DRAINAGE FOR SALINITY CONTROL
IN KIMORIGO / KAMLEZA IRRIGATION SCHEMES

By

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aster of Science in Agricultural Engineering.

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DECLARATION

hereby, declare that this thesis is my original work and has not been presented for a degree in any other versity.

27.9.90.

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s thesis has been submitted with our roval as the university supervisors.

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27.9.90

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CEC	Cation exchange capacity
Dc	Critical watertable depth
EC	Electrical conductivity
ECe	Electrical conductivity of saturated soil extract
Eo	Evaporation
ET	Evapotranspiration
ETp	Potential evapotranspiration
ESP	Exchangeable sodium percentage
	Leaching effeciency factor
	Amount of groundwater rise by capillarity
i	Infiltrating irrigation water
'ss	Total net groundwater flow
ss	Net lateral groundwater flow
m	Matric suction head
h	Capillary conductivity
	Hydraulic conductivity
	Percolation below crop rootzone
do	Discharge from groundwater table downwards through a semi-permeable membrane
up	Recharge to groundwater table from an aquifer through a semi-permeable membrane
dr	Discharge from groundwater table to open water surfaces
inf	Recharge into groundwater table from open water surfaces
lsi	Lateral groundwater inflow
lso	Lateral groundwater outflow

Precipitation

o Rate of capillary rise

Rate of capillary rise

Drainable pore space

Height of capillary rise above groundwater table

Critical height of capillary rise above groundwater table

Change in groundwater table height

s Change in salt content of the soil

sm Change in soil moisture content

grw Change in groundwater storage

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ABSTRACT

This thesis provides detailed information on the lrainage and soil salinity status of the Kimorigo/Kamleza irrigation schemes and adjacent areas. In order to provide information on the areas' drainage, a groundwater survey was carried out over an area of approximately 2400 ha. Investigations on the groundwater conditions consisted of vatertable depth measurements and groundwater quality analysis over a period of 10 months from October, 1988 to July, 1989. Soil samples were collected from the field and analysed for salinity and sodicity levels and also soil texture. The underlying calcareous layer was investigated vith respect to depth of occurrence below the surface, its slope and form so as to determine its influence on surface and subsurface drainage of the area. Hydraulic conductivity neasurements, using the augerhole method, were carried out n several locations to help in obtaining field drain spacings in areas or parts which may require subsurface lrainage.

A topographical survey of the area was carried out so as to determine the surface and subsurface drainage conditions with respect to ground slopes and outlet conditions. In addition, the topo-investigations were to provide a base map covering the two irrigation schemes and adjacent areas and finally to obtain ground elevations from which groundwater and the calcareous layer levels could be letermined.

A groundwater balance assessment was carried out for four areas within the two schemes using the indirect method to determine in quantitative terms the possible causes of the subsurface drainage problem in the schemes.

From the results obtained, surface drainage problems in the area can be attributed to flood flow and excess precipitation during the rainy season. Overflow from canals and excess irrigation also at times result in surface drainage problems. Subsurface drainage problems are mainly caused by deep percolation from flood flow, excess precipitation and irrigation and seepage inflow from higher to lower areas. The groundwater balance assessment shows that the net subsurface inflow from irrigated to lower irrigated or non-irrigated areas may be as high as the evapotranspiration rate or higher.

Capillary rise from the shallow and salty groundwater results in substantial salt transport to the surface , and hence high soil salinity conditions. Salinisation is most pronounced in non-irrigated or fallow land with high groundwater tables maintained by seepage inflow.

Remedial measures to improve the drainage and salinity status of the schemes include flood control, provision of surface and subsurface drainage facilities and improved water management.

1. INTRODUCTION

1 The problem

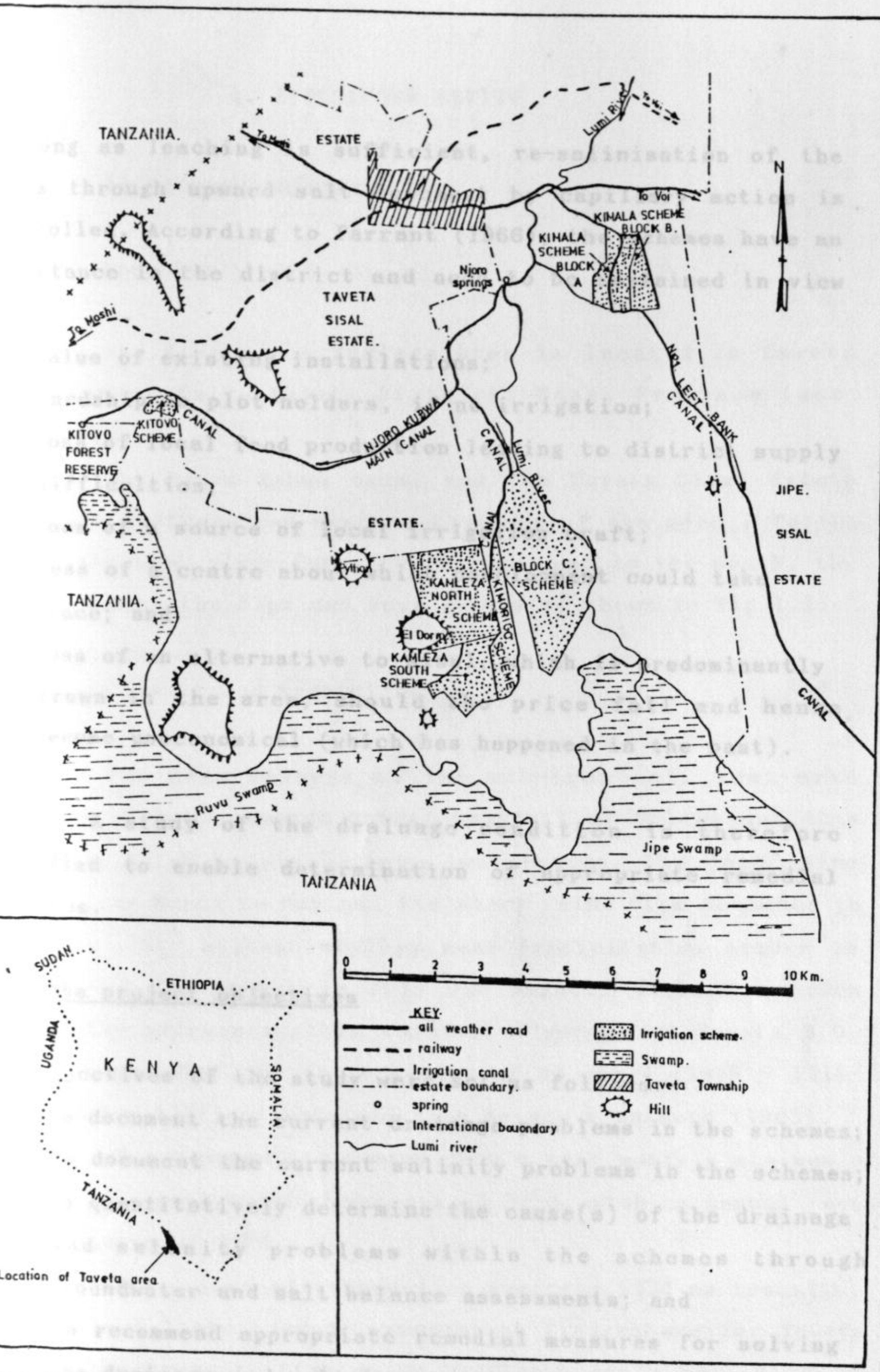
The problem affecting Kimorigo and Kamleza Schemes cc Fig.1.1), is one of land deterioration under irrigation e to rising salinity and sodicity of the soils. Under the lty soil condition, low crop production has resulted. verely salt affected parts have been abandoned by farmers.

Past reports on the area by Asol (1984), Berger and lders (1983), De Ridder (1974), Farrant (1966), Kanake 982), Underhill (1955) and Van Alphen et al. (1979), dicate that the development of salty soil conditions is e to poor or inadequate drainage, especially after the troduction of irrigated agriculture, and this has promoted pillary salinisation, more so as groundwaters in the area e salty (Kanake, 1982; Van Alphen et al., 1979).

2. Project justification

The project is justified as no studies have been ne on the groundwater conditions to enable quantification the possible causes of the drainage problem mentioned ove. It is only when the causes are known and antitatively characterized that the appropriate remedial asures can be recommended, as supported by De Ridder 974) and Van Alphen et al. (1979).

