/sec/km^2
Kerio	2C7	893	5.37	6.01	0.074	0.083
Perkerra	2EE7	1,180	3.03	2.57	0.40	0.34
Molo	2EG1	595	1.67	2.81	0.17	0.29
Waseges	2EB3	331	0.643	1.94	0.044	0.13

Of the four rivers the Kerio has the highest annual runoff per km^2, possibly owing to the steep slopes and low infiltration rates prevailing in its upper watershed. On the other hand the Perkerra and Molo have markedly higher base flows per km^2 than the Kerio, owing possibly to higher infiltration rates on their watersheds and higher ground-water return flows during dry weather.

As suggested in reference A, map no. 3, the base flow runoff (95% flow duration) in the higher rainfall areas of the Elgeyo Escarpment, the Tugen Hills, and the Rumuruti Plateau may range from 0.15 to 0.50 l/sec/km^2. In the lower rainfall areas of the Kerio Valley and the Baringo-Borgoria lowland of the Lake Baringo basin the base flow runoff is less than 0.15 l/sec/km^2. Mean annual runoff in the higher rainfall areas (reference A, map no. 5) ranges from about 5 to 7 l/sec/km^2 on the Elgeyo Escarpment and adjacent parts of the Uasin Gishu Plateau and in the Tugen Hills. On the Rumuruti Plateau mean annual runoff in the higher areas is about 1 to 3 l/sec/km^2. In the lower rainfall areas of the Kerio Valley and the Baringo-Borgoria lowland mean annual runoff is less than 1 l/sec/km^2.

The chief type of surface-water storage utilized in the Baringo-Kerio area is the earth dam and reservoir. There are presently estimated to be about 30 to 40 such machine-excavated reservoirs with study area with an average initial capacity of about 6,000 m^3. In addition there are many more hand-excavated water-holes which provide temporary water supplies for people and livestock. There are apparently very few, if any, subsurface dams and rock catchments in the study area. Lake Baringo itself provides important natural water storage and is utilized in peripheral areas for human and livestock consumption as well as for some limited pump irrigation. The water from Lake Borgoria is too saline for human consumption, but the water at the north end of the lake is occasionally used by livestock.

4.4.1 Surface water utilization: Irrigation on a small scale is practiced in a few places in the study area by pumping or gravity diversions from streams. A small experimental farm of about 8 hectares is located at Nakuratapin about 10 km north of Kampi ya Samaki. The farm is irrigated by water pumped from Lake Baringo. Melons, papayas and potatoes are cultivated by the trickle irrigation method, and water is distributed through one-half inch plastic pipes. East of Marigat and south of Lake Baringo is the Perkerra Irrigation Scheme constructed during 1954-58. The command area, which covers 415 hectares, is served by a main canal of about 0.57 m^3/sec capacity. This canal depends on a run-of-the river diversion weir on the Perkerra River near Marigat. The chief crops cultivated are onions and chilies with bananas as profitable windbreaks.

Elsewhere in the study area water supplies for human consumption and livestock from surface water sources are taken directly from perennial streams, from Lake Baringo, from waterholes or from earth-dam reservoirs.

4.5 Hydrogeology: Within the Baringo-Kerio study area there are three groups of rocks which store and yield ground water to wells, boreholes and springs. These groups include Precambrian basement complex rocks, Tertiary and Quaternary lava flows with interbedded pyroclastic deposits of volcanic origin, and in some places late Quaternary lacustrine and alluvial deposits.

The Precambrian basement complex includes several kinds of interbedded sediments which have been metamorphosed, principally to hornblende gneisses with lesser interbeds of quartz-feldspar gneisses, crystalline limestones, quartzites and biotite gneisses. These rocks crop out in the basal and middle slopes of the Elgeyo Escarpment and form a belt some 1.5 to 3 km wide extending north-south along the entire 55 km width of the study area. They also underlie a cover of Quaternary alluvial detritus in the Kerio Valley extending about as far east as the longitude of the Kerio River. Along this line they are apparently in fault contact in the subsurface with the Tertiary volcanic rocks which form the eastern slopes of the valley. Near the top of the Elgeyo Escarpment the Precambrian rocks are capped by Tertiary volcanic rocks which form spectacular cliffs, in places more than 300 m high.

The Tertiary and Quaternary volcanic succession includes basalt flows at the base overlain by tuffaceous sediments, phonolites, welded tuffs, more basalts, trachytes and tuffs. These rocks underlie all the study area, with the exception of the Precambrian belt of the Elgeyo Escarpment. Throughout most of the study area these volcanic rocks have been broken into narrow slices by a closely spaced gridwork of north-south faults. The Kerio Valley and the Baringo-Bogoria lowland occupy two down-dropped blocks or graben in this fault system while the Tugen Hills, which are uplifted relative to the two grabens,

form a horst.

Unconsolidated Quaternary stream deposits of poorly sorted clay, silt, sand and gravel directly underlie the surface of most of the Kerio Valley north of the Cherbloch Bridge and also form a thin veneer over Tertiary volcanic rocks in much of the valley floor south of the bridge. The lowland lying 10 to 15 km south and southwest of Lake Baringo and extending to the north end of Lake Borgoria is underlain largely by fine silts and sands of lacustrine and deltaic origin. These deposits were apparently laid down when Lake Baringo and Lake Borgoria were interconnected during higher lake stages in Pleistocene time. A young Holocene alluvial fan deposited by the Waseges River at the debouchment of Sandai Gorge now partly blocks this connection and ponds the lower course of the Loboi River in Loboi Swamp.

4.5.1 Water-bearing character of the rocks: The rocks of the Precambrian basement complex store and yield ground water chiefly from the weathered rock and contiguous fracture systems. A number of small springs rise from the Precambrian rocks along the middle and lower slopes of the Elgeyo Escarpment. Most of these springs are temporary and go dry soon after the rains cease. During 1950 three boreholes were drilled on the floor of the Kerio Valley as part of the Kerio Valley Scheme (reference D, p. 149). All three boreholes (C-1127, C-1128 and C-1167, tables 3 and 4) tapped ground water in Precambrian basement rocks at depths of 87, 57 and 77 m, respectively. The yields obtained, 28, 18 and 17 l/min, respectively, lie between the 50 and 25 country-wide percentiles for boreholes tapping water in Precambrian basement rocks. These yields are thus less than average but better than "poor". The yields can be categorized as "fair". Aside from the middle and lower slopes of the Elgeyo Escarpment and the substratum west of the Kerio River, which together constitute about 6% of the study area, the Precambrian basement rocks are unimportant as sources of ground water elsewhere in the study area.

Along the contact between the Precambrian basement rocks and the overlying Tertiary volcanic rocks there is an important spring zone which lies about 300 m below the lip of the Elgeyo Escarpment. This zone gives rise to 25 or more tapering streams in the study area which are fed by perennial springs in their upper reaches. These streams commonly lose most if not all their flows by infiltration into the talus fans at the base of the escarpment. At least four such springs were developed during the 1950's by enclosing the spring heads with masonry walls (captations) and leading the flow down the slopes by gravity pipelines to points of use on the Kerio Valley floor. These gravity water-supply systems, known as the Emsea, Lekwa, Kabulwa and Sanguru pipelines, all tap springs feeding tapering streams on the slopes of the Elgeyo Escarpment (reference D, p. 149). The delivery pipelines range from about 2.5 to 3.5 km long.

The Tertiary and Quaternary volcanic rocks also give rise to many small perennial springs which feed tapering streams draining from the slopes of the Tugen Hills and also from the Rumuruti Plateau in the southeastern part of the study area. Prior to 1962 a number of the springs were developed by protective captations for local use. One of these springs, whose flow is controlled by a small masonry dam, provides part of the water supply of Kabarnet. The water from the spring is pumped to a distribution tank in the higher part of the town.

Apparently, there are only four boreholes (C-1838, C-3506, C-3526, and C-4077) of record drilled in the Tertiary and Quaternary volcanic rocks of the study area. One of these, C-3526 at Kabartonjo, produced very little water and was abandoned. The other three produced yields of 23,227 and 183 l/min, respectively (table 3). The median yield of boreholes in Kenya tapping water in volcanic rocks is about 95 l/min. Thus the yields from boreholes C-3506 and C-4077 are considered "excellent" while the yield from C-1838 is "poor". All four boreholes apparently tap water in fractures or pervious weathered zones in tuffs or lava flows (table 4).

The Quaternary alluvial deposits in the Kerio Valley appear to be generally above the regional water table and hence do not yield water in significant quantity to wells or boreholes. For example, in boreholes C-1127 and C-1128 unconsolidated Quaternary alluvial deposits are 27.4 and 43.9 m thick, respectively. At these boreholes, however, the deposits are unsaturated as the water table lies in the deeper Precambrian basement rocks (table 4). The water table in the Quaternary deposits of the Baringo-Borgoria lowland appears to lie within a few meters of the land surface. These deposits have relatively low permeability, but they do, however, yield small quantities of water to some open dug wells sufficient for limited household and livestock use.

4.5.2 Ground-water utilization: Aside from limited watering of fruit trees, shrubs and gardens there is virtually no present use of ground water for irrigation in the study area. Borehole C-3506 and a developed protected spring provide the municipal water supply for Kabarnet. Tambach, Biretwo, Kabartonjo and Tenges are also provided with either pumped or gravity water supplies obtained from protected spring captations or weirs on spring-fed streams. Protected or open springs also provide water supplies for the rural population and livestock along the Elgeyo Escarpment, in the Tugen Hills, and in the escarpments on the western edge of the Rumuruti Plateau. The rural population and livestock in the Kerio Valley, which is very thinly populated, and in the Baringo-Borgoria lowland depend virtually entirely for water supply on the nearest perennial stream, swamp, and/or lake.

4.5.3 Chemical quality of ground water: With a few exceptions, there appear to be no data available on the chemical quality of waters from wells, boreholes and springs in the study area. The waters from all these are generally reported to be of good quality and potable. Locally, however, some unprotected wells

and springs may be bacteriologically contaminated. Chemical analyses are available in reference V, table III for the warm springs at Maji Ya Moto, at Loboi, and on Ol Kokwe Island on Lake Baringo. The chemical analyses from all three localities suggest that the waters are of shallow meteoric origin and that warming (approximately body temperature or a little higher) has been effected by deep circulation through the fault grid-work. The chemical characteristics of these waters summarized from reference V, table III are given below:

	Maji ya Moto	Loboi	Ol Kokwe Island
Total dissolved solids (mg/l)	420	425	238
pH	6.7	6.9	10.4
Fluoride (F) (mg/l)	4.3	4.6	18.8

The analyses indicate that the waters from Maji Ya Moto and Loboi are of sodium bicarbonate type, very slightly acidic, and (judged by regional standards) low in fluoride content. The analyses also suggest a common geologic origin for the waters from the two spring groups. The water from the springs on Ol Kokwe Island, although lower in total dissolved solids than the other two, appears to be of sodium carbonate--bicarbonate type and markedly alkaline. With the exception of high fluoride content, the waters from all three spring localities are potable and suitable for human and animal consumption.

4.6 Conclusions:

1. Extractable ground water in small quantities is available from boreholes tapping water-bearing zones in Precambrian basement rocks in the Kerio Valley west of the Kerio River. The yields obtainable from boreholes in this area would range from about 15 to 30 l/min (0.9 to 1.8 m^3/hr). Elsewhere in the study area somewhat higher yields ranging from 20 to 200 l/min (1.2 to 12 m^3/hr) can be expected from boreholes tapping water-bearing zones in the Tertiary and Quaternary volcanic rocks. Perhaps 5 to 10% of the boreholes drilled in these rocks, however, can be expected to produce yields of less than 5 l/min (0.3 m^3/hr).

2. Ground water is not available in the study area for large or even moderate scale irrigation projects. Small supplies are available at many places, however, and could be developed by pumping from boreholes which individually could effectively irrigate areas of the order of 1 acre (0.4 ha) or more of vegetable gardens and/or tree crops. Also there are many high-level springs which could be developed by captation boxes and the flows delivered by gravity pipelines to irrigate side-hill plantings of tree crops. Where needed supplemental tanks could be provided to store unutilized night flows.

3. There are many high-level springs which could also be developed by protected captation boxes and the flows delivered by gravity pipelines to population centers and for livestock watering on lower ground.

4. Spring captations, of course, have a number of advantages over borehole supplies, namely low initial construction and maintenance costs plus provision of water of sanitary quality equal to that from boreholes. The chief expenses are the capital and maintenance costs for the spring captation boxes, the delivery pipelines and any balancing storage tanks that may be required at the points of use.

5. There appears to be only limited scope, if any, for utilization of subsurface dams and rock catchments in the study area.

6. The chemical quality of the ground water obtained from wells, boreholes and springs appears to be generally satisfactory for human and animal consumption and also for irrigation. Chemical data on ground water quality in the study area are now almost totally lacking and are urgently needed for planning appropriate water development in the study area.

7. At present the total extraction of ground water from boreholes in the study area is miniscule. There is thus ample scope for borehole construction and ground-water development in most parts of the study area but more particularly in the lowland area where gravity supplies cannot be feasibly delivered. Provided boreholes are spaced at intervals of 1 km or more apart there is little hazard of local overdevelopment.

4.7 Recommendations:

1. For water-development planning there is urgent need for detailed local surveys to locate developable springs, to determine their flow and water-quality characteristics, to design appropriate captation structures and pipeline structures, and to establish a socially viable local milieu for economically satisfactory use of the water.

2. There is also a need for planning for borehole construction and ground-water development in the study area. Such future boreholes would probably be located mostly near villages or larger population centers, where viable borehole use and maintenance can be reasonably assured. Adequate geophysical and geological studies for proper borehole site selection should be completed well in advance of actual borehole construction operations.

5.0 Costs of borehole construction and development: At present in Kenya, boreholes are constructed departmentally by the Ministry of Water Development and also by a number of private drilling contractors who serve the general public. The Ministry of Water Development (MWD) is presently underwriting the construction of about 200 boreholes per year on a countrywide basis. Of this number 80 to 100 boreholes per year are constructed departmentally, and the balance are put down under contract with private drilling companies. The MWD maintains a register of all boreholes drilled in Kenya, and by law drilling companies must provide the MWD with well logs and other construction details of boreholes drilled for private individuals and companies. The MWD also provides borehole siting services through its Geological Department for both public agencies as well as private landowners. The MWD also does some drilling with its departmental rigs for small private land owners.

The MWD now constructs its boreholes with 4 percussion rigs and 2 recently acquired down-the-hole air hammer rigs. Acquisition of the latter rigs has greatly accelerated the rate of departmental construction of boreholes. Some 4 to 6 weeks are required for completion of a borehole 100 m deep in the Precambrian basement rocks when put down by the percussion drilling method. A borehole of the same depth in the same rocks would require only about 2 days for completion when put down by the air hammer drilling method. The total cost per borehole is, however, about the same. The percussion drilling method is technologically simple and labor intensive but time consuming. On the other hand the air hammer drilling method is technologically complex, efficient and time saving but is operationally costly. Where a large number of boreholes are to be constructed in a short span of time, the air hammer drill is the obvious choice.

At present a departmentally drilled borehole 100 m deep in basement or volcanic rocks including: a 10-inch surface mild steel casing reduced to 6-inch below; the mobilization and setting up of the drilling rig; amortization of a fraction of drilling rig costs; fuel and test pumping costs (but not including the permanent pump installation) costs about K sh 40,000 to 55,000 or about K sh 400 to 550 per meter. The same borehole if drilled by private contractor would cost about double, that is about K sh 80,000 to 110,000 or about K sh 800 to 1100 per meter. The higher costs for private contractual drilling are due chiefly to administrative overhead and technical services costs, which the private contractor must absorb, plus losses as well as a profit margin which must be added.

Mild steel casing in Kenya now sells for about K sh 409/m for 8-inch and K sh 283/m for 6-inch. These diameters are the two most commonly used throughout the country. Plastic casing of the British-manufactured Durapipe type costs K sh 269/m for 8-inch and K sh 201/m for 6-inch. Plastic pipe is increasingly

used in Kenya, where it does not have to be driven. The plastic pipe also is corrosion resistant to aggressive waters.

Test pumping of boreholes, when the percussion method has been used, is reported to cost about K sh 90/hr and K sh 317/hr when the air hammer method has been used, owing chiefly to higher fuel costs. Most boreholes are developed by test pumping for 24 to 48 hours.

Most boreholes now used for rural and urban water supply in Kenya are fitted with electric submersible pumps which are powered by air or water-cooled diesel driven generators. The diesel engines break down much more frequently than the pumps, owing chiefly to lack of preventive maintenance. The pumping schedules for public water-supply boreholes are less than 8 hours per day in about 70% of the services, about 8 to 16 hours per day in 15% of the services and more than 16 hours in the rest. An electric submersible pump of 3 1/2 inch diameter without motor costs about K sh 20,000 and of 5 1/2 inch diameter, about K sh 45,000. A pumping installation with a 3 1/2 inch submersible pump, a small diesel electric generator and pump house costs about K sh 50,000. A pumping installation with a 5 1/2 inch submersible pump, a large diesel electric generator and a pump house costs about K sh 100,000.

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7.0 Tables

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MINISTRY OF WATER DEVELOPMENT

BOREHOLE DATA

UP TO DATE AS OF 15-12-77

Table 1.
Machakos-Kitui
Study area

Note: Boreholes marked by asterisk (*) lie in study area

KEY TO HEADINGS

B/H REF NUM = BOREHOLE REFERENCE NUMBER
LONG/LAT = LONGITUDE AND LATITUDE OF THE BOREHOLE, TO THE NEAREST MINUTE. A VALUE REPORTED AS 3639S1C6 IS READ 36 DEG. 39 MIN. EAST LONGITUDE, 1 DEG. 6 MINUTES SOUTH LATITUDE.
MAP REF = 50.000 SCALE MAP REFERENCE NUMBER.
BASIN = HYDROLOGIC CATCHMENT. E.G. 4E0 REFERS TO DRAINAGE AREA 4, BASIN E, SUB-BASIN 0.
DIST = DISTRICT CODE. THESE ARE --

10 NAIROBI
CENTRAL PROVINCE
21 KIAMBU
22 KIRINYAGA
23 MURANGA
24 NYANDARUA
25 NYERI
COAST PROVINCE
31 KILIFI
32 KWALE
33 LAMU
34 MOMBASA
35 TAITA
36 TANA RIVER

EASTERN PROVINCE
41 EMBU
42 ISIOLO
43 KITUI
44 MACHAKOS
45 MARSABIT
46 MERU
NORTHEASTERN PROVINCE
51 GARISSA
52 WANDERA
53 WAJIR
NYANZA PROVINCE
61 KISII
62 KISUMU
63 SIAYA
64 SOUTH NYANZA

RIFT VALLEY PROVINCE
71 BARINGO
72 ELGEYO MARAKWET
73 KAJIADO
74 KERICHO
75 LAIKIPIA
76 NAKURU
77 NANDI
78 NAROK
79 SAMBURU
81 TRANS-NZOIA
82 TURKANA
83 WEST POKOT
WESTERN PROVINCE
91 BUNGOMA
92 BUSIA
93 KAKAMEGA

USE = PURPOSE OF BOREHOLE. THE CODES ARE --
A = AGRICULTURAL
L = LIVESTOCK
P = PUBLIC WATER SUPPLY
I = INDUSTRIAL/COMMERCIAL
X = EXPLORATORY
B = OBSERVATION
O = OTHER
U = UNKNOWN

OWN = OWNER. THE CODES ARE --
R = RURAL WATER SUPPLY, MWD
C = URBAN WATER SUPPLY, MWD
B = OBSERVATION, MWD
A = RANGE WATER, MWD
L = LIVESTOCK MARKETING DIVISION, MA
G = OTHER GOVERNMENTAL
P = PRIVATE
O = OTHER
U = UNKNOWN

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Table 1. (cont'd)

ELEV = GROUND SURFACE ELEVATION, METERS
TD = TOTAL DEPTH OF WELL, METERS
HOR = NUMBER OF PRODUCING HORIZONS
ROCK = ROCK TYPE. THE CODES ARE --

1 = VOLCANIC
2 = BASEMENT
3 = SEDIMENTARY
4 = VOLCANIC OVER BASEMENT
5 = SEDIMENTARY OVER BASEMENT
6 = SEDIMENTARY OVER VOLCANIC
7 = VOLCANIC OVER SEDIMENTARY
8 = OTHER
9 = UNKNOWN

DEPTH TO WATER LEVEL
STK = WATER STRUCK DEPTH, METERS
RST = REST LEVEL DEPTH, METERS
DIF = DIFFERENCE, STRUCK - REST.
REST ELEV = ELEVATION OF REST LEVEL, METERS
CASING/OPENINGS
DI = DIAMETER AT BOTTOM - CENTIMETERS
T = TYPE OF OPENING. THE CODES ARE --
H OPEN HOLE
P PERFORATIONS OR SLOTS, GRAVELLED
F PERFORATIONS OR SLOTS, NO GRAVEL
S SCREEN, GRAVELLED
C SCREEN, NO GRAVEL
B BACKFILLED
P PLASTER
O OTHER
U UNKNOWN
TOP = DEPTH TO TOP OF OPENINGS, METERS
L = TOTAL LENGTH OF OPENINGS, METERS.
% = PERCENT OF TOTAL DEPTH WHICH IS OPEN
NPT = NUMBER OF PUMPING TESTS
FINAL PUMPING TEST
Q = DISCHARGE IN LITERS PER MINUTE
DYN = DYNAMIC LEVEL , METERS
S = DRAWDOWN DURING THE TEST, METERS
H = LENGTH OF PUMPING, HOURS
R = NUMBER OF MEASUREMENTS OF RECOVERY
POT = POTABILITY. THE CODES ARE --
G GOOD
B SALINE, POTABLE
S SALINE, NON-POTABLE
U UNKNOWN
STA = STATUS OF WELL. THE CODES ARE --
C COMPLETED/IN USE
A ABANDONED
L ABANDONED AFTER SERVICE
S ABANDONED BUT SERVICEABLE
U UNKNOWN
MON = MONITORING FREQUENCY. THE CODES ARE --
N NEVER
Y YEARLY OR LESS FREQUENTLY
M MORE FREQUENTLY THAN YEARLY
E FORMERLY, BUT NOT NOW
U UNKNOWN
DATE = DATE OF COMPLETION, YEAR AND MONTH
Q/S = SPECIFIC CAPACITY (LITERS/MIN-METER)
EST T = ESTIMATED TRANSMISSIVITY

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Table 1. (cont'd)

B/H REF NUM	LONG/LAT	MAP REF	BASIN	DISTRICT	SUBWARD	GRND ELEV	TD	HOLE	CASING	STK	RST	DTF	REST ELEV	CASING/OPENINGS DI	T	TOP	L	S	NPT	FINAL PUMPING TEST Q	DYN	S	H	PORT	SAMPLE	DATE	Q/S	EST T M2/DAY
C1622	3702S102	149 /1	3C8	21	U P	1540	92	2	1	72	10	22	1440	15	H	23	69	100	1	241	61	10.6	12	G	C U	53 2	22.7	34
C2233	3702S102	149 /1	3C8	21	A C	1539	216	3	1	122	41	81	1496	15			216		2	57	149	107.6	9	G	C U	54 5	0.5	1
C1207	3702S103	149 /1	3C8	21	1 P	1540	108	1	1	137	57	80	1483	15	H	67	121	100		23			15	G	U N	50 3		
C2743	3702S103	149 /1	3C8	24	A C	1524	216	4	1	216	37	179	1487	20	H	4	212	100	2	471	94	57.3	24	4 G	C N	5710	8.2	12
C1678	3702S105	149 /1	3C8	21	A P	1524	121	2	1	117	40	77	1484	15	H	3	173	100	1	56			9	G	U U	5211		
C1621	3703S106	149 /1	3C8	21	A C	1506	75	1	1	44	31	13	1477	15	H	20	55	100		123			30	G	C U	51 1		
C1417	3703S102	149 /1	3C8	21	U P	1522	166	2	1	156	57	101	1475	20	H	5	161	100	1	6			8	G	C N	51 2		
C2736	3703S103	149 /1	3C8	21	U P	1524	229	2	1	229	30	199	1494	15	H	53	176	100	1	91	220	190.0	12	G	C N	5710	0.5	1
C1566	3703S104	149 /1	3C8	21	A P	1508	136	2	1	134	55	59	1453	15	H	13	123	100		15			12	G	C N	5111		
C1940	3704S103	149 /1	3C8	21	U P	1503	137	2	1	128	34	94	1469	15	H	6	131	100	1	211	92	58.0	12	G	C U	53 3	3.6	5
C2645	3704S103	149 /1	3C8	21	U P	1524	110	0	1					15	H	19	91	100	1	45			12	G	C U	5811		
C3030	3704S103	149 /1	3C8	21	U P	1493	126	2	1	134	46	88	1447	25	H	4	132	100	1	31	128	82.0	12	G	C U	60 2	0.4	1
C2064	3704S104	149 /1	3C8	21	U P	1478	200	2	1	187	47	140	1431	20	H	67	133	100		229	124	77.0	18	G	C U	5310	2.0	4
C1468	3705S105	149 /1	3C8	21	A C	1478	115	2	1	61	25	36	1453	15	H	23	92	100	2	42			15	G	C N	51 6		
C4006	3705S105	149 /1	3C8	21	L P	1447	122	2	1	53	8	45	1439	15	U	118	4	100	1	97	56	47.6	24	4 G	C N	74 4	2.0	3
C2603	3707S106	149 /1	3C8	21	A C	1478	159	1	1	151	68	83	1410	15	P	30	120	93	1	114	151	83.2	20	G	C U	56 9	1.4	2
C3581	3808S114	NONE/0	3DA	21	U P	2024	70	2	1	58	29	29	1995	15	H	12	58	100	1	73			5	G	U U	65 1		
C1694	3712S103	149 /1	3DA	21	A P	1440	107	1	2	22	27		1413	15	P	59	49	100		114			8	G	C U	52 2		
C3092	3712S104	149 /1	3DA	21	U P	1463	123	4	1	120	37	83	1426	20	H	27	96	100	2	72	92	55.0	24		C U	60 2	1.3	2
C1295	3712S105	149 /1	3DA	21	A P	1463	113	1	1	53	48	45	1415	20	H		113			6			10	G	C U	51 2		
C2922	3714S104	149 /1	3DA	21	U C	1433	35	1	1	35	0		1433	20	H	31	4	100	1	606		4.8	21	U	U		126.3	180
C3013	3715S113	149 /1	3DA	21	U P	1585		3	2	54	26	68	1559	20	R	12			2	11	89	63.0	9	G	C U	60 4	0.2	6
*C1769	3717S106	149 /2	3DA	21	A P	1372	122	3	2	76	50	26	1322	15	H	10	112	100	2	19	79	24.9	15	G	U U	54 4	0.6	1
*C2132	3718S109	149 /2	3DA	21	L P	1493	105	1	1	65	39	30	1454	15	H	49	56	100	1	21	65	26.0	9	G	C U	53 6	0.8	1
*C2615	3719S106	149 /2	3DA	21	U P	1250	135	2	2	128	40	88	1210	15	H	21	114	100	1	86	61	21.0	20	G	C U	58 7	4.1	6
*C2943	3719S106	149 /2	3DA	21	A P	1311	107	2	2	85	14	71	1297	20	H	35	72	100	3	174	92	78.0	61	G	U U	5911	2.3	3
*C4000	3719S112	149 /2	3DA	44	U P	1446	123	1	2	37	4	29	1444	15	U	6	117	100	5	151	74	70.1	24	6 G	C U	74 5	2.2	3
*C3603	3720S106	149 /2	3DA	21	C C	1372		0	2					15	H	9	101		4	164		83.0	40	G	C U	67 9	1.0	3
*C1989	3720S108	149 /2	3DA	21	U P	1280	113	2	1	99	49	50	1231	15	H	6	107	100	1	32	87	36.0	9	G	C U	53 2	0.6	1
*C1949	3722S117	149 /4	3DA	44	U P	1615	114	3	2	119	47	72	1563	15	H	24	95	100	4	68	107	60.0	17	G	C U	53 4	1.1	2
*C1133	3726S111	149 /2	3DA	43	U P	1290	153	2	1	121	23	98	1267	15	H	16	137	100	2	240			10	G	C N	50 6		
*C1493	3727S111	149 /2	3DA	44	A G	1341	64	1	1	30	24	6	1317	15	H	9	55	100		75			24	G	C N	51 2		
*C2406	3727S121	149 /4	3DA	44	P C	1315	93	2	2	90	19	71	1290	15	P	32	61	100	1	74	80	60.6	30	G	C N	55 7	1.3	2
*C4039	3727S125	149 /4	3DA	44	A P	1300	92	2	2	74	10	64	1290	15	H	12	80	100	1	136	21	10.5	12	4 G	C N	74 6	12.0	19
*C2407	3729S122	149 /4	3DA	44	P G	1316	104	2	2	86	20	68	1299	15	H	30	74	100	1	14	37	37.4	15	G	C N	55 7	0.4	1
*C2019	3731S112	150 /1	3DB	44	U P	1311	160	2	1	110	17	93	1294	15	H	6	154	100	2	10	137	120.0	24	G	C U	53 8	0.1	0
*C2024	3733S112	150 /1	3DB	44	U P	1236	138	1	2	90	9	81	1217	15	H	6	132	100	2	24	92	85.0	8	G	C U	53 7	0.3	0.2
*C1430	3738S120	150 /3	3DB	44	A C	1301	98	1	2	70	19	51	1282	15	H	6	92	100	2	125			24	G	C N	53 6		
*C2884	3709S135	162 /1	3EA	44	U P	1676	81	0	2															U	U U	58 9		
C3206	3709S136	162 /1	3EA	44	U P	1539	169	1	2	92	66	26	1473	20	U		169		1	2	169	103.0	3	U	U U	61 6	0.0	0
C0646	3710S132	162 /1	3EA	44	U P	1676	128	1	2	59	92	7	1564	15	H	18	110	100		12			6	G	C U	48 2		
C1677	3710S133	162 /1	3EA	44	U P	1678	40	0	1								40								A N	52 2		
C1966	3711S131	162 /1	3EA	44	U P	1676	141	2	2	141	37	104	1641		U		141		1	152			11	G	C U	62 7		
C2470	3711S131	162 /1	3EA	44	U P	1385	47	0	2					15			47			0					A N	56 1		
C3267	3711S132	162 /1	3EA	44	A P	1676	208	1	2	39	35	3	1641	15	H	12	195	100	4	64	106	71.2	24	G	C N	6310	0.9	1

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Table 1 (cont'd)