The improvement of the drainage conditions in the hemes and adjacent area is important for the stainability of the irrigation schemes. It is through ainage that excess salts are evacuated out of the soil and



ig.1.1: Locational map of the project area.

o long as leaching is sufficient, re-salinisation of the oils through upward salt movement by capillary action is ontrolled. According to Farrant (1966), the schemes have an mportance in the district and need to be sustained in view f:-

a) value of existing installations;

b) hardship to plot holders, if no irrigation;

c) loss of local food production leading to district supply difficulties;

d) loss of a source of local irrigation craft;

e) loss of a centre about which development could take place; and

f) loss of an alternative to sisal, which is predominantly grown in the area, should the price fall and hence become uneconomical (which has happened in the past).

A study of the drainage condition is therefore ustified to enable determination of appropriate remedial easures.

.3 The project objectives

he objectives of the study were set as follows:-

(1) To document the current drainage problems in the schemes;

(2) To document the current salinity problems in the schemes;

(3) To quantitatively determine the cause(s) of the drainage and salinity problems within the schemes through groundwater and salt balance assessments; and

(4) To recommend appropriate remedial measures for solving the drainage and salinity problems.

2. LITERATURE REVIEW

1 Background information

) Location

The Kimorigo - Kamleza area is located in Taveta vision of Taita-Taveta District, Coast Province (sec g. 1.1).

The Njoro Kubwa canal and the Taveta Sisal Estate rm the northern and western boundary of the area. To the st, the Lumi river forms the border, and to the south, the ea borders the Jipe and Ruvu swamps as shown in Fig.1.1.

) Climate and vegetation

The area belongs to the sub-tropical, semi-arid imate with an average annual rainfall of 600 mm and this distributed mainly between two seasons. The long rains ccur from March to May and the short rains From November to ecember. The highest monthly mean precipitation occurs in pril and the lowest in July and August. Table 1.1 below ows the average monthly rainfall figures for Taveta D.O. tation No. 93.37/00 for a period of 43 years (1905 - 1914 nd 1920 - 1971) as obtained from Berger & Kalders (1983).

The temperature ranges from a mean monthly minimum of 3^{o}C to a mean monthly maximum of 33^{o}C, with an annual mean emperature of 22^{o}C.

The potential evaporation averages 1930 mm annually. n Table 2.1 the average evaporation figures are for Taveta ater Development, Station No.93.37/110 for a period of 17 ears (1964-1981) as obtained from Berger & Kalders (1983a).

Table 2.1. Monthly average rainfall data (Taveta D.O Station) and potential evapotranspiration (Taveta Water Development).

Month	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Rainfall (mm)	39	45	106	139	65	9	7	6	7	27	91	54	595
Eo (mm)													
Penman	175	175	175	150	140	135	135	145	165	185	175	175	1930

Source: Berger and Kalders (1983).

From the above table it can be seen that the evaporation exceeds the mean monthly rainfall for all months except in April when there is a small surplus.

The vegetation in the area is not wholly indicative of what is expected for Agro-ecological zone V, that is: bushland. This is because the soil conditions have been altered by the existing high groundwater tables and irrigation schemes. Along the Lumi River, there exists a Riverine forest. Between the river and Kimorigo Scheme (Block C area) the vegetation is mainly woody acacias and salt-tolerant bushes, interspersed by short grasses which are also salt-tolerant. On the swampy edges water loving plants occur in abundance. In areas with high saline water-table, Doum palm and wild date palm are found. The drier areas around the hills are predominantly vegetated by drought-resistant acacias.

(c) Geology and physiography

The soils of the area are primarily developed on calcareous tuffaceous grits which are of Pleistocene to Recent Age (Bear, 1955; Kanake, 1982). Part of the area ever, falls in the floodplain of the Lumi river, which nsists of Recent Alluvial silts and clays.

Physiographically, the area may be considered as part the piedmont plain which forms the gap between the Pare untains, composed of Basement Systems Rocks, and the Mt. limanjaro Volcanic pile. Two hills, Eldoro and Kitogoto, se above the general level of the plain. The area is devoid any marked natural drainage pattern, but it slopes gently -2% slope) to the marshes surrounding Lake Jipe.

) Hydrology and water resources

i) Surface water

The main surface water source in the area is Lumi ver from which Kimorigo scheme derives its water for rigation.

The discharge of the Lumi river before the morigo/Kamleza area averages 0.6 m^3/s and it runs in a eeply eroded bed of approximate depth of 3.5 m. Just before enters the Kimorigo - Kamleza area, more water is added rom the Njoro Kubwa group of springs (total discharge = 6 $^3/s$) and this increases the discharge to an annual average f 6.6 m^3/S (about 7 m^3/s). The river in this section now lows full and its water level is often higher than the urrounding land. Consequently, the adjacent lands exhibit igh groundwater tables and are often flooded during high lows. Flood discharge has been estimated to be as high as 50 m^3/s (Underhill, 1955).

The quality of the river water is fairly good and ould cause very low or no potential soil hazards. A hemical analysis report of the water is shown in Table 2.2.

able 2.2: Report on chemical analysis of water sample
(Lumi River, 1982)

lectrical conductivity (EC. at 25°C)	660 μS/cm
icarbonate	239 mg/l
arbonate	36 "
hloride	70 "
ulphate	11 "
odium	64 "
otassium	6 "
alcium	47 "
agnesium	24 "

ource: (Kanake, 1982)

ii) Groundwater

The groundwater level in the area varies between 10 cm elow the soil surface in the southern swamps to about 1.5 - .0 m below the surface in the northern sectors (dry season) - (Kanake, 1982).

The quality of the groundwater in the area is not good. Chemical samples taken in the past from various locations show that the water has a high degree of salinity and sodicity. It also has a high content of bicarbonates and ther toxic elements (Kanake, 1982). Table 2.3 indicates that the EC varies between 950 μS/cm and 16,000 μS/cm (640 mg/l - 10,240 mg/l).

Table 2.3. Chemical analysis results of groundwater sample

Parameters	Groundwater Sample no. (1)	(2)	(3)	(4)
pH	8.2	9.0	9.0	8.8
EC (µS/cm)	1400	16000	5500	950
Sodium (me/l)	6.3	156.0	50.0	5.5
Pottasium (me/l)	0.1	0.14	0.15	0.35
Calcium (me/l)	2.8	2.7	0.7	1.3
Magnesium me/l	5.2	0.9	0.06	1.8
Carbonates (me/l)	0.4	27.0	10.0	0.4
Bicarbonates (me/l)	9.2	52.0	40.0	5.6
Chlorides (me/l)	4.1	77.0	3.3	3.1
Sulphate (me/l)	0.35	4.7	0.05	0.03

Source: (Kanake, 1982)

2.2 : Soil salinity in project area

2.2.1: Origin of salty soils in the project area

Salty soils in the area were first noted to occur in areas with high groundwater tables near the Lumi River, according to reports by Farrant (1966). Where high groundwater tables occur, soil salinisation is common as upward capillary flow is able to reach the rootzone, bringing with it salts which are deposited on the surface as water is lost through evapotranspiration. It is therefore possible that capillary salinisation, promoted by the high evaporative conditions in the project area, caused the salty soil conditions in the high groundwater table areas close to the river.

After the introduction of irrigation in the Block C rea in the early 1940's (see Fig.1.1), many areas developed igh groundwater tables, a condition which enhanced apillary salinisation. By the early 1950's, severe saline nd sodic soil conditions had developed leading to the bandonment of the Block C irrigation scheme.

Irrigation continued in the adjacent areas of Block , but as noted by Underhill (1955), excess irrigation, in he absence of adequate drainage, caused groundwater tables o rise. At the time of the investigations (in 1954), roundwater was at a depth of about 1.0 m from the surface. alinity and sodicity problems soon developed in these reas, which are no longer cultivated.

Investigations by Asol (1984) and Kanake (1982), evealed the occurrence of maximum salt concentration at the urface, in parts of the schemes, this being an indication f capillary salinisation (Ayers & Westcot, 1985; itzPatrick, 1987; Smedema and Rycroft, 1983).

As no improvements have been made on the drainage onditions in the schemes to date, re-salinisation from the hallow and salty groundwaters continues to be a threat to reas presently under cultivation. Kimorigo Scheme, whose pper areas have already been abandoned, appears to be hreatened most as a report by Asol (1984) indicates that oth leaching and drainage are inadequate.

.2.2 Past reclamation and control measures

A few attempts to improve the drainage conditions in he schemes, have been undertaken in the past. The first ttempt was the plan to install a 2.0 m deep main drain for rigo scheme. This was, however, not possible as the rrence of hard calcareous layer beneath the topsoil ted the drainage depth to only 1.0 m (Farrant, 1966). d drains necessary for the control of salinity have r been installed.

The second attempt was a proposed pilot project by er and Kalders (1983), aimed at comparing the bility of various field drainage methods, but as of now project has never taken off. In the design of the field nage system, the authors did not consider the influence ossible subsurface inflow which, according to De Ridder 4), may be substantial and therefore needs to be stigated.