B/H REF NUM	LONG/LAT	MAP REF	BASIN	CIST	USE	CON	GROUND ELEV	TD	HOLE	CASE	DEPTH TO WATER LEVEL STK	RST	DIF	REST ELEV	CASING/OPENINGS CI	T	TOP	L	%	NPT	FINAL PUMPING TEST Q	DYN	S	H	PTRN	SMTD	DATE	Q/S	EST T M2/DAY
C0224	3711S137	162 /1	3EA	44	A	P	1676	56	1	2	45	38	12	1643	15	H	22	34	100		61			10	G	L	N 43 6		
C0179	3711S139	162 /1	3EA	44	U	P	1676	64	2	2	58	49	7	1627	15	H	35	49	100		5			16	G	C	U 42 5		
C0406	3712S122	149 /3	3EA	44	U	P	1565	147	1	2	35	19	16	1546	15	H	26	121	100		6			24	U	C	U 46 2		
C2580	3712S123	149 /3	3EA	44	U	P	1446	9	3	2					20	U		9			0					A	N 56 9		
C2581	3712S123	149 /3	3EA	44	U	P	1461	12	2	2					20	U		12			0					A	N 56 9		
C0218	3712S130	149 /3	3EA	44	U	P	1646	148	3	2	106	91	15	1555	15	R	56	92	100		24			27	G	U	N 43 4		
C0340	3712S130	149 /3	3EA	44	A	P	1676	131	3	2	131	26	105	1650	15	H	15	116	100		227			11	G	C	U 61 2		
C4339	3712S130	149 /3	3EA	44	A	P	1710	109	1	2	70	42	28	1676	15	D	15	94	100							C	U 77 4		
C3111	3712S131	162 /1	3EA	44	U	P	1645	127	3	2	122	23	99	1562	15	H	46	81	100	2	120	122	98.8	2	G	C	N 61 2	1.8	3
C3591	3712S131	162 /1	3EA	44	U	P	1676	171	4	2	143	30	113	1646	15	R	48	123	100	4	152	132	102.1	24	G	C	U 64 7	1.5	2
C4323	3712S131	162 /1	3EA	44		P	1645	136	2	2	105	43	62	1602	20	H	3	153	100							A	N 77 3		
C2759	3712S132	162 /1	3EA	44	A	P	1676	128	6	2	108	28	80	1648	15	H	23	103	100	3	227	55	27.4	10	G	C	U 58 2	8.3	12
C0233	3712S134	162 /1	3EA	44	U	P	1615	53	4	2	49	4	45	1611	15	H	6	49	100		273			14	G	U	N 43 6		
C0254	3712S134	162 /1	3EA	44	L	P	1676	46	2	2	37	7	30	1669	15	H	2	44	100		10			7	G	U	N 43 7		
C1072	3712S140	162 /1	3EA	44	U	P	1707	110	1	2	51	12	39	1645	15	R	58	52	100		7			9	G	C	N 53 8		
C0326	3712S128	149 /3	3EA	44	U	C	1631	43	5	2	50	3	47	1628	15	H	15	33	100		121			11	G	U	N 44 8		
C1037	3712S129	149 /3	3EA	44	U	P	1666	153	1	2	123	12	116	1566	15	H	12	141	100	1	45	17	5.2	7	G	C	N 61 1	8.7	13
C3059	3712S131	162 /1	3EA	44	L	P	1539	126	4	2	126	14	110	1525	15	H	5	121	100	2	152	70	56.0	21	G	C	U 6012	2.7	4
C2469	3712S134	162 /1	3EA	44	C	P	1565	61	5	2	22	7	45	1536	15	H	14	47	100	1	115	60	52.7	23	G	C	U 5512	2.2	3
C0243	3712S136	162 /1	3EA	44	A	P	1646	65	3	2	49	16	33	1630	15	H	13	72	100		11			10	G	C	U 45 5		
C2737	3712S136	162 /1	3EA	44	A	P	1666	76	2	2	73	42	31	1609	15	P	76	76		4	129	51	6.5	5	G	C	N 5712	15.2	23
C0265	3713S139	162 /1	3EA	44	U	P	1615	62	2	2	45	35	10	1561		U				3	62	56	20.7	9	G	U	N 33 8	2.0	4
C3730	3714S124	149 /3	3EA	44	U	P	1570	158	5	4	156				20	H	4	154	100	1	217		21.0	18	G	C	U 71 3	10.3	15
C3066	3714S125	149 /3	3EA	44	U	P	1524	58	2	2	53	36	17	1488	15	H	32	26	100	2	22	55	19.0	4	G	C	U 6011	1.2	2
C0268	3714S125	149 /3	3EA	44	I	C	1798	91	4	2	72	14	58	1764	15	H	28	63	100		14			15	G	U	U 43 9		
C0292	3714S126	149 /3	3EA	44	I	C	1646	61	4	2	55	15	40	1631	15	H	23	40	100		113			10	G	U	U 4312		
C0906	3714S127	149 /3	3EA	44	A	D	1615	95	1	2	81	37	44	1578	15	H	30	65	100		91			10	G	C	N 49 3		
C1515	3714S129	149 /3	3EA	44	A	D	1753	111	3	2	85	15	70	1738	15	H	14	97	100		85			24	G	U	N 5913		
C4308	3714S129	149 /3	3EA	44	A	P	1580	153	2	2	113	32	81	1546	20	U	7	146	100	2	136	127	95.0	24	G	C	N 77 2	1.4	2
C2096	3714S130	149 /3	3EA	44	U	P	1799	94	1	2	91	27	64	1772	15	H	38	56	100		101	87	60.0	24	G	C	U 5211	1.7	3
C3099	3714S130	149 /3	3EA	44	U	P	1539	79	2	2	75	4	71	1535	25	H	5	74	100	3	338			24	U	C	U 6111		
C3152	3714S130	149 /3	3EA	44	U	D	1207	91	1	2	18	6	12	1201	15	H	16	75	100	1	345	18	11.9	7	G	C	U 6112	28.0	43
C2755	3714S131	162 /1	3EA	44	L	P	1636	122	3	2	91	24	67	1652	15	P	5	117	100	1	28	118	94.2	23	2 G	C	N 5712	0.3	0
C4291	3714S131	162 /1	3EA	44	L	P	1560	96	2	2	38	2	36	1558	20	C	6	88	100	2	300	85	82.9	24	7 G	C	N 7612	3.6	5
C0294	3714S132	162 /1	3EA	44	U	P	1585	91	2	2	87	11	76	1574	15	H	8	83	100		91			9	G	U	U 4311		
C2628	3714S136	162 /1	3EA	44	L	P	1585	72	1	2	49	34	15	1551	15	H	14	58	100	1	72	45	11.0	8	G	C	U 58 9	6.5	10
C0577	3715S131	162 /1	3EA	44	U	G	1676	162	2	2	93	12	81	1664	15	H	20	142	100		73			49	G	C	U 47 8		
C0661	3715S131	162 /1	3EA	44	P	C	1522	154	1	2	98	13	85	1507	15	H	10	144	100		49			38	G	C	U 46 4		
C0424	3715S132	162 /1	3EA	44	O	G	1676	122	7	2	117	8	109	1668	15	H	30	92	100		242			44	G	C	U 4512		
C1061	3715S141	162 /1	3EC	44	L	P	1581	122	0	2					15	U		122			0				U	A	N 53 5		
C0323	3715S145	162 /1	3EC	44	L	P	1766	155	2	2	70	41	29	1725	15	U		155			2			8	G	U	U 44 4		
*C3275	3716S129	149 /4	3EA	44	U	P	1707	62	1	2	62	20	42	1687	15	P	3	59	100	2	113			2	G	C	N 64 1		
*C0598	3716S130	149 /4	3EA	44	U	G	1676	183	1	2	92	8	84	1668	15	H	8	175	100		23			26	G	C	U 4710		
*C4111	3716S130	149 /4	3EA	44	P	C	1640	131	3	2	38	32	6	1608	15	H	6	125	100	1	91	111	79.0		G	C	M 75 4	1.2	2
*C0044	3716S131	162 /2	3EA	44	U	G	1890	99	2	2					15	H	22	77	100		75			34	G	C	U 39 1		

BEST AVAILABLE DOCUMENT

(5) Table 1 (cont'd)

B/H REF NUM	LONG/LAT	MAP REF	BASIN	CISTEN	USWN	GRND ELEV	TD	HOR	RCK	DEPTH TO WATER LEVEL SIK	RST	DIF	REST ELEV	CASING/OPENINGS DI	T	TOP	L	%	NPT	FINAL PUMPING TEST Q	DYN	S	H	RT	PTA	STN	DATE	Q/S	CST M3/DA
*C0145	3716S131	162 /2	3EA	44	P	P	1920	66	1	2	63	1	62	1919	15	H	14	52	100		175			43		G	C	U	4111	
*C0374	3716S121	162 /2	3EA	44	P	G	1121	168	1	2	37	4	33	1117	20	H	25	143	100	7	29			18		G	C	U	45 9	
*C0433	3716S131	162 /2	3EA	44	P	G	1622	122	4	2	82	22	60	1600	15	H	31	91	100		152			55		G	C	U	4510	
*C0772	3716S140	162 /2	3EC	44	U	P	1844	61	1	2	16	6	10	1836	15	H	19	42	100		91			4		U	U	N	46 9	
*C0352	3716S142	162 /2	3EC	44	A	P	1652	70	1	2	56	9	49	1603	15	H	9	61	100		68			12		G	C	U	45 6	
*C2066	3716S143	162 /2	3EC	44	U	P	1701	70	1	2	27	26	1	1675	15	H	30	40	100	1	49	70	44.0	10		G	C	U	5311	1.1	2
*C3760	3717S117	149 /4	3EA	44	P	G	1492	114	1	4	61	15	46	1477	15	H	32	82	100	1	210	74	58.8	12	1	G	C	M	71 6	3.6	5
*C0242	3717S143	162 /2	3EC	44	L	P	1981	73	2	2	55	10	45	1971	15	H	7	66	100		2			10		G	U	N	4311		
*C0236	3717S146	162 /4	3EC	44	U	P	1554	91	2	2	35	22	13	1552		U					3			14		G	U	N	4310		
*C0509	3717S146	162 /4	3EC	44	U	P	1643	82	1	2	35	21		1612	15	H	16	66	100		188			19		G	C	U	47 2		
*C0436	3718S116	149 /4	3EA	44	P	G	1520	122	1	2	23	7	16	1513	15	H	9	113	100		175			31		G	C	U	46 3		
*C1667	3719S147	162 /4	3EC	44	P	R	762	63	0	2					15	H	32	31	100		71			24		U	C	U	5111		
*C0401	3721S117	149 /4	3EA	44	P	G	1530	34	1	2	29	0		1530	15	H	13	21	100		284					G	C	U	46 1		
*C3775	3721S117	149 /4	3EA	44	A	P	1560	166	3	1	143	5	138	1555	15	H	26	142	100	2	91	151	145.0	24	4	G	C	M	71 4	0.6	1
*C3957	3721S120	149 /4	3EA	44	U	R	1370	167	1	2	128	69	59	1331	15	U				1	5	160	91.1	1	7	G	C	U	7311	0.1	0
*C1664	3722S119	149 /4	3EA	44	O	G	1615	98	1	1	55	26	29	1589	15	H	9	89	100	1	63			9		G	U	U	5211		
*C3642	3722S121	149 /4	3EA	44	A	P	440	70	0	5					20	D	15	55	100	1	143		28.6	24	7	G	C	U	72 6	5.0	8
*C2260	3722S127	149 /4	3EB	44	P	G	1311	109	2	2	50	10	30	1301	15	H	12	97	100	1	0	73	63.1	12		G	U	U	54 9		
*C2267	3722S133	162 /2	3EB	44	P	G	1470	173	1	2	57	7	50	1463	15	H	10	63	38	1	137	61	54.3	12		G	C	U	5410	2.5	4
*C3755	3722S134	162 /2	3EB	44	U	P	1301	107	3	1	47	26	11	1265	15	H	19	88	100	1	13			12		G	C	U	71 4		
*C3967	3726S128	149 /4	3EB	44	U	R	1230	182	1	2	39	22	17	1206	15	U	10	172	100	2	63	152	130.2	24	7	G	C	U	74 1	0.5	1
*C3454	3726S131	162 /2	3EB	44	U	P	1234	91	1	2	43	29	14	1205	15	U	21	70	100	1	55	46	56.9	10	3	G	C	M	57 8	0.0	1
*C2655	3726S137	149 /4	3EB	44	L	P	1646	92	1	2	76	59	17	1587	15	H	29	11	84	1	60	74	20.0	12		G	C	U	59 1	3.0	5
~~*C2[illegible]~~	~~3726S140~~	~~149 /4~~	~~3EB~~	~~44~~	~~L~~	~~G~~	~~1134~~	~~107~~	~~3~~	~~2~~	~~103~~	~~8~~	~~100~~	~~1131~~	~~20~~	~~H~~	~~107~~	~~0~~		~~3~~	~~303~~	~~6~~	~~1.5~~	~~10~~	~~1~~	~~G~~	~~U~~	~~U~~	~~55 2~~	~~202.0~~	~~300~~
*C1516	3726S132	162 /2	3EB	44	P	G	1230	152	1	2	81	54	27	1226	15	H	25	127	100		20			41		G	C	U	51 8		
~~*C2476~~	~~3726S132~~	~~162 /2~~	~~3EB~~	~~44~~	~~L~~	~~G~~	~~1231~~	~~107~~	~~2~~	~~2~~	~~101~~	~~7~~	~~94~~	~~1225~~		~~G~~	~~107~~			~~1~~	~~1137~~	~~10~~	~~7.0~~	~~56~~		~~G~~	~~C~~	~~U~~	~~5[illegible]~~	~~1~~	~~142.0~~	~~210~~
*C2453	3730S136	162 /4	3EC	44	P	G	1217	61	0	2																	A	U	5211			
*C3453	3732S129	150 /3	3EC	44	U	P	1305	56	3	2	62	17	65	1241	15	D	16	71	100	1	136	86	69.1	19		G	C	U	67 7	1.0	3
*C2669	3732S135	163 /1	3EB	44	L	P	1570	108	1	2	60	58	2	1652	15	H	16	92	100	1	9	87	27.0	3		G	C	U	53 9	0.3	0
*C2427	3733S124	150 /3	3EB	44	P	G	1262	93	1	2	87	76	11	1186	15			93		1	1			10		U	U	N	55 9		
*C2451	3733S140	163 /3	3EC	44	P	G	1214	70	2	2	42	6	36	1213	15	H	14	64	100	1	109	62	56.3	12		G	C	U	5510	1.9	3
*C1560	3734S144	163 /1	3EC	44	U	P	1463	94	1	2	45	27	18	1436	15	H	27	57	100		63			25		G	C	U	51 9		
*C2269	3735S131	163 /1	3EB	44	P	G	1155	104	1	2	55	8	47	1150	15	H	20	114	100	3	1	90	81.7	9		G	C	U	5411	0.0	0
*C2426	3735S136	163 /1	3EC	44	P	G	1280	122	2	2	130	49	81	1231	15	H	38	84	100	1	24	107	57.9	12		G	C	U	55 6	0.4	1
*C0406	3735S147	163 /3	3EC	44	P	P	1158	123	2	2	91	13	78	1145	15	H	12	111	100		51			38		G	C	U	4611		
*C4105	3736S140	163 /1	3EC	44	O	P	1200	91	0	2																	A	U				
*C0437	3736S146	163 /3	3EC	44	P	R	1230	123	2	2	115	15	100	1205	15	H	6	117	100		120			99		G	U	U	46 4		
*C0440	3736S146	163 /3	3EC	44	P	G	1128	122	2	2	109	18	91	1110	15	H	6	117	100	1	106			6		G	C	U	46 8		
*C4006	3736S146	163 /3	3EC	44	A	P	1066	124	1	5	36	39	7	1027		H	0	124	100	4	13	114	84.5	24	5	G	A	M	74 4	0.2	0
*C4016	3736S146	163 /3	3EC	44	A	P	1066	92	1	2	4	3	1	1062	20	D	10	82	100	2	76	71	68.0	24	6	G	C	M	74 5	1.1	2
*C0421	3740S145	163 /3	3EC	44	P	R	1067	124	2	2	57	48		1019	15	H	57	67	100		273			43		G	C	M	46 7		
*C1576	3740S147	163 /3	3ED	44	U	C	1158	70	1	2	43	21	21	1137	15	H	11	66	100		117			24		G	C	U	5111		
*C1649	3742S150	163 /3	3EC	44	U		1120	76	0	2								76		0							A	N	5210		
*C1650	3742S150	163 /3	3EC	44	U	P	1210	61	0	2																	A		5211		
*C1945	3742S150	163 /3	3EE	44	U	G	1402	125	1	2	119	61	59	1341	15	H	6	119	100	1	7	70	9.0	5		G	C	M	53 3	0.8	1