3 Soil salinity condition

Soil salinity /sodicity conditions in the area have classified by Kanake (1982), according to the US nity Laboratory Classification System. The sification of salty soils according to this system is as n in Tab.2.4.

e 2.4: The US Salinity Laboratory System for Classification of Salty Soils (USDA,1974).

	ECe < 4 mS/cm at 25°C	ECe > 4 mS/cm at 25°C
ESP < 15%	non-saline) soils non-sodic)	saline soils
ESP > 15%	sodic soil	saline) soils sodic)

ce: Smedema and Rycroft (1983).

For EC measurements carried out in the field at a
il to water ratio of 1:2.5, the classification as given in
ble 2.5 below holds. These values are a third of the ECe-
lues.

ble 2.5: Classification of field measurements of electrical conductivity ($EC_{2.5}$).

$_{2.5}$ (mS/cm)	Classification
- 1.3	non-saline
3 - 2.7	slightly saline
7 - 5.3	moderately saline
5.3	strongly saline

urce: MOA (1984).

From the results of the soil survey investigations, nake (1982) prepared a soil salinity map according to the ove classification. A simplified soils map consisting of e major soil salinity boundaries is shown in Fig.2.1.

Out of the total surveyed area of 2165 ha, 530 ha nsisted of non-saline, non-sodic soils; 1394 ha consisted saline-sodic soils and 138 ha of sodic soils. From the p in Fig.2.1, non-salty soils occur in many parts of mleza scheme and the central to lower parts of Kimorigo heme. The whole of Block C area, the Northern parts of morigo scheme and the Ngutini area consist mainly of line and/or sodic soils. For the saline and / or sodic ils, the ESP-value in some places is as high as 90 %, ile the EC-values vary between 1.5 and 10 mS /cm.

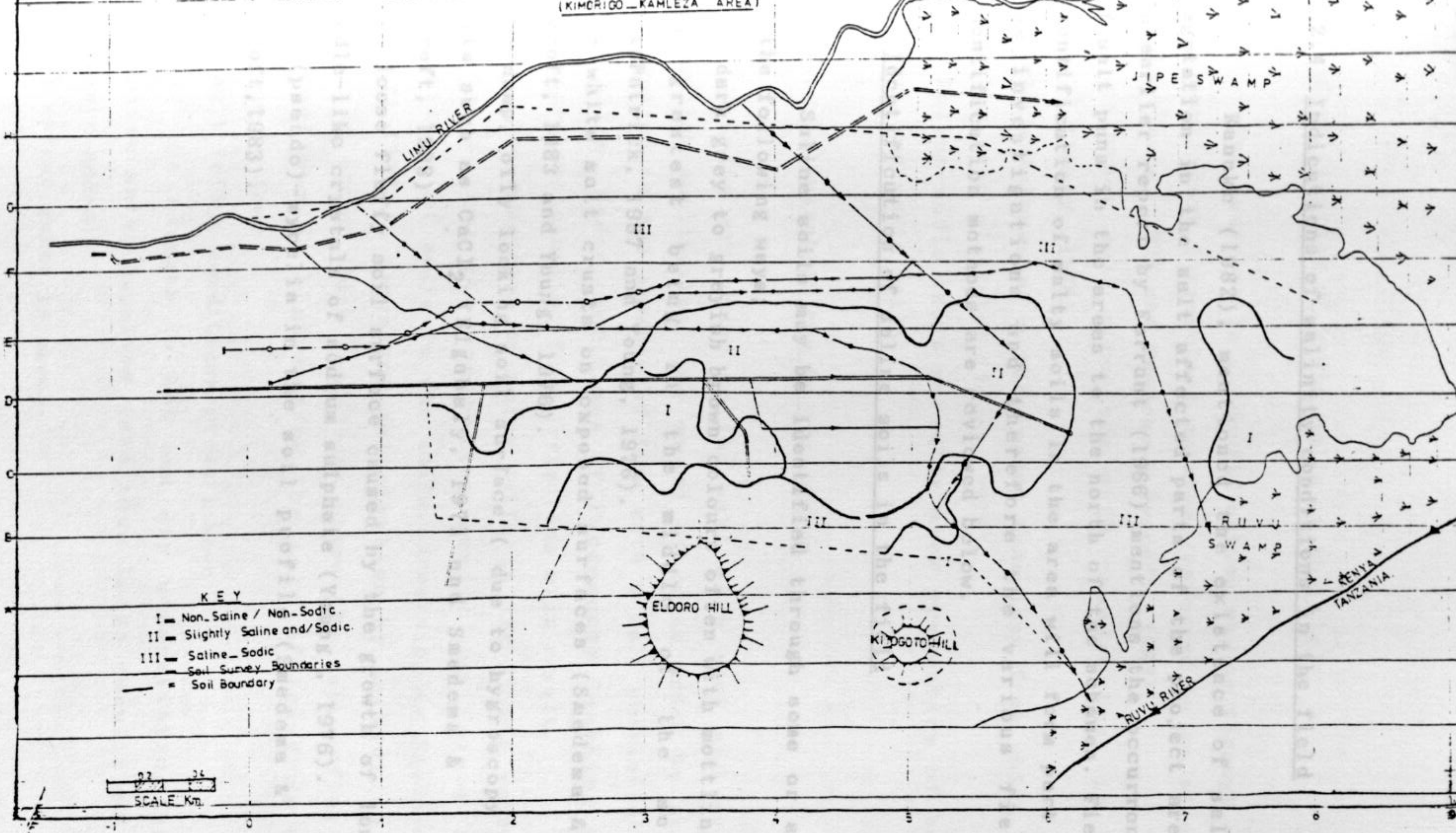


Fig.2.1: Soils map of the Kimorigo/Kamleza area (Kanake, 1982).

.4 Indications of salinity conditions in the field

Kanakc (1982), mentioned the existence of salty etation in the salt affected parts of the project area. earlier report by Farrant (1966) mentions the occurrence salt pans in the areas to the north of the schemes. Field ntification of salty soils in the area will form part of investigations and therefore the various field ntification methods are reviewed below.

Identification of saline soils in the field

Saline soils may be identified through some or all the following ways;

- dark grey to greyish brown colours often with mottling, greatest being in the middle of the soil tzPatrick, 1987 and Young, 1976).
- white salt crusts on exposed surfaces (Smedema & roft, 1983 and Young, 1976).
- damp, oily looking soil surface (due to hygroscopy of ts such as $CaCl_2$ (Elgabaly, 1971 and Smedema & roft, 1983).
- loose fluffy soil surface caused by the growth of long dle-like crystals of sodium sulphate (Young , 1976).
- (pseudo)-mycelia in the soil profile (Smedema & roft,1983).

(b) Identification of sodic soils in the field

For sodic soils , identification may be through :

- small dark (irregular) patches, referred to as slick spots (Young, 1976 and Smedema & Rycroft, 1983).

- columnar soil structure with rounded tops in the subsoil (Young, 1976).

- the existence of a thin sandy A-horizon from which all clay has been eluviated (Young, 1976).

Saline-sodic soils normally show properties of both saline and sodic soils.

2.2.5. Salinisation due to irrigation

Salts are added to the soil with each and every irrigation application. The amount of salts added by each irrigation is the product of flow rate x salt concentration x duration. Under conditions of inadequate leaching and drainage, salinisation from irrigation will result.

The existence of salty soils in the Taveta schemes indicates that the prevailing conditions favour the accumulation of salts in the soils. According to Smedema & Rycroft (1983), secondary salinisation by irrigation is likely to occur under conditions where the salt influx to the rootzone is high and/or the salt efflux from the rootzone is low.

High salt influx conditions prevail when:

(i) the climate is hot and dry necessitating high irrigation water supplies (and thus large quantities of salts are added).

(ii) saline water is used.

w salt efflux conditions prevail when:-

(i) insufficient water is used for irrigation leaving no excess for leaching requirements (under-irrigation);

ii) the climate is hot and dry (low rainfall/high evaporation), so little excess rain goes into deep percolation for leaching;

ii) drainage conditions are poor, allowing insufficient percolation and drainage discharge.

The quality of irrigation water used in the schemes satisfactory and according to results obtained by Asol 984), the electrical conductivity (EC) is approximately 25 mS/cm. However, even with good quality water, linisation is bound to occur if the salts are not leached d evacuated out of the soil by drainage.

Reports by Farrant (1966) and Underhill (1955), ntion that excessive irrigation is prevalent in the area. owever, there is no supportive data. During the nvestigations, an indication will be given on the rrigation efficiency.