BEST AVAILABLE DOCUMENT

Table 1(cont'd)

B/H REF NUM	LONG/LAT	MAP REF	BASIN	DIST	USE	CON	GRND ELEV	TD	HOR	CON	DEPTH TO WATER LEVEL STK	RST	DIF	REST ELEV	CASING/OPENINGS DI	T	TOP	L	W	NP	FINAL PUMPING TEST Q	DYN	S	H	R	POT	STA	MON	DATE	Q/S	EST T M2/DA
*C0454	3745S147	162 /3	3EC	44	P	D	1036	54	3	2	14	16	68	1720	15	P	12	71	100		85			46		G	C	N	46 9		
*C1054	3745S148	162 /3	3FD	43	U	G	1047	53	2	2	61	11	77	1049	15	H	16	52	100	1	12	61	43.0	24		G	U	N	5210	0.3	0
*C0473	3745S147	163 /4	3EC	44	U	P	1032	60	1	2	14	8	6	1714	20	H	12	49	100		109			12		G	C	N	46 9		
*C0474	3745S147	163 /4	3FD	44	P	P	919	46	3	2	71	33	38	875	15	H	6	35	100		67			18		G	C	N	4610		
C0611	3645S147	161 /3	3F	73	P	R	1763	130	1	1	81	16	65	1700	10	P	19	111	100		74			38		G	U	U	49 1		
C0451	3645S20C	172 /1	3F	73	U	P	1657	122	2	2	73	15	58	1584	15	U	12	110	100	2	54	18	2.7	24		G	C	N	67 6	20.0	37
C0185	3645S20C	172 /1	3F	73	P	C	1600	120	0	2					15	H		120			0			0	P	U	A	N	76 1		
C0120	3645S152	161 /3	3F	73	L	P	1740	93	1	2	37	5	32	1641	15	H	14	55	100		25			22		G	C	U	41 5		
C3747	3645S152	161 /4	3F	44	U	P	1550	86	1	2	11	6	5	1539	15	H	67	24	100	1	151	80	74.0	24		G	C		7012	2.0	3
C3237	3645S206	172 /2	3F	73	L	P	1570	133	2	2	137	62	75	1768	10	P		133		2	83	131	69.2	6		G	C	U	71 6	1.2	2
C3745	3645S205	172 /2	3F	73	L	P	1620	137	2	2	12	6	6	1622	15	H	33	104	100	1	82	130	124.0	24		G	C	U	71 1	0.7	1
C3870	3647S146	161 /4	3F	73	L	C	1524	100	0	2					H		0	103	100	0	0			0		U	S	N	72 5		
C3743	3647S205	172 /2	3F	73	U	G	1540	105	1	2	24	14	10	1526	15	U	47	108	100	3	65	148	134.0	24		G	C	U	70 8	0.5	1
C0115	3648S150	161 /4	3F	73	L	P	1700	56	2	2	50	24	26	1653	15	H	18	38	100		60			8		G	C	U	42 2		
C2587	3648S151	161 /4	3F	73	P	P	1707	103	4	2	177	23	154	1534	15	H	15	165	100	6	49	167	144.2	24		G	C	U	5010	0.3	1
C0120	3648S157	161 /4	3F	73	U	P	1762	61	1	2	30	24	6	1698	15	P	9	52	100		75			41		G	C	U	41 4		
C0567	3648S157	161 /4	3F	73	U	G	1722	62	1	2	56	24	32	1698	15	H	12	50	100		151			24		G	C	U	47 9		
C3744	3648S203	172 /2	3F	73	U	P	1600	100	1	2	85	72	13	1756		U		108			4			3		G	C	U	7011		
C3742	3648S213	172 /2	3F	73	U	P	1524	122	2	2	58	21	37	1573	15	H	26	96	100	2	8	116	97.2	5		G	C	U	66 7	0.1	0
C3742	3648S214	172 /2	3F	73	U	P	1524	90	3	2	36	28	8	1496	15	H	47	43	100	2	122	84	55.5	24		G	C	U	7012	2.2	3
C1427	3649S151	161 /4	3F	73	P	G	1554	137	2	2	101	24	77	1530	15	H	15	123	100		44			64		G	C	N	51 6		
C0928	3649S206	172 /2	3F	73	P	C	1524	120	1	2	89	21	68	1503	15	H	14	108	100		49			97		G	C	N	49 5		
C0116	3649S216	172 /4	3F	73	U	P	1524	90	2	2	41	24	17	1500		U					69	46	22.0	30		G	C	U	57 4	3.1	5
C3746	3650S201	172 /2	3F	73	U	P	1524	65	2	2	12	6	6	1515	20	H	4	61	100	1	226	58	52.0	24		G	C	U	71 1	4.3	7
C2992	3650S217	172 /4	3F	73	U	G	1524	107	1	2	30	26	4	1498	15	H	13	154	100	3	23	61	35.0	22		G	U	U	5911	0.7	1
C3741	3650S219	172 /4	3F	73	U	P	1524	108	3	2	36	30	6	1494	20	H	43	65	100	2	49	102	72.0	9		G	C	U	7010	0.7	1
C1537	3652S153	161 /4	3F	73	P	P	1554	114	1	1	23	16	7	1539	15	H	9	105	100		175			24		G	C	N	51 2		
C2532	3652S217	172 /4	3F	73	U	P	1524	102	3	2	101	45	56	1479		H	31	91	100	4	30	114	68.8	14		G	U	U	6512	0.4	1
C3685	3652S219	172 /4	3F	74	U	P	1524	100	1	5	30	25	5	1499	15	P	37	72	100	1	114	99	74.3	24	16	G	C	N	72 3	1.5	2
C4250	3654S206	172 /2	3F	73	P	P	1524	179	0	2																	A	N	76 8		
C3666	3654S218	172 /4	3F	73	A	P	1524	92	3	2	85				15	H	38	54	100	2	64		49.0	36		G	C	U	70 7	1.3	2
C4047	3655S150	161 /4	3F	73	P	G	1730	132	1	2	120	9	111	1721	15	H	26	106	100	1	8	113	103.5	24	6	P	C	U	74 5	0.1	0
C3455	3655S157	161 /4	3F	73	P	G	1524	157	1	2	49	38	11	1486	15	P	26	141	100	3	25	59	21.3	9	3	G	C	U	67 9	1.2	2
C0568	3655S158	161 /4	3F	10	P	G	1565	137	1	1	120	30	90	1535	15	H	25	112	100		15			38		G	C	N	4911		
C4250	3657S151	161 /4	3F	73	L	P	1524	150	2	2	106	11	95	1513	20	H	39	111	100	1	156	139	127.5	24	58	G	C	N	76 4	1.2	2
C1534	3657S219	172 /4	3F	73	P	P	1524	63	1	2	39	21	17	1503	15	H	42	21	100		242			26		G	C	N	51 9		
C3587	3700S151	162 /3	3F	73	L	A	1524	113	3	2	0				H		0	113	100		0						A	N	69 6		
C1641	3700S153	162 /3	3F	73	L	P	1646	122	1	2	24	11	13	1635	15	U	14	108	100		118			24		G	C	N	51 1		
C4090	3700S200	162 /3	3F	73	P	G	1320	153	1	2		30		1290	15	H	13	170	100	1	42	43	13.4	24	20	G	C	N	7412	3.1	5
C4093	3700S200	162 /3	3F	73	P	G	1487	159	1	2	106	24	82	1473	15	H	12	146	100	1	67	65	40.9	24	4	G	C	N	75 3	1.6	2
C4165	3700S200	162 /3	3F	73	P	C	1400	145	1	2	111	82	29	1318	15	H	113	47	100	2	38	150	68.0	24	27	P	C	U	76 4	0.6	1
C4162	3700S200	162 /3	3F	73	P	G	1400	168	1	6	97	70	27	1330	15	U	18	150	100	1	108	108	34.2	24	26	G	C	U	76 4	2.8	4
C4158	3700S200	162 /3	3F	73	L	P	1400	152	1	1	137	9	128	1391	15	U	24	126	100	2	26	117	108.0	24	7	G	C	U	76 5	0.2	0
C3562	3701S152	162 /3	3F	73	L	A	1524	58	0	2	0				H		0	96	100		0						A	N	69 5		
C1290	3701S217	173 /3	3F	73	L	L	1250	96	1	2	39	37	2	1213	15	U	62	34	100		153			24		G	C	N	51 1		

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Table 1 (Contd)

B/H REF NUM	LONG/LAT	MAP REF	BASIN	DIST	USE	OWN	GRND ELEV	TD	HOR	RCK	DEPTH TO WATER LEVEL STK	RST	DIF	REST ELEV	CASING/OPENINGS DI	F	TOP	L	%	NPT	FINAL PUMPING TEST Q	DYN	S	H	R	PDT	STA	MON	DATE	Q/S	EST T M2/DA
C2034	3712S145	162 /1	3F	44	U	C	1565	55	1	2	32	26	6	1559	20	H	45	50	100	2	29	68	62.0	26		G	C	U	5310	0.5	1
C0246	3712S146	162 /3	3F	44	U	P	1707	65	1	2	59	54	5	1653	15	R	57	8	100		5					G	U	N	3811		
C2714	3712S146	162 /3	3F	44	U	P	1707	91	1	2	57	52	5	1655	15	R	73	18	100	2	680	67	14.6	4		G	C	N	57 9	46.6	79
C0010	3712S149	162 /3	3F	44	U	P	1768	60	0	2						U										U	U	U	35 2		
C0052	3712S151	162 /3	3F	44	U	P	1768	68	1	2	55	37	18	1731	15	R	13	55	100		143			31		G	C	U	39 7		
C2150	3712S152	162 /3	3F	44	U	P	1707	76	1	2	55	41	14	1666	15	H	44	32	100	1	75	73	32.0	18		G	C	U	54 2	2.3	4
C3128	3712S154	162 /3	3F	44	A	P	1524	144	1	2	76	69	7	1455	15	U		144			3					G	U	U	61 6		
C0003	3712S155	162 /3	3F	44	U	P	1524	152	2	2	61	21	40	1503	15	H	51	101	100		173			8		G	C	U	47 9		
C0013	3713S145	162 /1	3F	44	U	P	1676	74	1	2	52	40	12	1636	15	H	43	36	100	2	2	89	48.8	9		G	C	U	38 7	0.0	0
C0713	3713S145	162 /1	3F	44	U	P	1676	117	1	2	107	76	31	1600		H	35	82	100		11					G	A	N	47 5		
C1100	3713S145	162 /1	3F	44	A	P	1526	101	1	2	77	71	6	1455	15	P	101				45			72		G	C	N	50 6		
C0324	3713S146	162 /3	3F	44	U	P	1768	98	1	2	88	64	24	1704	15	H	7	83	100		170			11		G	U	N	44 1		
C2716	3713S146	162 /3	3F	44	U	P	1768	107	1	2	45	28	17	1740	15	P	48	59	100	4	110	103	75.2	9		U	C	U	5710	1.5	2
C2836	3713S147	162 /3	3F	44	U	P	1524	212	2	2	153	22	131	1502	20	H	22	190	100	4	60	118	96.0	98		G	C	U	5810	0.6	1
C2963	3713S147	162 /3	3F	44	U	P	1676	92	1	2	70	61	9	1615	15	H	73	19	100		0						A	N	60 1		
C0006	3713S148	162 /3	3F	44	U	P	1768	152	1	2	106	30	76	1738		H		152			30			19		G	C	U	34 6		
C0007	3713S148	162 /3	3F	44	U	P	1768	72	0	2						U										U	U				
C0004	3713S149	162 /3	3F	44	U	P	1768	61	0	2						U										U	U	U	3410		
C2624	3713S151	162 /3	3F	44	U	P	1524	116	3	2	116	60	56	1464						I	5	113	53.0	7		G	C	U	58 8	0.1	0
C3315	3713S152	162 /3	3F	44	U	P	1524	114	1	1		53		1471		U		114		I	10	109	55.8	9		U	U	U	64 9	0.2	0
C1221	3713S224	173 /3	3F	73	P	U	1173	77	1	2	70	20	50	1153	15	H	30	47	100		164			24		G	U	U	5010		
C0008	3714S147	162 /3	3F	44	U	P	1768	69	1	2	40	31	9	1737	15	S	32	37	100		11			8		G	C	U	39 1		
C0009	3714S147	162 /3	3F	44	U	P	1768	76	0	2						U										U	U	U	35 2		
C0015	3714S149	162 /3	3F	44	U	P	1565	48	1	2					15	R	27	21	100		150					G	C	U	33 5		
C0452	3714S149	162 /3	3F	44	U	P	1616	132	2	2	41	41	0	1575	15	R	46	86	100		121			19		G	C	U	46 5		
C2849	3714S150	162 /3	3F	44	U	P	1707	122	0	2						H	0	122	100							U	U	U	5812		
C2452	3714S151	162 /3	3F	44	U	P	1524	107	2	2	85	70	15	1454	15	H	64	43	100	2	30	97	27.4	9		G	C	U	5513	1.1	2
C0007	3714S152	162 /3	3F	44	U	P	1524	146	0	2						U		146								U	C	N	46 5		
C0016	3714S154	162 /3	3F	44	U	P	1524	50	0	2						U										U	A	N	33 5		
C3132	3714S154	162 /3	3F	44	A	P	1524	168	2	2	137	41	96	1483	15	H	26	132	100	2	44	81	40.2	5		G	C			1.1	2
C3679	3714S154	162 /3	3F	73	P	U	1266	153	1	2	57	50	7	1236	15	P	18	135	100	3	17	94	44.0	16		G	C	N	70 6	0.4	1
C4132	3714S227	173 /3	3F	73	P	U	1213	121	2	2	96	23	73	1196	15	H	12	109	100	1	130	39	15.5	24	25	G	C	N	75 6	11.6	17
C2747	3715S150	162 /3	3F	44	P	U	1272	162	3	2	131	59	112	1213	15	H	55	127	100	1	17	179	119.6	9		G	C	N	58 1	0.1	0
C0008	3715S152	162 /3	3F	44	U	P	1565	153	1	2	58	73	25	1512		U		153			10			10		G	C	U	48 7		
C1376	3715S152	162 /3	3F	44	U	P	1597	122	2	2	67	59	8	1538	15	H	54	68	100		45			12		G	U	U	51 3		
C1311	3715S154	162 /3	3F	44	U	P	1630	137	2	2	39	36	3	1594	20	P	51	86	100		114			20		U	U	N	51 2		
C2669	3715S154	162 /3	3F	44	U	P	1646	71	1	2	71	43	28	1603													C	U	39 2		
C0017	3715S156	162 /3	3F	44	U	P	1737	39	1	2					20	H	23	15	100		126			10		G	C	U	33 6		
C0060	3715S156	162 /3	3F	43	U	P	1433	44	0	2	25	20	5	1413		U					151			10		G	C	U	33 8		
C3956	3715S203	173 /1	3F	73	L	L	1265	138	1	5	45	38	7	1248	15	U	54	84	100	1	68	124	86.4	24	7	G	C	U	7311	0.8	1
C3963	3715S205	173 /1	3F	73	L	L	1390	152	2	2	67	44	23	1346	15	U	67	85	100	1	76	74	30.1	24	8	G	C	U	74 1	2.5	4
*C2621	3716S147	162 /4	3F	44	U	P	1707	102	0	2					15	U		102			0						A	N	5611		
*C2622	3716S147	162 /4	3F	44	U	P	1646	60	0	2					15	U		60			0						A	N	5611		
*C2623	3716S147	162 /4	3F	44	U	P	1707	47	0	2						U		47			0						A	N	5612		
*C0006	3716S150	162 /4	3F	44	U	P	1524	62	1	2	35	30	5	1494	15	H	18	44	100		13			10		G	C	U	3411		