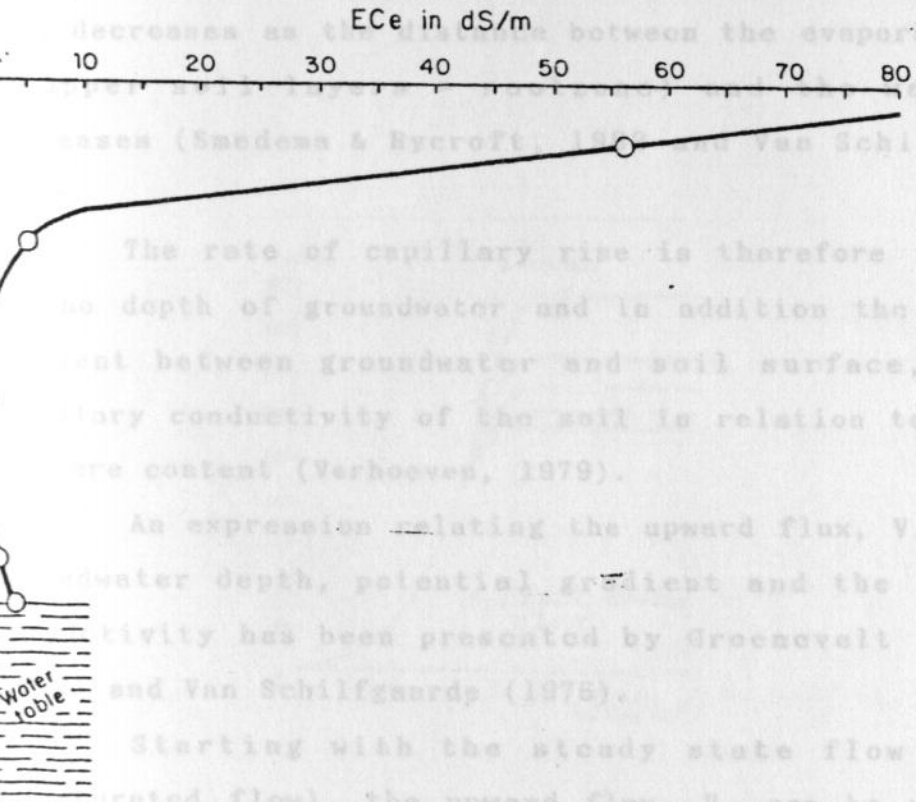
Excessive irrigation, under the poor drainage onditions, is likely to cause groundwater table rise and us enhance capillary salinisation.

.2.6 Salinisation from groundwater

Salinisation from groundwater (capillary linisation) occurs when salts brought to the upper soil ayers by upward capillary flow of groundwater are left ehind as water is lost by evapotranspiration.

The extent of capillary salinisation and the depth t which salts accumulate are governed by the rate of

pillary rise and the groundwater salinity counteracted by
ne leaching intensity (by rain or irrigation water). For
pillary salinisation to take place, a net upward movement
f water (and salts) is a must. This often results in a
ximum salt concentration at the surface followed by a sharp
op down the profile as shown in Fig. 2.2.



g.2.2: Typical salinity profile for a soil under capillary salinisation (Ayers and Westcot, 1985).

2.6.1 <u>Rate of capillary rise and critical watertable depth</u>

The amount of salts transported to the surface is he product of rate of capillary rise x salt concentration x uration of capillary rise. High rates of capillary rise ead to considerable salinisation. It has been shown that hile the upward capillary flow can reach to great heights, he rate of flow generally decreases with increasing height bove the watertable. Consequently, the rate of upward salt ovements, being proportional to the rate of upward flow, lso decreases as the distance between the evaporation zone = upper soil layers = rootzone) and the watertable ncreases (Smedema & Rycroft, 1983 and Van Schilfgaarde, 976).

The rate of capillary rise is therefore influenced y the depth of groundwater and in addition the potential radient between groundwater and soil surface, and the apillary conductivity of the soil in relation to the soil oisture content (Verhoeven, 1979).

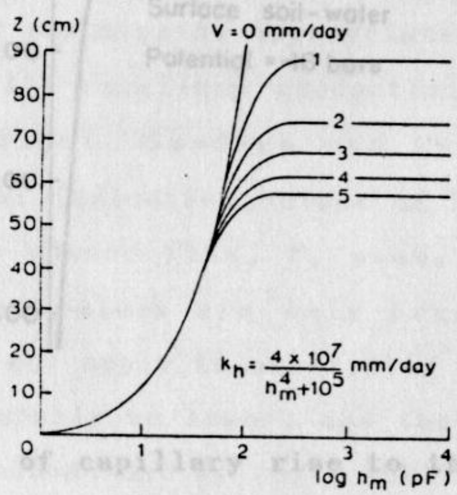
An expression relating the upward flux, V, with the roundwater depth, potential gradient and the capillary onductivity has been presented by Groenevelt and Kijne 1979) and Van Schilfgaarde (1976).

Starting with the steady state flow equation unsaturated flow), the upward flux, V, can be written in erms of matric and gravity potential gradient, both xpressed on a weight basis, in the form:

$$V = k_h (dhm/dz - 1) \qquad (1)$$

ere k_h = capillary conductivity; hm = suction head and z = ght of capillary above the water table.

The above equation can be solved through integration l solving the resultant integral for known values of the pillary conductivity, K_h. A graphical solution for a rse textured soil is shown in Fig.2.3 which indicates the te of capillary rise, V, at different groundwatertable oths and soil matric suctions.



g.2.3: Potential profiles calculated for a coarse textured soil under influence of capillary rise. (adopted from Groenevelt & Kijne, 1979).

In Fig.2.4, the variation in the rate of capillary rise with watertable depth for different soil textures has also been presented.

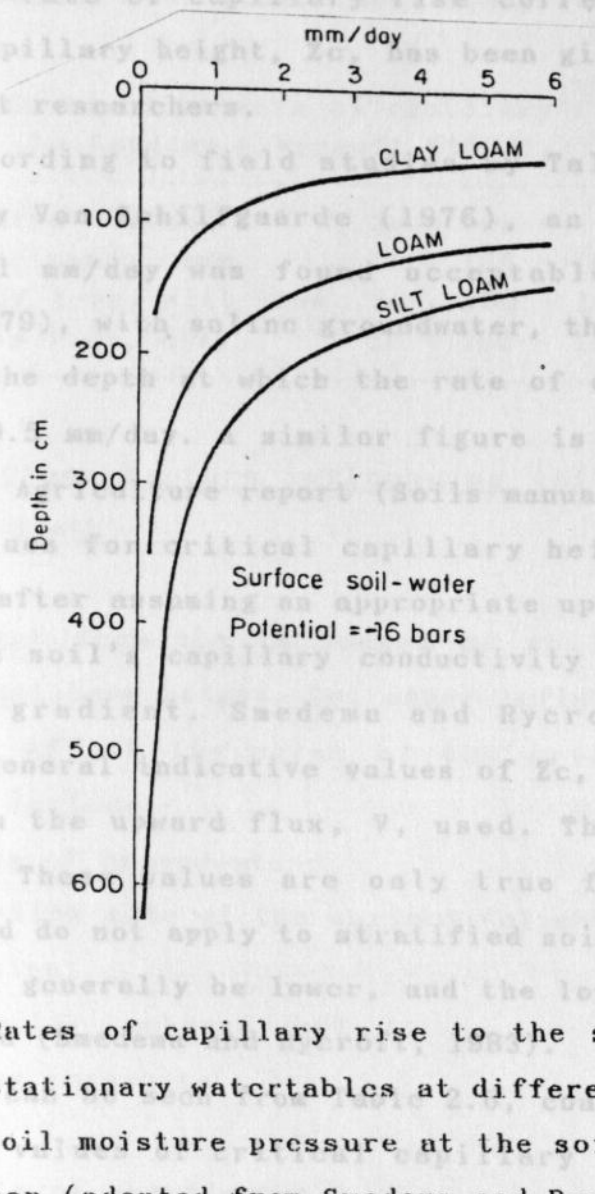


Fig.2.4: Rates of capillary rise to the soil surface from stationary watertables at different depths when the soil moisture pressure at the soil surface is - 16 bar (adopted from Smedema and Rycroft, 1983).

The two figures illustrate that as the groundwater table falls, so does the rate of capillary rise. The height above the watertable at which the rate of capillary rise becomes too small for any significant upward salt movement s called the critical capillary height, Zc, and the roundwater depth when this occurs is called the critical atertable depth, Dc.

The rate of capillary rise corresponding to the ritical capillary height, Zc, has been given varied values y different researchers.

According to field studies by Talsma (1963), as eported by Van Schilfgaarde (1976), an upward flux not xceeding 1 mm/day was found acceptable. According to essler (1979), with saline groundwater, the critical depth, hould be the depth at which the rate of capillary rise is ess than 0.5 mm/day. A similar figure is given by Kenya's inistry of Agriculture report (Soils manual, 1984).

Values for critical capillary height, Zc, can be alculated after assuming an appropriate upward flux, V, and nowing the soil's capillary conductivity and the existing otential gradient. Smedema and Rycroft (1983) have resented general indicative values of Zc, although they do ot mention the upward flux, V, used. The values are in able 2.6. These values are only true for uniform soil rofiles and do not apply to stratified soils where the high alues will generally be lower, and the low values may well e increased (Smedema and Rycroft, 1983).

As can be seen from Table 2.6, coarse textured soils ave lower values of critical capillary height, Zc, than edium textured soils such as silt loam. Medium textured oils have relatively high unsaturated capillary onductivity, and thus relatively high rates of capillary ise compared with coarse or heavy clay textured soils (essler, 1979; & Smedema and Rycroft, 1983). Consequently, igher values of critical capillary height, Zc, are nevitable to reduce the relatively high rates of capillary rise to acceptable levels, such as 0.5 mm/day for areas with saline groundwater and medium textured soils as in the Kimorigo/Kamleza area (see Table 2.6).

Table 2.6: Critical heights of capillary rise, Z_c, according to Smedema & Rycroft (1983).

- Sand (coarse - fine)	Zc = 50 - 75 cm
Loam sand, sandy loam	Zc = 100 - 150 cm
- Fine sandy loam, silt loam	Zc = 150 - 200 cm
Loam, clay loam, clay	Zc = 100 - 150 cm

2.2.6.2 <u>Other factors influencing critical watertable depth</u>

Apart from the influence of soil texture on the critical capillary height, Zc, other influencing factors which also affect the value of the critical watertable depth, Dc, include:-

(a) salinity of groundwater;
(b) evaporation rate of the surface (climate);
(c) vegetation;
(d) groundwater recharge; and
(e) leaching intensity.

(a) <u>Salinity of groundwater</u>

As already mentioned, the rate of salinisation at the surface is the product of flow rate and salt concentration. Therefore values of critical capillary height, Zc, should increase with increasing groundwater salinity.

cording to Elgabaly (1971), if there exists fresh rculating groundwater, a depth of 50 cm can be tolerated by ny field crops. With saline groundwater, in arid and semi-id regions, the critical watertable depth is recommended to c between 2.5 - 3.0 m below the surface (Elgabaly, 1971). cording to this same author, the critical salt ncentration should be between 1500 - 3000 ppm (EC = 2.3 - 7 mS/cm) and for sodic groundwater it should not exceed 750 m (1.2 mS/cm). Smedema and Rycroft (1983), also mention at very little salinisation will occur provided the salt ncentration in the upper groundwater layer remains < 1000 /l (1.5 mS/cm).

) Evaporation rate

Evaporation of moisture from the upper soil layers eates an upward moisture gradient leading to upward pillary flow. In arid and semi-arid areas, the existing gh evaporation rates lead to marked upward capillary flow d consequently extensive salinisation (FAO,1971). The atertable depth in these areas should therefore be intained below the critical depth, Dc, especially if the roundwater is saline as mentioned under (a); above the entioned critical salt levels.

In areas with low evaporation rates e.g. humid reas the watertable depths may be higher, more so as the roundwaters are often fresh.

) Vegetation

In bare soil water is lost only through evaporation l the evaporation zone is shallow (15 - 20 cm). In getated areas, water loss occurs through both evaporation l transpiration and over a much deeper zone, about equal depth to the main rootzone from which water is taken up r transpiration (Smedema & Rycroft; 1983 and Van ilfgaarde, 1976). The result is that in areas with getation (grass or shrubs) and no leaching (i.e. under llow), more water is lost and consequently more extensive linisation occurs. This was shown to be true by studies rried out by Balba (1976). However, with adequate rigation and/or rainfall to cause leaching, salinisation cropped areas is reduced.

The critical watertable depth with vegetation and no aching of salts is thus higher than for bare soil (Smedema Rycroft, 1983; Van Schilfgaarde, 1970). The actual value pends on the rooting depth and the other factors mentioned this section.

) Groundwater recharge

With no groundwater recharge (or subsoil water pply), the groundwater table falls as more and more water lost by upward capillary flow. The watertable depth may ll to or even beyond the critical watertable depth, Dc, at ch point capillary salinisation becomes insignificant.

With groundwater recharge, water lost by upward pillary flow is replaced and the groundwater tables remain gh. This leads to continued transport of salts to the surface and to substantial salinisation if the watertables remain high for prolonged periods.

The groundwater depth in areas with groundwater recharge (and saline groundwater) should therefore be maintained below the critical watertable depth, Dc, by providing adequate drainage, or by eliminating the source of the subsoil water supply (Smedema & Rycroft, 1983).

(c) Leaching intensity

Leaching of salts normally occurs during irrigation or rainy season. During this period the upward movement of salts is much reduced, occurring only for limited periods, i.e. in between two irrigations.

The reduction of the salt content in the soil brought about by irrigation water or rain depends on the quantity and quality of water percolating through the soil, water conducting properties of the soil (e.g hydraulic conductivity) and the moisture content of the soil (Verhoeven, 1979).

According to Van Schilfgaarde (1976), a favourable rootzone free of excess salts can be achieved by maintaining a net downward flux sufficient in magnitude to prevent excessive accumulation of salts in the soil solution. Even with a high watertable, upward flow will only occur when there is an upward gradient; an appropriate irrigation regime, in principle, can prevent such a gradient.

7. Effects of salinity and sodicity on crops and soils

Soil salinity and sodicity in various parts of the ect area have resulted in low crop production, forcing ners to abandon the salt-affected parts according to a rt by Asol (1984).

The effects of salinity and sodicity on crops and s can be categorised into three:-

Osmotic effects;

Toxicity effects;

Dispersion effects.

7.1. Osmotic effects

High total salt concentration of the soil solution ults in high osmotic pressures, making it more difficult plant roots to extract water from the soil. The amount water absorbed from the soil depends on the soil mois- stress which is the sum of the soil moisture tension osmotic pressure due to dissolved salts (Michael, 1983; dy, 1984).

The magnitude of osmotic pressure is linearly ated to the electrical conductivity of the soil solution hence salt concentration). Shainberg & Oster (1978) and doma & Rycroft (1983) give the following relationship;

otic pressure (bars) = 0.36 x EC, (mS/cm).

At low salt concentration the osmotic pressure is ignificant and water absorption depends more on the soil sture tension. Enough water for plant growth is absorbed n the soil moisture tension is below 1 bar (Michael, 3; Brady, 1984; USDA, 1971).

In saline soils (ECe > 4 mS/cm), the osmotic pressu- is over 1.4. bars, from the above relationship. If the ls moisture tension is 1 bar, then the total stress beco- 2.4 bars, causing a reduction in plant water uptake. In project area high ECe-values of 25 mS/cm in the topsoil - 30 cm) were obtained by Asol (1984). This would result an osmotic pressure of at least 9 bars and a total stress 10 bars and above. Far much less water than optimal would extracted from the soil and plant growth would be very ch more retarded; especially knowing that the permanent ting point for many crops is at about 15 bars.

2.7.2. Crop tolerance to salinity

The term "salt tolerance" indicates the degree of linity a plant can withstand without being appreciably fected in its growth and development. For each crop a rtain threshold value exists beyond which crop yields crease linearly with increasing salinity (Ayers & Westcot, 85; FAO, 1985; Jensen, 1983; Oosterbaan, 1987; Shainberg & ter, 1978). Crop tolerance tables exist indicating the e - values at yield potentials of 100%, 90%, 75%, 50% and . A table of crop tolerance for selected crops grown in e schemes is given in Table 2.7.

Crops with similar tolerance can be grouped together to 5 groups as shown in Table 2.8.

ble 2.7: Yield potential expected at the ECe-value indicated in the table, mS/cm.

	Yield potential				
ops	100%	90%	75%	50%	0%
tton	7.7	9.6	13	17	27
ize	1.7	2.5	3.8	5.9	10
ans	1.0	1.5	2.3	3.6	6.3
wpea	4.9	5.7	7.0	9.1	13
ions	1.2	1.8	2.8	4.3	7.4
mato	2.5	3.5	5.0	7.6	13
bbage	1.8	2.8	4.4	7.0	12
ange	1.7	2.3	3.3	4.8	8.0
mon	1.7	2.3	3.5	4.8	-
ocado	1.3	1.8	2.5	3.2	-

ource: Ayers & Westcot (1985); Smedema & Rycroft (1983); Shainberg and Oster (1978); Jensen (1983).

ble 2.8: Crop salt tolerance groups.

lative crop linity tolerance ting	Soil salinity at which yield loss begins ECe (mS/cm)
nsitive	< 1.3
derately sensitive	1.3 - 3.0
derately tolerant	3.0 - 6.0
lerant	6.0 - 10.0
suitable for most ops (unless reduced eld acceptable).	> 10.0

ource: Ayers & Westcot (1985); Jensen (1983); Shainberg & Oster (1978).