BEST AVAILABLE DOCUMENT

B/H REF NUM	LOCAG/LAT	MAP REF	CASIN	DISTRICT	USE	WATER	GOAD ELEV	TD	HOLE DIAM	SOURCE CODE	DEPTH TO WATER LEVEL SWL	RST	DIF	REST ELEV	CASING/OPENINGS DI	T	TOP	L	%	NO PUMP TEST	FINAL PUMPING TEST Q	DYN	S	H	RT	QUALITY	TEST METHOD	DATE	Q/S	EST T M2/DAY
*C2666	3716S154	162	74	3F	44	L	P	1372	65	1	2	55	43	12	1329					1	301					G	C	U	59 3		
*C1465	3716S156	162	74	3F	44	U	S	1753	133	2	2	119	42	107	1401	15	H	23	169	100	15			15		G	C	N	51 7		
*C0016	3716S157	162	74	3F	44	U	P	1505	47	1	2					15	R	31	16	100	50			10		G	C	U	33 7		
*C0120	3716S157	162	74	3F	44	U	P	1490	157	4	2	120	25	91	1364	15	H	41	117	100	68			69		G	C	U	4010		
*C0019	3716S158	162	74	3F	44	U	P	1463	66	1	2					15	R	24	40	100	68			9		G	C	U	33 8		
*C0143	3717S147	162	74	2F	44	U	P	975	137	2	1	107	46	61	929	15	H	8	125	100						U	C	U	41 4		
*C4127	3717S143	162	74	3F	44	A	P	1526	120	2	3	56	14	42	1412	15	H	12	100	100	1 113			24	3	G	C	U	75 4		
*C1132	3717S155	162	74	3F	44	U	P	1520	134	1	2	46	40	6	1349		R		134		2			12		G	C	U	50 4		
*C1923	3717S208	173	72	3F	73	I	P	1496	154	2	2	151	74	72	1415	15	H	64	100	100	1 64	145	66.0	24		G	C	U	63 3	0.0	1
*C1668	3718S147	162	74	3F	44	P	S	782	33	0	2					15			73		8						A	N	52 1		
*C1141	3718S156	162	74	3F	44	U	P	1727	82	1	2	52	41	11	1666	15	H	11	69	100	113			12		G	C	U	50 6		
*C1053	3718S158	162	74	3F	44	U	P	1565	52	1	2	43	34	9	1521	20	H	37	15	100	5			72		G	C	N	49 7		
C3338	3718S203	173	72	3F	72	P	R	1329	137	3	2	135	39	96	1486	15	R	55	82	100	1 98	132	93.0	40		G	C	U	65 1	1.1	2
*C2975	3718S208	173	72	3F	44	U	C	1505	55	1	2	86	86	1	1424	15	H	81	14	100	1 152			36		G	U	U	5911		
C3976	3718S209	173	72	2F	73	U	P	1440	145	1	2	43	25	21	1317	15	R	26	123	100	3 41	142	119.0	24	10	G	C	U	74 2	0.3	1
C3997	3718S209	173	72	3F	44	I	P	1240	214	5	1	25	19	16	1221	20	U	92	122	100	3 750	54	35.4	17	5	P	C	U	7312	21.2	32
*C2095	3718S210	173	72	3F	44	I	U	1311	108	2	2	102	84	18	1227	15	H	102	6	100	1 123	92	7.6		1	G	C	N	57 7	16.2	24
*C1694	3719S150	162	74	3F	44	U	P	1231	178	1	1	69	49	11	1192	25	H	67	111	100	15			99		G	U	N	52 5		
*C2128	3719S159	162	74	3F	44	U	P	1249	122	2	2	113	37	76	1228	15	H	36	86	100	2 151	55	18.2	6		G	C	U	54 1	8.3	12
C1071	3719S209	173	72	3F	73	I	D	1372	96	3	2	91	41	50	1331	20	H	17	79	100	3 53			4		G	C	N	50 4		
*C1034	3720S270	162	74	3F	44	U	P	1524	123	1	2	113	38	75	1449	15	R	51	72	100	1 152			8		G	C	N	61 4		
*C2182	3721S200	162	74	3F	44	U	P	1493	85	1	2	67	30	37	1456		R		85		1 1	85	54.9	5		U	U	U	54 4	0.0	0
*C2203	3721S200	162	74	3F	44	A	U	1524	120	2	2	76	40	31	1484	15	H	43	77	100	1 38	117	76.5	10		G	C	U	54 5	0.5	1
*C1061	3721S205	173	72	3F	72	P	R	1215	132	1	2	119	46	73	1173	15	U		132		1 205	69	22.9	36	1	G	C	N	65 2	8.0	13
*C0055	3722S200	162	74	3F	44	U	P	1524	122	1	2	37	32	5	1492	15	H	6	116	100	3			13		G	C	U	39 8		
C0062	3722S201	173	72	3F	44	U	P	1332	34	0	2						U									U	U	U	3012		
*C0375	3722S201	173	72	3F	44	U	G	1524	54	1	1	50	48	2	1476	15	P	55	4	100	5					U	U	N	44 8		
C0369	3722S201	173	72	3F	44	U	U	1524	62	1	1	50	46	4	1473	14	H	57	3	100	152			22		G	U	U	45 3		
*C2120	3722S201	173	72	3F	44	U	G	1372	73	2	4	63	52	11	1320	15	H	66	12	100	1 161			96		G	C	U	5312		
C2265	3722S201	173	72	3F	44	U	G	1372	76	1	1	67	55	12	1317						1 4			2		U	U	U	55 3		
C2270	3722S201	173	72	3F	44	U	G	1227	76	1	1	62	46	16	1181	15	R	73	3	100	1 136	64	18.2	17	1	U	U	U	55 4	7.5	11
*C2515	3722S197	162	74	3F	44	P	C	1243	55	0	2					15	U		55		0						A	N	56 6		
*C2516	3722S197	162	74	3F	44	P	P	1243	21	2	2	15	3	12	1262	20	U		21		0					U	U	N	56 7		
*C2639	3722S197	162	74	3F	44	P	A	1237	96	0	2								96		0					U	A	N	5610		
C2232	3723S201	173	72	3F	44	U	P	1224	90	1	1	81	41	40	1193	15	H	77	13	100	1 121	61	20.1	24		G	C	U	54 6	6.0	9
C3329	3723S207	173	72	3F	73	P	S	1323	107	3	2	88	34	54	1490	15	H	28	69	100	1 134	73	39.3	35		G	C	U	65 4	3.4	5
*C1183	3723S220	173	74	3F	72	P	G	1253	122	3	2	116	25	93	1230	15	H	12	110	100	60			30		G	C	U	56 9		
C3330	3724S200	173	72	3F	72	L	A	1219	109	1	2	44	33	11	1176	15	H	43	66	100	2 244	33	0.2	25		G	U	U	69 3	813.3	1200
*C0091	3726S202	173	72	2F	44	L	P	1234	91	1	4	39	33	6	1201	15	H	6	85	100	76			23		G	C	U	39 5		
C3561	3726S217	173	74	2F	73	L	A	1280	138	0	2	0					H	0	138	100	0						A	N	69 3		
C0003	3727S200	173	72	3F	73	U	P	1219	55	1	2	52	15	37	1204	15	H	13	82	100	1 271	84	69.0	27		G	C	U	38 7	3.9	6
*C1151	3727S225	173	74	3F	72	U	P	1059	103	3	2	92	34	58	1025	15	H	38	67	100	4 225			30		G	C	U	50 8		
C1557	3729S201	173	72	3F	44	U	O	1234	143	1	2	57	58		1176	15	H	47	101	100	34			24		G	C	N	5110		
*C2731	3730S159	162	74	3F	44	P	G	1636	75	4	2	66	2	64	1636	25	H	75			5 61	68	65.8	23		G	C	N	5712	0.9	1
*C2520	3730S159	162	74	3F	44	U	O	1234	122	2	2	117	54	63	1180	15	H	15	107	100	1 109	117	62.5	12		G	C	U	56 6	1.7	3

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Table 1 (cont'd)

B/H REF NUM	LONG/LAT	MAP REF	BASIN	CIST	USE	CWN	GROND ELEV	TD	HOR	RCK	DEPTH TO WATER LEVEL STK	RST	DIF	REST ELEV	CASING/OPENINGS DI	T	TOP	L	%	NP T	FINAL PUMPING TEST Q	DYN	S	H	R	PDT	SAN	DATE	Q/S	EST T M2/DAY
C1136	3730S224	173 /4	3F	73	L	G	1066	92	1	2	79	28	51	1038	15	H	35	56	100		160			13		S	C	U	50 7		
*C2454	3732S149	163 /3	3F	44	P	G	1219	110	2	2	105	14	91	1205	15	H	21	89	100	2	47	79	65.2	10		G	U	N	5511	0.7	1
*C4275	3732S157	163 /3	3F	44	U	U	1040	80	2	2	50	42	8	998	15	S	18	62	100	1	76	49	6.9	24	29	U	U	U	7611	11.0	17
C3535	3732S214	174 /1	3F	73	P	R	1066	65	0	2	0					H	0	69	100		0			0			A	N	6811		
C3537	3732S215	174 /1	3F	73	P	R	1067	77	0	2	0					H	0	77	100		0			0			A	N	6811		
C3552	3733S214	174 /1	3F	73	P	R	1067	65	0	2	0					H	0	69	100		0						A	N	66 2		
*C1635	3737S150	163 /3	3F	44	U	U	1219	915	0	2																	A	N	52 9		
*C1665	3737S150	163 /3	3F	44	U	P	1173	134	2	2	116	65	51	1108	15	H	26	108	100	2	160	104	39.3	24		G	U	N	5211	4.1	6
*C0545	3738S207	174 /1	3F	44	P	G	991	63	2	2	76	17	59	974	15	H	6	77	100		92			36		G	C	U	47 5		
C2139	3738S210	174 /1	3F	73	U	G	991	76	2	4	56	26	30	965	15	H	26	50	100	1	217			20		G	C	U	54 2		
*C0518	3739S158	163 /3	3F	44	U	G	990	132	3	2	110	165		825	15	U		132			52			64		G	C	U	47 3		
*C3461	3739S214	174 /1	3F	73	P	R	975	110	2	2	32	23	9	952	15	R	86	24	100		227			47		S	U	F	68 2		
*C1866	3740S154	163 /3	3F	44	U	P	1166	136	1	2	58	55	3	1131	15	H	6	130	100	2	7	104	49.0	6		G	U	N	5212	0.1	0
*C0328	3740S203	174 /1	3F	44	P	R	1006	76	1	2	48	42	6	964	15	H	13	63	100		4			24		G	C	U	47 5		
C2458	3740S207	174 /1	3F	44	A	O	1204	115	0	1					15	U		115			0						A	N	56 4		
*C0358	3742S153	163 /3	3F	44	P	R	1158	145	0	2		1		1157	15	U	0	136	93		0					U	A	N	46 2		
*C0414	3743S154	163 /3	3F	44	P	G	1189	135	2	2	84	47	37	1142	15	H	13	122	100					41		G	C	N	46 5		
*C0462	3743S154	163 /3	3F	44	P	R	1067	135	2	2	84	47	37	1020		U		135			80					G	C	N	46 6		
*C3977	3744S155	163 /3	3F	44	A	P	1040	152	2	3	94	41	53	999	15	U	20	132	100	1	23	150	100.4	1	42	G	C	U	74 2	0.2	0
C0497	3745S215	174 /1	3F	44	L	O	945	101	1	2	98	46	52	899	15	H	28	73	100		184			72		G	C	N	47 1		
C3813	3745S215	174 /3	3F	44	U	L	1036	91	1	2	18	16	0	1018	15	O	23	68	100	3	135	52	34.0	10	2	G	C	U	72 3	3.0	6
*C0560	3746S157	163 /4	3F	44	P	R	1067	67	1	2	12	9	3	1058	15	H	13	54	100		98			24		G	C	N	47 1		
C2208	3746S217	174 /4	3F	44	L	O	1066	37	2	1	37	3	34	1063	15	H	6	31	100	1	209	4	0.6	10		G	C	U	54 5	348.3	520
C2194	3746S217	174 /4	3F	44	I	P	1066	34	1	4	9	5	4	1061	15	H	6	28	100	2	215	7	2.0	10		G	C	U	54 5	107.5	160
C1875	3746S222	174 /4	3F	44	U	P	1082	45	1	1	24	24	0	1058	15	H	20	25	100	1	177	25	1.0	24		U	U	N	5211	177.0	260
C2915	3750S214	174 /2	3F	44	O	C	1066	56	2	2	24	10	24	996	15	H	12	44	100	1	164	26	16.4	24		G	U	U	59 7	10.0	15
C4231	3750S216	174 /4	3F	44	O	P	1066	65	2	2	76	17	61	1049	20	H	18	67	100	1	150	67	+9.8	24	49	G	C	N	78 6	3.0	5
C3748	3753S226	174 /4	3F	73	L	P	1272	77	3	2	29	31	8	1241	20	H	47	30	100	1	188	36	5.0	24		G	C		70 9	37.6	56
*C0496	3753S223	174 /4	3F	44	P	R	1797	101	1	1	59	8	51	1699	15	P	33	68	100		394			24		G	C	U	47 2		
*C2111	3754S146	163 /4	3F	43	P	G	1082	73	1	2	40	37	3	1045		U		73								U	A	N	5311		
C0493	3754S223	174 /4	3F	44	O	C	915	56	2	2	44	9	35	906	15	H	13	43	100		136			82		P	U	N	4610		
*C0492	3754S237	132 /2	3F	44	U	O	1219	28	0	2					20	U		28			0					U	A	N	4610		
C1876	3755S217	174 /4	3F	44	U	C	915	51	1	1	30	24	6	891	15	H	7	44	100	1	9	43	19.0	8		G	U	N	5212	0.5	1
*C0614	3755S222	174 /4	3F	44	P	R	915	152	2	2	75	28	48	887	15	H	21	131	100		7			42		G	C	U	4712		
C0645	3755S223	174 /4	3F	44	P	R	853	92	1	2	80	17	71	836	15	H	33	59	100		75			24		S	C	U	48 3		
C1241	3755S224	174 /4	3F	44	A	O	853	40	2	2	15	10	5	843	15	R	17	22	100		189			10		G	U	N	50 8		
*C1242	3756S224	174 /4	3F	44	A	O	914	28	1	1	10				15	H	23	5	100		91					G	U	N	50 9		
C1006	3757S225	174 /4	3F	44	A	O	867	140	1	2	61	61	0	806	15	H	9	135	100		38			5		P	C	N	4912		
*C2476	3800S244	163 /1	3F	44	P	R	1067	145	1	2	127	121	6	946	30	U		145		1	76		0.0			U	A	N	5510	HIGH	HIGH
C1583	3801S202	175 /1	3F	43	P	R	1372	91	1	2	45	38	7	1334	15	H	11	80	100		11			36		G	C	N	5111		
C0640	3801S219	175 /3	3F	44	P	R	762	102	2	1	96	5	91	757	15	H	26	76	100		202			28		G	C	U	45 1		
*C3547	3801S231	163 /1	3F	44	P	R	884	20	1	4	15	11	4	873	20	H	0	500	***	5	117	34	22.6	48		U	U	U	55 5	5.2	8
C0673	3802S229	175 /3	3F	44	U	P	878	95	3	2	95	11	84	867	20	H	10	85	100		75			99		G	C	U	3811		
*C2477	3802S243	163 /1	3F	44	P	R	1066	100	1	2	47	46	1	960		U	1	80	74		1			1		U	A	N	5511		
C1004	3803S227	175 /3	3F	44	A	O	838	173	1	2	85	76	9	762	15	H	30	143	100		38			6		G	C	N	4910		

BEST AVAILABLE DOCUMENT

Table 1 (cont'd)

B/H REF NUM	LONG/LAT	MAP REF	BASIN	DISTRICT	SUBDIVISION	GROUND ELEV	TD	HOLE DIR	RECORD	DEPTH TO WATER LEVEL SIK	PIT	DIF	REST ELEV	CASING/OPENINGS DIAM	TOP	L	%	NPT	FINAL PUMPING TEST Q	DYN	S	H	RT	PUMPING TEST ATM	DATE	Q/S	REST 82/06
C1336	3707S 57	135 /3	400	23	L P	1462	160	2	1	79	18	61	1476	15 H	5	103	100	1	55	123	105.0	24	G	8 N	5011	0.5	1
C3049	37035 57	135 /3	400	23	U P	1494	57	2	1	79	12	67	1502	15 H	6	81	100	1	151	46	24.0	24	G	C U	60 7	4.4	7
C0144	3707S 58	135 /3	400	21	U P	1518	53	1	1	46	33	11	1480	15 H	7	46	100		203			10	G	C U	41 8		
C1169	3707S100	135 /3	400	21	L P	1494	121	4	1	95	27	68	1467	20 H	91	30	100		250			12	G	C U	50 7		
C0310	3707S101	149 /1	400	21	U C	1494	124	2	1	113	14	99	1493	15 H	45	79	100		136			10	G	C N	44 8		
C1462	3707S101	149 /1	400	21	A C	1470	110	1	1	68	9	59	1461	20 H	35	75	100		417			30	G	C U	51 9		
C1465	3707S103	149 /1	400	21	A C	1478	219	1	1	215	49	166	1429	15 H	142	77	100		465			50	G	C N	51 7		
C1394	37065 56	135 /3	400	23	L S	1494	93	1	1	19	13	6	1481	15 R	35	58	100		57			24	G	U U	51 4		
C1471	37065 57	135 /3	400	22	A P	1504	78	1	1	70	40	30	1463	15 H	7	65	100		136			12	G	U U	50 5		
C1596	37065 55	135 /3	400	21	U P	1494	137	2	1	125	30	95	1464	15 H	6	131	100	2	74			9	G	C U	53 7		
C1762	37065102	149 /1	400	21	U P	1463	152	2	1	149	55	94	1408	15 H	138	14	100		182			18	U	U N	52 6		
C1410	37065103	149 /1	400	23	A P	1463	131	1	1	129	35	93	1427	20 H	7	124	100	4	38			5	G	U N	50 8		
C0640	37065 56	135 /3	400	23	L P	1494	46	1	1	32	16	15	1475	15 H	7	39	100		53			9	G	U N	49 4		
C1635	37065 57	135 /3	400	23	U P	1494	76	1	1	41	35	6	1459	15 H	10	66	100		45			12	G	C U	51 9		
C2171	37065 57	135 /3	400	23	U P	1494	64	1	1	32	30	2	1494	15 H	6	58	100	1	50			12	U	U U	54 2		
C4175	37065 58	135 /3	400	23	L P	1490	122	2	1	87	28	59	1462	15 H	73	49	100	3	182	49	21.0	24	7	G C N	7511	8.7	13
C1894	37065 55	135 /3	400	23	U P	1463	65	1	1	58				24 H	3	66	100	1	15					G U U	5212		
C0511	37065101	149 /1	400	21	P G	1478	112	2	1	46	40	6	1433	15 P	112			1	72			10		G C U	4310		
C1991	37065101	149 /1	400	21	I P	1478	107	3	1	99	31	68	1447	15 H	37	70	100	2	61			9		G C U	53 1		
C1210	37065 56	135 /3	400	23	U P	1494	181	1	1	68	64	4	1430	R		161			15			3		G C U	50 5		
C1153	37065 56	135 /3	400	23	L P	1494	65	1	1	62	29	33	1466	15 H	7	62	100		150			18		G C N	50 7		
C0724	37065102	149 /1	400	23	U P	1463	110	1	1	102	40	62	1423	15 H	5	105	100		164			12		G U N	4510		
C1120	37115 58	135 /3	400	23	U P	1463	40	3	1	34	16	18	1447	25 H	3	37	100		47			3		G C U	50 5		
C1228	37115102	149 /1	400	23	A P	1463	61	2	1	55	24	31	1434	15 H	36	25	100		98			17		G U N	5011		
C0495	37125 58	135 /3	400	21	A O	1433	27	2	1	23	13	10	1420	15 H	7	20	100		227			9		G C N	47 1		
C1115	37125 58	135 /3	400	24	U P	1437	40	3	1	26	14	10	1421	25 H	3	37	100		47			3		G C U	50 2		
C1900	37125 59	135 /3	400	21	U P	1433	60	0	1	53	21	32	1412	15	3	57	100	1	137			9		G U	53 1		
C0464	37135 58	135 /3	400	21	C P	1433	27	1	1	18	11	7	1432	15 H	13	14	100		227			20		G C N	47 1		
C2013	37135 59	135 /3	400	21	A P	1433	63	2	1	60	27	33	1406	15 H	3	60	100	1	36			9		G C U	53 3		
C1339	37135101	149 /1	400	23	A P	1463	113	2	1	107	54	53	1409	15 H	2	111	100		53			10		G A N	51 3		
C2472	37135101	149 /1	400	23	A P	1554	122	1	1	50	24	26	1530	15		122		2	1	116	92.0	3		U C U	56 1	0.0	0
C2529	37135101	149 /1	400	21	A O	1463	61	2	1	22	27	5	1436	15 P	61			1	24	55	28.3	4	4	G C N	56 5	0.8	1
C2762	37145 56	135 /3	400	23	U C	1430	73	1	2	8	6	2	1424	15 U		73		1	4	73	67.1	3	4	G U N	58 3	0.1	0
C0776	37145102	149 /1	400	21	A P	1455	105	2	2	85	24	61	1431	15 H	11	94	100		7			6		U U N	4512		
C0387	37155 58	135 /3	400	23	A C	1433	137	2	1	107	2	105	1421	15 P	51	86	100		52			24		G C U	46 1		
C2204	37155100	135 /4	400	23	A O	1439	183	0	2		46		1393	15 U		183		1	0			3		U C U	54 6		
C2748	37175 57	135 /4	400	23	O P	1532	131	2	1	119	2	117	1530	15 H	46	85	100	3	47	122	120.0	7	3	G C N	58 1	0.4	1
C3160	37175 58	135 /4	400	23	O P	1554	115	2	2	107	2	105	1552	15 H	12	103	100	2	17	92	89.6	45		G C U	6111	0.2	0
C1375	37215 54	135 /4	400	23	U P	1158	46	1	2	27	23	4	1135	15 H	15	31	100		45			5		G U U	51 3		
*C2635	37215101	149 /2	400	23	U P	1325	105	1	2	101	6	95	1319	15 H	6	97	100	1	67	67	61.0	9		G C U	5810	1.1	2
*C2168	37265108	149 /2	400	21	U P	1204	86	0	1					U										U A N	54 1		
*C2167	37265106	149 /2	400	21	U P	1158	28	0	1					U										U A N	5311		
*C2169	37265106	149 /2	400	21	U P	1158	38	1	1	37	24	13	1134	15 H	7	31	100		11			12		U U U	54 3		
C4316	37165 30	121 /4	403	22	U P	1615	77	2	2	39	14	25	1601	15 H	48	29	100	1	151	23	9.1	24	4			16.6	25
C4221	37165 35	135 /2	407	22	A P	450	61	2	1	50	26	24	424	20 H	49	12	100	2	184	54	28.1	24	5	G C U	76 5	6.5	10

42 42

(11)
Table 1 (cont'd)

B/H REF NUM	LONG/LAT	MAP REF	BASIN	DIST	USE	CWN	GRND ELEV	TD	HOLE	FOCK	DEPTH TO WATER LEVEL STK	RST	DIF	REST ELEV	CASING/OPENINGS DI	T	TOP	L	%	NPT	FINAL PUMPING TEST Q	DYN	S	H	R	DOT	STA	MTD	DATE	Q/S	EST T M2/DAY
C1262	3726S 13	121 /2	4DE	25	U	P	1745	122	C	2						U										U	A	N	5012		
*C4182	37295 55	135 /4	4DE	44	C	R	1133	200	2	2	111	40	71	1098	15	H	31	169	100	2	5	179	139.1	6	40	G	C	N	7510	0.0	0.0
*C1459	37225109	150 /1	4DE	44	U	P	1224	97	1	2	41	27	14	1207	15	H	13	44	100		35			24		G	C	N	51 6		
*C2257	3726S102	150 /1	4DE	44	U	U	1142	110	3	2	84	20	64	1120	15	H	6	104	100	1	65	104	83.5	24	4	G	U	N	55 4	0.8	1
*C2252	3726S 40	136 /1	4DC	41	P	R	1295	83	3	2	70	18	52	1277	10	H	12	71	100	1							A	N	55 3		
*C1973	3736S104	150 /1	4DE	44	U	P	1196	121	2	2	111	16	95	1173	15	H	15	106	100	1	47	108	92.0	22		G	C	U	53 5	0.5	1
*C3760	3736S105	150 /1	4DE	43	A	G	1204	198	2	2	61	28	33	1176	15	H	25	173	100	5	5	105	77.4	24	39	P	C	N	71 7	0.1	0
*C1732	3728S 42	136 /1	4DC	41	U	U	1143	45	1	2	29	28	1	1115	15	H	14	31	100		4			8		U	U	N	52 3		
*C1571	3736S 56	136 /3	4DE	44	U	G	1067	24	1	2	29	23	6	1044	15	H	19	15	100		76			55		G	C	N	5110		
*C0397	3736S105	150 /1	4DE	44	P	R	1402	155	0	2		53		1349	15	U		155			5			48		U	A	N	4512		
*C3760	3736S105	150 /1	4DE	43	A	G	1224	152	3	2	51	23	68	1211	15	U	15	137	100	2	25	142	119.2	24	19	P	C	N	71 8	0.2	0
C2195	3725S 25	122 /3	4BC	41	U	P	1472	93	1	1	90	79	11	1323	15	R	70	23	100	1	113	91	12.0	24		G	C	U	54 2	9.4	14
C3136	3725S 25	122 /3	4BC	41	U	C	1402	66	3	1	86	39	47	1363	15	H	49	37	100	1	38			24		G	C	U	61 5		
C2270	37395 20	122 /3	4EB	46	P	G	1341	156	2	1	145	61	84	1280	15	H	114	42	100	3	112	122	61.0	24	5	G	C	U	5410	1.8	3
C3139	3740S 11	122 /1	4BA	46	U	C	1372	91	3	1	91	47	44	1325	15	H	39	61	100	2	40			22		G	C	U	61 5		
C4233	3740S 14	122 /1	4BB	46	C	P	1646	154	1	1	109	66	43	1580	15	H	50	124	100	1	96	100	34.0	24	26	G	C	U	76 6	2.4	4
C4272	3740S 16	122 /3	4BB	46	U	U	1365	123	2	2	109	60	49	1305	15	H	50	73	100	1	61	94	33.5	24	3	G	U	U	7611	2.7	4
C4251	3740S 17	122 /3	4BB	46	U	P	1422	201	2	1	75	76		1356	15	H	29	172	100	1	51	140	63.6	18	33	G	C	N	7610	0.8	1
*C3587	3740S 42	136 /1	4BC	24	U	C	1143	121	2	3	105	75	30	1068	15	U	30	91	100	2	113	116	41.0	24	7	G	C	U	74 3	2.5	4
*C4261	3740S 43	136 /1	4BC	41	U	P	1142	158	2	2	98	34	64	1104	15	U	12	146	100	2	8	128	94.0	24	41	G	C	N	77 3	0.1	0
*C2041	3743S 56	136 /3	4BD	44	U	G	1067	122	2	2	117	76	41	991		R		122		1	3	117	41.0	8		G	C	U	5310	0.1	0
*C2030	37495 40	136 /1	4BC	41	P	G	1219	60	2	1	186	91	95	1128	15	H	37	43	100	4	34	184	93.3	24		S	A	N	53 8	0.4	1
*C2376	37495 42	136 /1	4BC	41	U	P	991	49	0	2											0						A	N	55 4		
*C1973	3748S109	150 /1	4BC	44	U	U	1268	172	1	2	21	18	3	1253	15	H	6	166	100		11			32		G	C	N	51 9		
*C1714	3749S 42	136 /2	4BC	41	U	P	1021	61	1	2	58	41	7	980	15	H	13	43	100		55					G	U	N	62 2		
*C1507	3749S102	150 /2	4BC	44	U	C	1226	111	1	2	44	38	6	1190	15	H	6	105	100		12			51		G	C	U	51 8		
*C2191	3746S109	150 /2	4BC	43	U	C	1211	122	2	2	109	55	49	1266	15	H	73	49	100	1	104	86	31.0	24		G	C	U	54 4	3.4	5
*C0128	3751S103	150 /2	4BC	43	U	P	1152	22	2	2	18	13	5	1139	15	H	12	10	100		15			1		G	C	U	41 3		
*C0127	3752S101	150 /2	4BC	43	U	P	914	25	0	2						R		25								U	A	N	41 2		
*C2196	3752S101	150 /2	4BC	43	U	P	1113	67	2	2	61	24	37	1089	15	H	12	55	100	1	13	26	2.0	24		G	C	U	54 5	6.5	10
*C0125	3755S111	150 /2	4BC	43	U	P	991	66	1	2	32	19	13	972	15	H	30	35	100		135			24		G	C	U	4011		
*C0096	3803S 56	137 /3	4BD	43	U	P	996	124	1	1		108		268	15	H	41	83	100		2					S	U	U	40 7		
*C0104	3803S 27	137 /3	4BD	41	U	P	914	91	1	2		8		906	23	H	12	79	100		14			20		P	C	U	40 8		
*C4223	3805S105	151 /1	4BD	43	A	P	1190	139	4	2	119	11	108	1142	20	O	13	100	85							G	A	N	7511		
C3137	3742S 2	136 /3	4B	46	U	C	1229	21	1	1	15	13	3	1215	20	H	6	15	100	1	2			22		G	C	U	61 5		
C3295	3742S 2	136 /3	4B	46	U	U	1326	21	1	1	40	9	11	1317	15	P	21			1	90			5		U	C	U	64 5		
*C0617	3804S 51	137 /3	4B	43	P	R	1126	138	2	2	130	37	93	989	15	H	38	95	100		22			12		G	C	U	4712		
*C0573	3805S 51	137 /3	4B	43	P	G	919	153	1	2	20	45		866	15	H	17	136	100		6			45		G	C	U	47 6		
*C3907	3810S110	151 /1	4B	43	U	P	823	92	1	2	19	5	14	818	20	P	85	6	85	2	58	45	47.3	24	7	G	C	U	73 3	1.4	2
*C3913	3810S110	151 /1	4B	43	P	C	823	42	0	2					15	H	0	42	100	0	0			0	0	U	A	N	73 2		
C0696	3811S 39	137 /1	4B	43	P	P	1097	166	1	2	76	67	9	1030	15	H	76	93	100					1		G	C	U	48 7		
*C3922	3813S 58	137 /3	4B	43	P	P	685	56	1	2	18	6	12	679			15	43	100	2	58	55	48.3	24	5	G	C	U	73 6	1.1	2
C3912	3818S 46	137 /4	4B	43	U	R	686	46	1	2	24	9	15	677		H	9	46	100	4	10	47	37.8	8	5	S	U	U	73 4	0.3	0
C0519	3820S 42	137 /2	4B	43	P	D	763	93	2	2	32	46	6	791	15	P	65	28	100		47			14		S	A	U	49 7		
*C3242	3826S148	164 /4	4B	43	P	G	762	40	1	2	17	5	12	757	15	H	14	26	100	1	211		0.0	24		P	C	U	63 1	HIGH	HIGH