Asol (1984) found that the ECe-value in the crop otzone (<100 cm) was mostly above 5 mS/cm, for soils in e central part of Kimorigo scheme. From Table 2.7, only tton and, to a lesser extent, cowpea can produce tisfactory yields. The other more sensitive crops, cording to Kanake (1982), are grown in areas with low soil linity levels and adequate leaching. These areas are found ose to the Lumi river and in some parts of Kamleza scheme ere ECe - values of less than 1 mS/cm occur.

2.7.3. Toxicity effects

Problems due to toxicity are caused by a high ncentration in the soil solution of some particular ion by the imbalance between two or more ions, harming plant owth.

Most toxicity problems are related to excess up-ke of sodium, chloride and boron. In the project area, ly sodium levels have been noted to be high. ESP -values high as 90% have been reported by Kanake (1982). Symptoms e to Na-toxicity appear as a burn or drying of tissues rst appearing at the outer edges of leaves (Smedema & croft, 1983). Table 2.9 gives the tolerance of some ops grown in the schemes to exchangeable sodium percentage SP) under non-saline conditions.

From the table, cotton and tomatoes stand out as po-ible choices in areas with ESP-values of less than 60%, der non-saline conditions. Fruits are extremely sensitive d would be restricted to areas with low ESP-values in mleza (Kanake, 1982).

able 2.9: Tolerance of selected crops to exchangeable sodium percentage (ESP) under non-saline conditions.

olerance to ESP and ange at which affected	Crop	Growth response under field conditions
xtremely sensitive (ESP = 2-10)	Citrus Avocado Decidous fruits	Sodium toxicity symptoms are low ESP-values
ensitive (ESP = 10 -20)	Beans	Stunted growth at these ESP values even though the physical condition of the soil may be good
oderately tolerant (ESP = 20-40)	Rice Oats	Stunted growth due to both nutritional factors and adverse physical soil conditions
olerant (ESP = 40-60)	Cotton Tomatoes Wheat Barley	Stunted growth usually due to adverse physical soil conditions
ost Tolerant(ESP > 60)	Grass	"

Source: (Jensen, 1983; FAO, 1985).

So long as the ESP-values in affected scheme areas re not lowered, choice of crops will remain limited, mainly o cotton. In less affected areas, care should be taken to revent the ESP-values from rising too high.

.7.4. Dispersion effects

A high exchangeable sodium percentage (ESP) results dispersion of clay particles. This causes the soil ucture to deteriorate, leading to poor soil physical ditions (Smedema & Rycroft, 1983; Verhoeven, 1979; nberg & Oster, 1978).

That high ESP-values occur in the Taveta schemes is dent from results of both Asol (1984) and Kanake (1982). se high ESP-values have been particularly noted to occur heavy textured soils of the schemes (Kanake, 1982). This a major concern as problems due to dispersion are known generally increase with the increase of easily persible clay (Michael, 1983; FAO, 1985; Smedema & roft, 1983).

The poor physical soil conditions which result m dispersion of soil colloids include:

i) low hydraulic conductivity due to a) blockage of pores dispersed particles and b) also reduced size of soil es due to swelling or wetting;

i) unfavourable soil consistency; soils are hard to work n dry and plastic-sticky when wet;

i) low resistance to slaking which leads to the formation surface crusts hampering the infiltration of water into soil and the mechanical strength of the crust is likely hinder proper germination (irregular, patchy stands);

v) waterlogging, resulting from the general deterioration the internal drainage characteristics of the soil ociated with the above effects.

.3. Water quality

The quality of both irrigation and groundwaters are f prime importance because of their influence on the amount nd type of salts added to the rootzone. Waters of poor uality result in soil and cropping problems which reduce ields unless special management practices are adopted.

The suitability of water for irrigation is not only etermined by its quality but also by other factors such as oil, crop, irrigation, leaching and drainage conditions Van Hoorn, 1971). The quality of water may be considered as uitable for a certain type of soil or crop but as nsuitable for others.

The quality of both irrigation and groundwater are etermined by the following chemical characteristics of he soil solution:

. Total concentration of soluble salts, or salinity;
. Concentration of sodium relative to other cations, or sodicity;
. Anionic composition of the water, especially the concentration of HCO_3^- and CO_3^{2-} anions; and
. Concentration of boron and other elements that may be toxic to plant growth.

References for the above named four characteristics nclude Smedema & Rycroft (1983), Shainberg and Oster 1978), Van Hoorn (1971), FAO (1985).

The first three characteristics are briefly iscussed below as they are the most relevant to the study.

.3.1. Total salt concentration

Soluble salts in water principally include NaCl, aCl_2, $MgCl_2$, Na_2SO_4, $MgSO_4$, $NaNO_3$, KNO_3, Na_2CO_3, $NaHCO_3$ ccording to FAO/UNESCO, (1973); Shainberg & Oster, (1978); nd Smedema & Rycroft, (1983).

The total salt concentration may be expressed in g/l, e/l, ppm or by the electrical conductivity (EC) in mS/cm at 5°C and gives an indication of the salinity hazard. General lassifications exist with regard to the salinity hazard amely:

- Classification of the U.S. Salinity Laboratory (Smedema and Rycroft, 1983);
- USSR classification (Van Hoorn, 1971);
- Classification of Durand for North Africa (Van Hoorn, 1971);
- Classification of FAO (FAO, 1976/85).

The classification of the U.S. Salinity Laboratory s the one employed in Kenya and therefore the salinity azard of the waters in the project area will be classified n accordance with this classification. The salinity hazard nder this classification is as shown in the Table 2.10.

It should be noted that this classification and the thers mentioned can be utilized as a guide, but should not e used as a generalisation.

Waters of high salinity may be used for irrigation n highly permeable soils, where drainage is adequate, where rrigation water is applied in excess to provide onsiderable leaching and where very salt tolerant crops

Table 2.10: Classification of the U.S. Salinity Lab.

Salt concentration EC_i (mS/cm)	Salinity hazard
< 0.25	Low salinity(Class - C1)
0.25 - 0.75	Medium salinity(Class-C2)
0.75 - 2.25	High salinity (Class-C3)
> 2.25	Very high salinity(Class-C4)

Source: Van Hoorn (1971) and Smedema and Rycroft(1983)

selected (Van Hoorn, 1971). This is the case in North African countries where irrigation waters may have salinity values of 2 mS/cm and above. In these countries, the classification of Durand for North Africa is used. However, this classification is not presented here as it is not used in Kenya. The USSR classification is also not presented for the same reasons.

The classification of FAO is presented in Table 2.11 below. This classification sets higher limits than the U.S. Salinity Laboratory and is presented for comparison purposes only.

2.3.2. <u>Sodicity hazard</u>

The sodium content in water is very important, owing mainly to its effect on the soil. A high sodium content in the soil leads to high ESP-values and thus results in dispersion problems in other than sandy soils (see section 2.2.6.4).

ble 2.11: FAO Guidelines for irrigation water quality appraisal.

linity EC_i (mS/cm)	Evaluation
0.75	No problem
75 - 3.0	Moderate problem
3.0	Severe problem

urce: Smedema and Rycroft (1983)

The sodicity hazard of irrigation (or groundwater) given by the Sodium Absorption Ratio, (SAR - value) cording to Van Der Molen (1979), Smedema and Rycroft 983), Shainberg and Oster (1978).

R: = $(Na^{+})/((Ca^{2+} + Mg^{2+})/2))^{0.5}$ .... (2)

ere Na^{+}, Ca^{2+}, Mg^{2+} represent the concentrations of these ements in the irrigation water (me/l).

The relation between the ESP-value of the soil and e SAR-value is given below (Van der Molen, 1979 and Van orn, 1971).

P=100(-0.0126+0.01475SAR)/(1+(-0.0126+0.01475SAR)) ....(3)

The classification of the sodicity hazard according the US Salinity Laboratory system which is used by the nya Soil Survey is presented in Table 2.12.

able 2.12: US Salinity Laboratory Classification (adopted from Smedema and Rycroft, 1978)

odicity Hazard		SAR
ow	Class - S1	0 - 10
edium	Class - S2	10 - 18
igh	Class - S3	18 - 26
ery High	Class - S4	> 26

3.3: The adjusted Sodium Adsorption Ratio (SAR_{adj})

he Adjusted sodium adsorption ratio can be expressed as:- Smedema & Rycroft, 1983; Shainberg & Oster, 1978).

$$AR_{adj} = (Na^{+}/[(Ca^{2+} + Mg^{2+}/2)]^{0.5}) \times (1 + (8.4 - pH_{c})) \quad ...(4)$$

here $pH_c = (pK_2' - pK_c') + p(Ca^{2+} + Mg^{2+}) + p(AIK)$;

nd $(pK_2' - pK_c') = Ca^{2+} + Mg^{2+} + Na^{+}$;

$(Ca^{2+} + Mg^{2+}) = Ca^{2+} + Mg^{2+}$;

$(AIK) = CO_3^{2-} + HCO_3^{-}$;

p = concentration sum of;

AlK = alkalinity.