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Table 1 (cont'd)

D/H REF NUM	LONG/LAT	MAP REF	BASIN	DISTRICT	SUBZONE	GROUND ELEV	TD	HOLE DIA	CASING DIA	DEPTH TO WATER LEVEL STK	RST	DIF	REST ELEV	CASINGS/OPENINGS DIA	TYP	TOP	L	%	NPT	FINAL PUMPING TEST Q	DYN	S	H	R	PTAN	DATE	Q/S	EST T M2/DA
*C0538	3826S149	164 /4	4G	43	P G	732	153	2	2	143	65	78	667	25	H	102	51	100		24			68		G C U	47 5		
*C0103	3932S 29	126 /3	4G	51	U P	243	146	1	3	146	129	16	114		U					8			24		S C U	49 8		
C3737	3935S230	166 /1	4G	31	O P		152	1	3	122	114	8		25	H	1	151	100	1	90	135	21.0	25		S U		4.3	6
*C3906	3928S 41	140 /1	4G	32	L R	125	76	1	3	53	36	17	89	15	H	0	76	100	1	120	39	3.1	2	5	G C U	73 1	38.7	53
C3841	3927S240	166 /1	4G	31	L L	132	174	0	3								174								U C U	69 2		
C2667	3949S 27	126 /3	4G	51	P R	180	55	2	2	52	43	9	117	20	U		55			23			2		L A N	57 6		
*C3550	3949S 26	126 /4	4G	51	X C	229	153	1	2	146	104	44	125	15	R	156	2	100		0					A N	6712		
C3552	3949S 29	126 /4	4G	51	X C	229	232	1	2	137	151		76		H	0	232	100		45					P U N	68 1		
*C3598	3950S 23	126 /4	4G	51	X C	229	232	1	2	149	137	11	92	15	R	190	42	100		68					P U N	68 1		
C4235	3952S 25	126 /4	4G	51	O C	213	120	1	3	109	101	8	112	15	S	107	13	100	1	65	102	1.4	24	59	G C U	76 5	46.4	79
C4242	3952S 35	126 /4	4G	51	I C	213	110	1	3	103	102	1	111	20		109	9	100							G A N	76 7		
C4207	4000S141	166 /1	4G	52	L P	274	42	2	3	34	7	27	267	20	U	42			3	5	33	25.5	24	7	G C U	76 4	0.2	0
C3463	4047S223	179 /4	4G	33	A P	25	46	1	3	24	22	2	3	13	O	20	26	100	1	28					G U N	6710		
*C1595	3740S106	150 /1	4H	44	U U	1264	82	1	2	64	30	34	1234	15	H	25	57	100		182			28		G C U	51 9		
*C1972	3742S122	150 /3	4H	44	L P	1176	52	1	2	64	62	2	1114		U		92		1	2	90	28.0	3		G A N	53 5	0.1	0
*C1208	3743S108	150 /1	4H	44	P C	1249	112	1	2	56	49	49	1200	15	H	16	97	100		65			24		G C N	51 8		
*C1596	3743S113	150 /1	4H	44	U U	1206	101	1	2	85	14	71	1190	5	H	5	96	100		5			1		G U U	5111		
*C1243	3742S123	150 /4	4H	44	A C	635	35	1	2	15	13	2	625	15	P	12	22	100		53			24		G U N	50 9		
*C1572	3745S116	150 /4	4H	44	U G	1155	91	0	2					15	U		91								U A N	51 9		
*C0438	3745S127	150 /4	4H	43	P C	1057	61	1	2	54	35	19	1062	15	H	14	47	100	1	159			52		G C M	45 7		
*C0095	3755S114	150 /2	4H	43	L P	1272	92	1	2	88	16	72	1356	15	H	13	79	100		82			69		G C U	40 6		
*C1238	3756S122	150 /4	4H	43	P C	1123	63	1	2	35	35	0	1093	15	H	20	43	100		189			19		G U M	52 4		
*C4059	3755S123	150 /4	4H	43	P R	1137	120	3	5	68	27	41	1110	15	O	6	114	100	1	4	112	85.0	1	6	G U U	74 9	0.0	0
*C4130	3756S123	150 /4	4H	43	P C	1152	94	4	2	50	40	10	1112	15	C	20	74	100	1	342	49	9.1	72	26	G C M	7510	37.6	56
*C4183	3756S123	150 /4	4H	43	P R	1120	110	3	5	57	41	56	1079	15	U	4	106	100	1	0	99	58.4	1	27	G A N	7512		
*C1543	3758S135	163 /2	4H	43	P R	1372	61	0	2					15	U		61								U A N	51 9		
*C1022	3759S122	150 /4	4H	43	P G	1152	134	1	2	53	43	10	1109	15			134			7			24		G A U	5112		
*C3326	3755S132	150 /4	4H	43	P R	1140	62	1	2	5	5	0	1135	25	U		62			4					U U N	65 2		
*C3326	3755S122	150 /4	4H	43	P R	1158	45	1	2	27				20	U		45			1					U A N	45 3		
*C4020	3756S122	150 /4	4H	43	P C	1095	152	1	2	20	4	16	1091	15	H	6	146	100	1	7	136	132.1	1	4	G C M	74 8	0.1	0
*C4259	3755S122	150 /4	4H	43		1260		0	2																			
*C3795	3755S123	150 /4	4H	43	P R	1009	60	0	2	43	44	4	964	13	P	36	24	100	2	76	50	6.0		43	G C U	76 8	12.7	19
*C2179	3801S125	151 /3	4H	43	U P	1091	56	2	2	55	5	50	1036	15	R	44	12	100	2	45	51	46.0	10		G C U	54 3	0.0	1
*C0425	3801S121	151 /3	4H	43	P C	1159	122	1	2	9	5	4	1154	15	H		122			6			24		U U			
*C0773	3801S157	164 /3	4H	43	O G	1737	77	2	2	18	15	3	1722	15	H	21	56	100		76			24		U U U	4510		
*C1452	3801S158	164 /3	4H	43	O G	1062	128	1	2	31	13	18	1069	15	R	30	58	100		67			28		G C N	51 6		
C1500	3801S201	175 /1	4H	42	P R	1197	97	1	2	11	8	3	1189		H		43			25			24		S U U	51 1		
*C3564	3802S142	164 /1	4H	43	P R	860	37	1	2	3	4		856	20	U	9	28	100	2	16	30	25.9	24	7	U C N	7211	0.6	1
*C1201	3802S157	164 /3	4H	43	L G	1128	110	2	2						H		110		0						U A N	51 2		
*C3563	3803S140	164 /1	4H	43	P R	860	82	1	2	6	4	2	856	15	O	37	45	100	2	45	70	65.9	24	14	G C N	7211	0.7	1
*C1521	3803S147	164 /3	4H	43	P R	1219	101	0	2		72		1147	15	U		101			3			24		G U N	51 6		
*C3196	3805S154	164 /3	4H	43	O G	914	73	2	2	49	1	48	913	15			75		3	58	31	30.2	24		G C N	62 7	3.2	5
*C1522	3807S157	164 /3	4H	43	P R	1067	43	0	2					15	U		43								U A N	51 8		
*C2260	3809S146	164 /3	4H	43	O G	914	172	3	1	49	49	0	865	15	H	19	153	100	1	34	166	118.6	24		G C N	54 9	0.3	0
C0134	3810S215	175 /1	4H	43	U P	762	84	1	2	51	51	0	711		R		84			2					U C U	4011		

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Table 1 (cont'd)

B/H REF NUM	LONG/LAT	MAP REF	BASIN	DISTRICT	USE	DOWN	GROUND ELEV	TD	HOLE	CASING	DEPTH TO WATER LEVEL STK	RST	DIF	REST ELEV	CASING/OPENINGS DI	T	TOP	L	A	NP T	FINAL PUMPING TEST Q	DYN	S	H	R	POT	STAN	DATE	Q/S	EST T M2/DAY
*C0464	3612S150	164 /3	4H	43	P	B	1057	83	2	2	53	35	18	1062	15	H	22	61	100		83			24		G	C	N	4610		
*C0452	3612S152	164 /3	4H	43	P	B	914	83	0	2					15	U		88		1	140		28.1	24		G	C	U	7210	4.0	7
*C0496	3620S155	164 /4	4H	42	P	G	762	131	2	2	88	12	76	750	15	H	8	123	100	3	18			48		S	C	N	62 4		
*C3165	3824S212	175 /2	4H	35	U	G	680	13	0	2					20			15			0						A	N	62 1		
C3643	3844S222	176 /3	4H	36	L	G	1224	98	2	3	85							95			30					U	U	U			
C3644	3845S222	176 /3	4H	36	L	G	1219	142	2	3	85							122			30					U	U	U			
C3968	3915S204	177 /1	4H	36	L	P	167	85	1	3	60	52	8	128	15	U	80	5	100	1	37	77	25.1	24	7	G	C	U	74 2	1.5	2
C3903	3923S225	177 /4	4H	36	L	P	183	170	1	3	150	140	10	43	20	H	33	137	100	1	34	163	23.4	24	7	P	C	U	73 4	1.5	2
C3770	3945S 8	126 /2	4J	51	P	A	223	183	1	3	146	138	8	91	15	P	166	17	100	2	64	163	25.0	24		S	C	N	7111	2.6	4
C3017	4006S105	155 /1	4J	51	I	P	61	195	0	3						U		195								U	A	U	56		
C3016	4009S102	155 /1	4J	51	I	P	91	219	4	3	168	219		-128	15	H	122	97	100							U	C	U	57		
C3015	4010S117	155 /3	4J	51	U	U	198	122	0	3						U		122								U	C	U	60		
C3110	4014S139	168 /1	4J	53	P	R	152	183	0	3		123		29	23	P	140	37	86	1	34					P	U	N	61 1		
C4205	4015S 30	127 /3	4J	53	U	P	152	120	0	3								12		0								N	76 3		
C4204	4015S 32	141 /1	4J	51	L	P	152	195	1	3	172	168	4	-16	15	U	79	116	100	4	60	189	20.9	24					3	2.9	4
C3065	4015S139	168 /1	4J	51	U	G	75	185	2	3	165	92	93	-16	12	H	126	59	100							U	C	U	69 8		
C3224	4015S140	168 /1	4J	36	U	P	564	123	0	3		86		478	20	P	122	1	100	1	38			2		P	U	N	62 8		
C3225	4015S140	168 /1	4J	36	U	P	76	123	0	3		83		-7	20	P	123				38			24		P	U	N	6210		
C3226	4015S140	168 /1	4J	36	U	P	76	79	0	3						U		79			0					U	A	N	6213		
C3227	4015S140	168 /1	4J	36	U	P	76	123	0	3		83		-7	16	P	120	3	100	1	49			5		P	A	N	6210		
C3228	4015S140	168 /1	4J	36	U	P	76	123	0	3		83		-7	16	P	122	1	100	1	54			12		P	A	N	6212		
C3033	4016S 22	127 /4	4J	51	U	G	152	127	1	3	111	111	0	41	15	H	124	13	100	1	38			12		P	C	U	60 5		
C4163	4022S 12	127 /2	4J	51	L	A	152	167	1	2	136	124	12	28	15	S	160	7	100	1				24		P	U	U	77 4		
C4159	4022S 54	141 /4	4J	51	I	C	116	152	1	3	104	101	3	13	15	P	109	43	100	1	93	110	8.5	17		P	C	U	75 9	10.9	16
C4160	4022S 54	141 /4	4J	51	I	C	114	116	1	3	104	101	3	13	20	P	106	10	100	1	93	107	6.4	24	2	P	C	U	75 9	14.5	22
C4175	4025S 46	141 /4	4J	51	I	P	114	116	1	3	104	101	3	13	15	S	107	9	100	1	58	107	6.2	24	28	P	C	U	7510	9.4	14
C3408	4036S 28	126 /3	4J	51	A	P	137	152	1	3	148	143	5	-6	15	P	138	14	100	1	42					G	U	N	66 5		
C3065	4037S 6	126 /1	4J	51	P	G	137	128	1	3		115		22	12	H	113	15	100	1	37			12		G	C	U	6711		
C3410	4038S 30	126 /3	4J	51	X	P	122	140	1	3	138	133	5	-11	12	R	134	6	100					48			A	N	64 5		
C3009	4023S109	179 /2	4K	32	U	G	23	58	1	3		45		-22	12	H	44	14	100	1	30			8		P	C	U	50 9		
C3595	4041S151	169 /3	4K	51	X	G	200	143	1	2	41					H	0	43	30							P	A	N	66 9		
C3593	4042S218	160 /3	4K	33	X	G	200	112	1	2	8				13	R	9	3	2		34					G	U	N	68 3		
C3596	4045S155	169 /3	4K	51	X	G	200	100	1	2		5		195		H	0	3	7		34					G	U	N	68 7		
C3594	4047S204	160 /2	4K	33	A	G	200	26	1	2		18		182		H	0	26	100								A	N	68 5		
C3038	4048S110	155 /2	4K	51	U	G	76	107	1	3		70		6	10	H	92	15	100	1	27			24		S	C	U	60 7		
C3223	4011S114	160 /2	4K	33	L	P	30	47	0	3					15	H	9	33	100							U	A	N	63 5		
C3070	4100S130	157 /3	4K	51	U	G	41	98	1	3		25		16	12	H	82	16	100	1	37			4		S	C	U	60 9		
C3626	4105S109	157 /1	4K	51	P	R	91	73	1	3	60	60	0	31	12	R	55	18	100	3	12			40		S	C	H	69 9		
C3236	4105S152	170 /3	4K	33	P	C	61	9	1	3	8	7	1	54	15	P	9			1	60			10		P	C	N	6610		
C3237	4105S152	170 /3	4K	33	P	C	61	82	0	3		25		34	18	P	80	2	100	1	75			12		P	C	U	63 4		
C3238	4105S152	170 /3	4K	33	P	C	61	92	0	3		26		35	18	P	91	1	100	1	113			12		P	C	U	63 5		
C3239	4105S152	170 /2	4K	33	P	C	37	82	0	3		25		36	18	P	81	1	100	1	75			12		P	C	U	64 6		
C3597	4110S145	170 /1	4K	51	X	G	510	11	1	2	4					H	0	11	100							S	A	N	6610		
C2718	4113S109	157 /1	4K	51	U	G	46	79	1	3	72	70	0	-24	20	H	26	52	100	1	640	75	4.6	24		S	A	N	57 8	139.1	203
C2719	4113S109	157 /1	4K	51	U	U	46	79	1	3	62	62	0	-16	20	H	64	15	100	1	640	64	2.1	24		S	A	N	5710	304.8	450

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Table 2.- Logs of typical boreholes in the Precambrian Basement Complex rocks of the Machakos-Kitui study area

	Thickness (meters)	Depth (meters)
C-461 (Sheet 163/3)	Drilled in 1946	
Altitude 1,067 m D/W 48 m*		
Soil, sandy	1.2	1.2
Gneiss	38.4	39.6
Gneiss, quartz-feldspar; water at 47 m	11.4	51.2
Gneiss, quartz-muscovite	38.7	89.9
Schist, mica	15.9	105.8
Schist, biotite	9.7	115.5
Gneiss, granite	16.8	132.3
Gneiss, muscovite and schist	6.4	138.7
C-500 (sheet 163/4)	Drilled in 1947	
Altitude 1,067 m D/W 9 m		
Soil, sandy	3.3	3.3
Gneiss, micaceous, weathered	3.4	6.7
Schist, talc-mica; water at 12 m	11.0	17.7
Schist, quartz-biotite	21.3	39.0
Schist, mica	4.9	43.9
Schist, mica and quartz-biotite gneiss	12.2	56.1
Pegmatite, biotite and gneiss	11.0	67.1
C-1580 (sheet 163/1)	Drilled in 1951	
Altitude 1,219 m D/W 27 m		
Clay	14.0	14.0
Gneiss, biotite	12.8	26.8
Gneiss; water at 45 m	57.6	84.4
C-1595 (sheet 150/1) Kangondi	Drilled in 1951	
Altitude 1,264 m D/W 30 m		
Rock, weathered with boulders	33.5	33.5
Gneiss	22.9	56.4
Gneiss, weathered; water at 64 m	9.1	65.5
Gneiss	16.8	82.3
C-3453 (sheet 150/3)	Drilled in 1967	
Altitude 1,308 m D/W 17 m		
Soil, red	3.6	3.6
Clay	5.5	9.1
Gneiss, weathered	9.2	18.3
Gneiss; water at 82 m	70.4	88.7

*D/W = Depth to water below land surface

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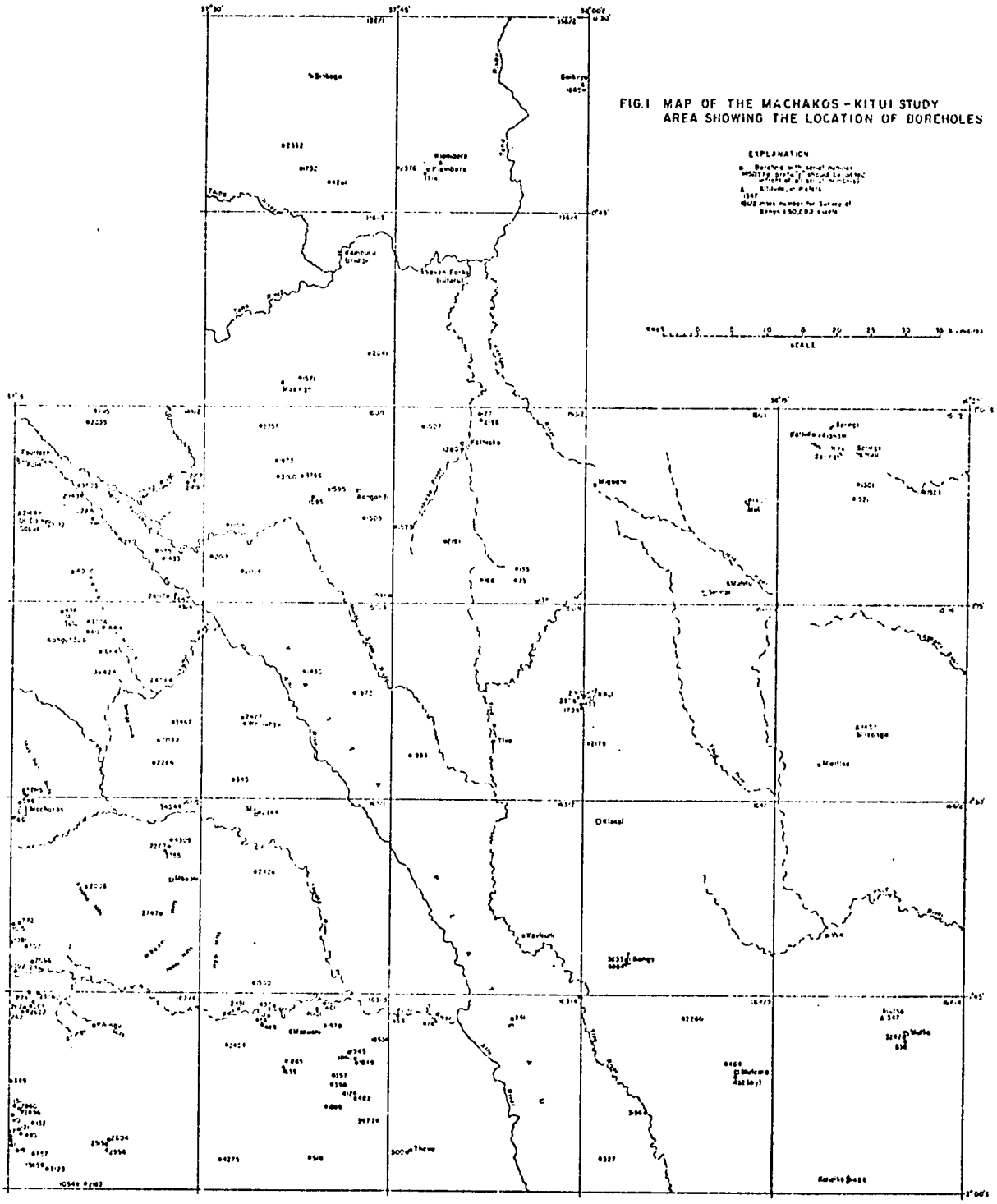

FIG.1 MAP OF THE MACHAKOS - KITUI STUDY AREA SHOWING THE LOCATION OF BOREHOLES

EXPLANATION

SCALE

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Table 3.-Records of boreholes in the Baringo-Kerio study area

Borehole no.	Long. E.	Lat. N.	Altitude (meters above sea level)	Total depth (meters)	Depth of first water (meters)	Static water level (meters below land surface)	Diameter (mm)	Yield (l/min)	Remarks
C-1127	35°34'	0°39'	1,089	122	87	85	152	28	Drilled in 1950. Taps water in Precambrian metamorphic rocks. Private use.
C-1128	35°34'	0°40'	1,219	122	57	57	--	18	Drilled in 1950. Taps water in Precambrian rocks. Abandoned.
C-1167	35°35'	0°43'	1,219	163	77	76	152	17	Drilled in 1950. Taps water in Precambrian rocks. Private use.
C-1838	35°32'	0°17'	2,591	110	75	73	152	23	Drilled in 1952. Taps water in Tertiary volcanic rocks. Private use.
C-3506	35°44'	0°30'	1,725	152	103	13	204	227	Drilled in 1968. Taps water in Tertiary volcanic rocks. Public use. Yields 227 l/min with 41 m drawdown.
C-3526	35°47'	0°42'	2,134	166	64	83	--	0	Drilled in 1968. Taps water in Tertiary volcanic rocks. Abandoned. Yield negligible.
C-4077	35°59'	0°24'	1,340	226	220	84	152	183	Drilled in 1974. Taps water in Tertiary volcanic rocks. Government use. Yields 183 l/min with 31.7 m drawdown.

Table 2. (cont'd)

C-4136 (sheet 150/4) Drilled in 1975

Altitude 1,152 m D/W 40 m

	(meters)	(meters)
Soil, sandy	4.0	4.0
Granite	18.0	22.0
Gneiss	14.0	36.0
Granite; water at 50 m	18.0	54.0
Gneiss; weathered	20.0	74.0
Granite; weathered	20.0	94.0

Table 4.-Logs of boreholes in the Baringo-Kerio study area

C-1127 (Sheet 90/3)	Drilled in 1950	
Altitude 1,089 m D/W 85 m*	Thickness (meters)	Depth (meters)
Clay, silty, brownish	8.8	8.8
Gravel, pebbly, detrital	18.6	27.4
Gneiss, hornblende, weathered	51.6	79.0
Gneiss, hornblende, fresh; water at 87 m	42.9	121.9
C-1128 (Sheet 90/3)	Drilled in 1950	
Altitude 1,219 m D/W 57 m		
Silt, dark brown	9.4	9.4
Gravel, pebbly, detrital	39.5	43.9
Gneiss, hornblende, weathered; water at 57 m	53.7	97.6
Gneiss, hornblende, fresh	24.3	121.9
C-1838 (Sheet 104/1) Foster's Farm, Kipkabus	Drilled in 1952	
Altitude 2,591 m D/W 73 m		
Clay, tuffaceous with boulders	49.4	49.4
Tuff, fresh; water at 75 m	44.5	93.9
Tuff	15.8	109.7
C-3506 (Sheet 104/1) Kabarnet	Drilled in 1968	
Altitude 1,725 m D/W 13 m		
Soil, red	0.3	0.3
Tuff, weathered	1.5	1.2
Tuff, dark brown	3.4	4.6
Tuff, yellow	1.5	6.1
Tuff, gray	4.6	10.7
Tuff, brown	33.5	44.2
Lava, reddish-brown; water at 103 m	108.2	152.4
C-3526 (Sheet 90/4) Kabartonjo	Drilled in 1968	
Altitude 2,134 m D/W 83 m		
Soil	0.6	0.6
Tuff, brown	1.2	1.8
Tuff, gray	8.9	10.7
Tuff, brown	18.3	29.0
Tuff, yellow	4.5	33.5
Basalt (?), light brown	15.3	48.8
Lava and basalt; water at 64 m	15.2	64.0
Tuff, yellow	15.3	79.3
Tuff, brown	3.0	82.3
Tuff, gray and lava	6.1	88.4
Lava	77.7	166.1

*D/W = Depth to water below land surface

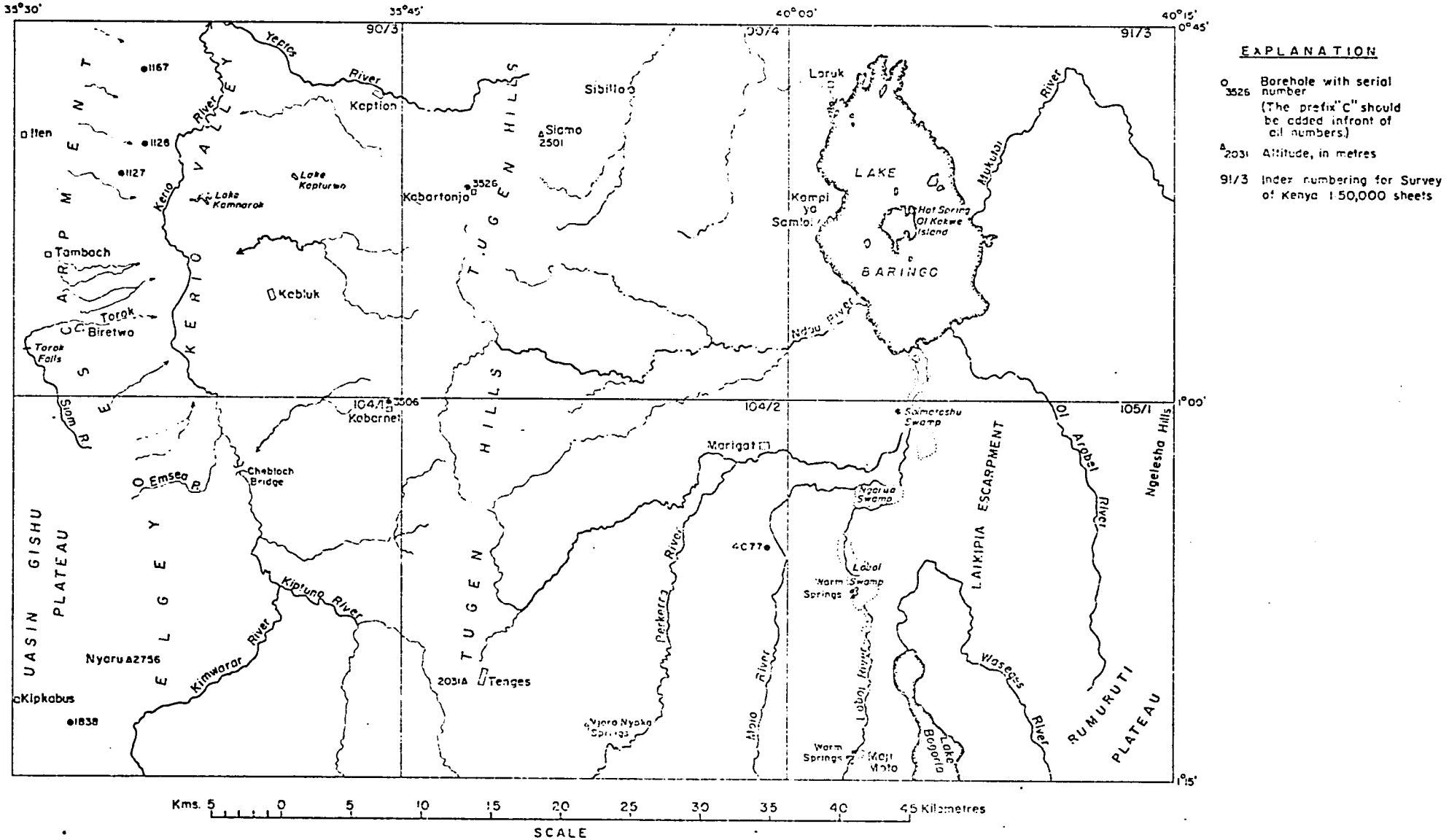

FIG. 2 MAP OF BARINGO-KERIO STUDY AREA SHOWING THE LOCATION OF BOREHOLES