All units expressed in me/l. The adjusted SAR takes nto consideration changes in soil water composition that re expected to result due to certain combinations of water alts which either dissolve lime ($CaCO_3$) from the soil adding Ca) or deposit lime from the soil (reducing Ca). The sence of CO_3^{2-} and HCO_3^- can increase the sodium hazard irrigation water since they bring about the precipitation Ca and to a lesser extent Mg in the soil, hence reasing the relative amount of sodium in the soil ution and therefore the ESP-value. (Smedema and Rycroft, 3). Previously, the Residual Sodium Carbonate (RSC) was d to assess the risk of the concentration of HCO_3^- and $^{2-}$ in water. The RSC is given as below:

$$= (CO_3^{2-} - HCO_3^-) - (Ca^{2+} + Mg^{2+}) \text{ .... } (5)$$

All concentrations in me/l. The ratings are as lows shown in Table 2.13 (adopted from Van Hoorn, 1971; dema & Rycroft, 1983).

le 2.13: Classification of RSC-values

(me/l)	Water Suitability
25	Safe (no problem)
5 - 2.5	Marginal (moderate)
.5	Unsuitable (severe)

.4 Groundwater salt balance

For areas with drainage problems, the assessment of groundwater balance is of primary importance because;

a) the assessment enables the cause(s) of the drainage roblem to be determined in quantitative terms. This helps n the selection of the appropriate remedial measures e.g. f the cause is determined as seepage inflow, then a cut-off rain may be selected (Kessler & De Ridder, 1980 and zabolcs, 1976).

b) the assessment also enables predictions on the probable hanges in drainage status (or groundwater table conditions) f a given area to be made. The changes may be due to nfluencing environmental factors such as rainfall or human nterventions such as irrigation, drainage and control of looding. Based on the predictions made, the most ppropriate control measures(s) can be selected in advance Szabolcs, 1976).

As the project area has drainage problems such an ssessment for areas within the scheme is important.

4.1 Groundwater balance equation

The general expression of a water balance equation, given by Kessler and De Ridder (1980) and Oosterbaan 1987) is;

$$- 0 = \triangle \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

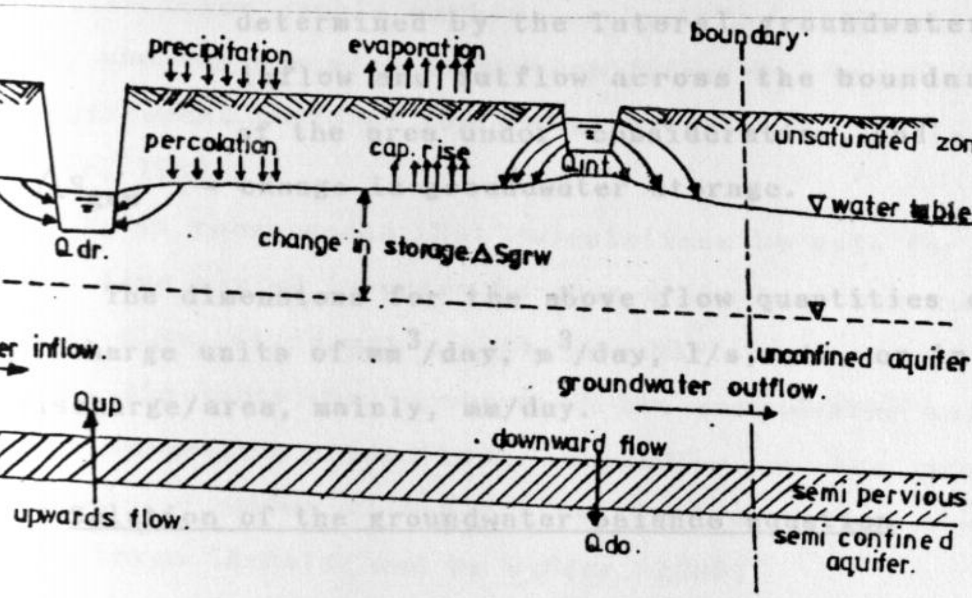
ere, I = inflow over time period, t days

0 = outflow over time period, t days

$\triangle$ = change in water storage in t days

In terms of the various recharge and discharge
onents, a more detailed equation can be written as
ows (see Fig. 2.5for the various groundwater flow
onents);

$$c-Cap)+(Q_{inf}-Q_{dr})+(Q_{up}-Q_{do})+(Q_{lsi}-Q_{lso}) = \Delta S_{grw} \quad ...(7)$$



2.5: Flow components of a groundwater sub-system (Kessler & De Ridder, 1980).

Where,

(Perc - Cap) = the recharge - discharge conditions determined by the water balance of the unsaturated zone.

$(Q_{inf} - Q_{dr})$ = the recharge - discharge conditions determined by the position of the water level in the stream channel and open water courses in relation to the water table.

$(Q_{up} - Q_{do})$ = the recharge - discharge conditions determined by the potential metric head in the underlying semi confined aquifer (see Fig.2.5).

$(Q_{lsi} - Q_{lso})$ = the recharge - discharge conditions determined by the lateral groundwater inflow and outflow across the boundaries of the area under consideration, and

ΔS_{grw} = change in groundwater storage.

The dimensions for the above flow quantities can be in discharge units of mm^3/day, m^3/day, l/s, etc, or in units of discharge/area, mainly, mm/day.

2.4.2 Solution of the groundwater balance equation

The components of the groundwater balance equation may be determined directly or indirectly to be able to solve the equation. Direct methods of determining the components are often expensive, especially for the vertical and lateral groundwater flow components, which require a lot of pumping tests and field work to find reasonable estimates of the transmissivity (KD - product of hydraulic conductivity of transmitting layer, K, and the depth of the layer, D) .

Kessler & De Ridder (1980) have recommended the use of the indirect method as it is less expensive and still gives a good indication of the magnitude of the groundwater flow components. The principle of the indirect method is that the area and time are chosen in such a manner that the conditions of recharge, discharge and storage are uniform and quantitatively known, except for one flow component. This component can then be solved from the equation. The component thus found can subsequently be introduced into the equation for another unknown item provided the value of the component remains reasonably constant. In general, lateral groundwater terms remain rather constant for different time periods, whereas percolation and capillary rise usually vary during different parts of the hydrological year (Kessler and De Ridder, 1980).

It is recommended that calculations be made for more than one time period in order to have a check on the results obtained. Also, it is not always possible, nor necessary to solve all the individual members of the groundwater balance equation separately. Sometimes, depending on the problem under study, a number of members can be lumped, and the net value be taken (Kessler and De Ridder, 1980).

Through the indirect method, the various components may be determined as follows:-

a) <u>(Perc-Cap)</u>

This may be determined by solving the water balance equation of the unsaturated zone expressed as;

$$(R + I_i - R.off) - ET - (P - Cap) = \Delta Ssm \quad .... (8)$$

where, R = precipitation; I_i = irrigation; R.off = surface runoff; ET = evapotranspiration; and $\triangle$Ssm = change in soil moisture storage.

During the rainy season, the following equation may be used;

$$P = R - ET - R.off \text{ ....}(9)$$

as $\triangle$Ssm = 0 (soil moisture at field capacity) and Cap = 0 (as there is percolation). For a short period of intense rainfall, covering only a few days, $\triangle$Ssm = Cap = 0 (as in eqn. (12) above) and Et can also be neglected during this short and wet period (Kessler and De Ridder, 1980), therefore,

$$P = R - R.off \text{ ....}(10)$$

The (P - Cap) term, may also be determined from the groundwater balance equation, as shown in (b) below.

(b) Total net groundwater flow

The groundwater flow components may be lumped together so that their total net effect can be found from the ground water balance equation, provided all other members are known. The net effect may be expressed as,

$$I'ss = (Q_{lsi} - Q_{lso}) + (Q_{up} - Q_{do}) \text{ ....}(11)$$

where, I'ss = total net effect of the individual groundwater flow components.

A period or area may be selected such that (Q_{inf} - $_{dr}$) term (from eqn. 9), is zero, i.e. when the channel network s dry or far away and does not directly influence the roundwater table of the selected area. The I's term may hus be determined from;

'ss = $\triangle$Sgm - (P - Cap) ....(12)

or a period when $\triangle$Sgrw = 0,

'ss = (Cap - P) ....(13)

f both P = Cap = 0 (no rainfall or irrigation and a deep ater table then;

I'ss = $\triangle$Sgrw ....(14)

c) <u>Determination of change in groundwater storage (/\Sgrw)</u>

According to Kessler and De Ridder (1980),

$\triangle$Sgrw = $\mu\triangle$h ....(15)

here μ = drainage pore space (or effective porosity).

Through frequent recording of the groundwater table, .e. from wells, the value of $\triangle$h may be determined. The ffective porosity, u, may be determined by:-

i) Estimation from the hydraulic conductivity, K, of the articular soil according to Smedema and Rycroft (1983)as,

= $(K)^{0.5}$ ....(16),

(ii) Estimation from tables, giving values of different soil textures from past experiments as below,

Table 2.14 : Effective porosity ranges for different materials (after Johnson, 1966).

Material	Effective Porosity (%) Range	Mean
Clay	0 - 5	2
Silt	3 - 19	8
Sandy clay	3 - 12	7
Fine sandy	10 - 32	21
Medium sandy	15 - 32	26
Coarse sand	20 - 35	27
Gravelly sand	20 - 35	25
Fine gravel	17 - 35	22
Medium gravel	13 - 26	23

Source: Kessler and De Ridder (1980)

(iii) Selecting a period of intense rainfall, such that,

$\mu = P / (\triangle h)$ ....(17),

(all other terms being zero),

(iv) If both P = Cap = 0 (no rainfall or irrigation and a deep watertable), and the value of I'ss is known, then;

$\mu = I'ss / (\triangle h)$ ....(18),

(v) If both I'ss and μ are unknown, then they can be determined from two different periods for which the supply is known, assuming the values are constant over two periods, a condition which is satisfied if the water table during the two periods is at the same elevation. By solving the two imultaneous equations below, the values of I'ss and u can be etermined.

$$'ss = u \Delta h /(\Delta t)_1 - (P - Cap)/(\Delta t)_1$$

.....(19)

$$'ss = u \Delta h/(\Delta t)_2 - (P - Cap/(\Delta t)_2$$

hese equations will be used during groundwater balance alculations in Chapter 7.

.4.3 <u>Salt balance and leaching requirement</u>

A salt balance can be prepared for a given area nd/or for a given soil layer and also for different periods f time. Quantification of the various components of a salt alance can serve to indicate if salinity is increasing or ecreasing, if measures should be taken and, if so, to uantify such measures (mostly in terms of extra irrigation ater and the drainage requirement).

As salinity problems exist in the crop rootzone of he project area, a salt balance assessment, for the crop ootzone, is of utmost importance. A salt balance equation f the crop rootzone can be derived from the water balance quation of the rootzone (unsaturated layer). Fig.2.6 shows he various water flows into and out of the rootzone. The ater balance of the rootzone can be written as :

ncoming water = Outgoing water + Change in moisture torage,

$$+ \ I_i + G \ = \ ET + P + \Delta Ssm, \qquad .... (20)$$

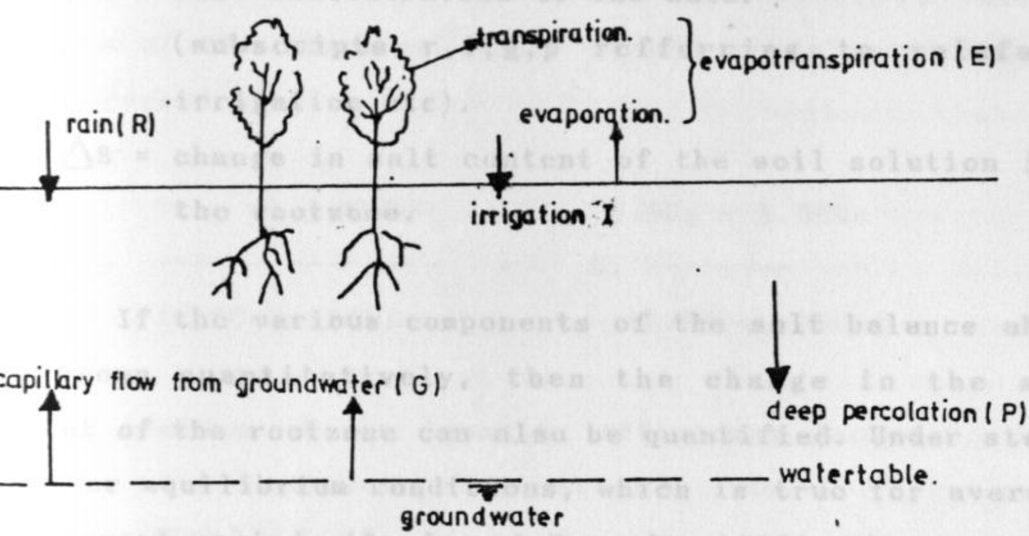


Fig.2.6: Water balance of irrigated land (Smedema & Rycroft, 1983)

where, R = infiltrating rainfall,

I = infiltrating irrigation water,

G = groundwater rising by capillarity,

ET = evaporation by crop or soil surface,

P = percolation below the rootzone,

$\triangle$Ssm = change in the soil moisture content (+ or −).

By affixing the salt concentrations of the various nflow and outflow water components above, the salt balance quation becomes,

$$.c_r + I_i.c_i + G.c_g = P.c_p + \Delta S, \ldots\ldots\ldots\ldots(21)$$

here, c = salt concentration of the water (subscripts r,i,g,p refferring to rainfall, irrigation,etc).

ΔS = change in salt content of the soil solution in the rootzone.

If the various components of the salt balance above re known quantitatively, then the change in the salt ontent of the rootzone can also be quantified. Under steady tate or equilibrium conditions, which is true for averages ver annual periods (Smedema & Rycroft, 1983), the change in oth the moisture can be considered as zero. In order to chieve a constant salt content in the rootzone over a imilar period, sufficient excess water can be provided to lassh out excess salts, consequently, $\Delta S = 0$. Also $c_r = 0$ s rainfall contains very little salt; Equations 20 and 21 an therefore be written as (for steady state);

$$_i = (ET - R) + (P - G) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(22)$$

$$.c_i = P.c_p - G.c_g \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(23)$$

The term (ET-R), represents the net crop irrigation equirement and (P-G), is the leaching requirement or the dditional irrigation water that must be applied to maintain he existing salt balance in the rootzone, i.e keep $\Delta S = 0$.

The salt concentration terms c_i, c_g, and c_p can be replaced by ECi, ECg, and ECp respectively as they are linearly related. The salt concentration or electrical conductivity of the of the percolating water on average equals 1.5ECe (Lenselink, 1988; Smedema & Rycroft, 1983). By incorporating the leaching efficiency factor, f, the salt balance of the rootzone, under steady state conditions can be expressed as;

$$f.I_i = \frac{(ET - R).1.5ECe}{(1.5ECe - ECi)} + G.\frac{ECg - 1.5ECe}{(1.5ECe - ECi)} \quad .....(24)$$

Values of the leaching efficiency factor, f, depend on the soil texture and structure, and the irrigation method. Table 2.15 gives f-values of different soil textures.

Table 2.15: Leaching efficiency factors

soil texture	f
loam, sandy clay loam, silt clay loam	0.4 - 0.5
silt loam, sandy loam	0.5 - 0.6
(heavy)- clay	0.1 - 0.3
silt clay	0.6
fine sandy soil	0.7 - 0.8

Source: Van Der Molen (1979)

5 Calcic and petrocalic horizons

(Petro)calcic layers are horizons of $CaCO_3$ cumulation which are mainly found in soil profiles of d and semi-arid climatic environments. Calcic horizons e discontinuous accumulations of $CaCO_3$ i.e. - are cemented, in mass, though nodules may be cemented (Wilding al., 1983 and Ruellan, 1973). In the project area, these cumulations have been referred to as soft caliche by ake (1982).

Petrocalcic horizons are continuously cemented or durated accumulations of $CaCO_3$ (Chorley, 1984; Brady, 36; FitzPatrick, 1980; Flint et al., 1983; and USDA, 59). The terms often used to describe this layer are iche (in USA); Croute Calcaire (or encroutement calcaire) France with the English translation being calcareous ust (lime crusting or calcareous encrustation). As ntioned by Bear (1955) and Kanake (1982), most parts of e Kimorigo and Kamleza Schemes are believed to be derlain by this petrocalcic horizon.

.1 Formation and development

These $CaCO_3$ accumulations are believed to be relicts om different climatic conditions in the Pleistocene to cent Age as reported by Young (1976), Wilding et al.(1983) Bear (1955).

There exists three different mechanisms which have en put forward to explain how the accumulations have been rmed. The mechanisms are:-

) Downward leaching model;

) Upward movement of calcium (bi)-carbonate rich groundwater; and

e) Lacustrine sedimentation.

a) Downward leaching model

This mechanism, as named by Young (1976), involves a process of salt movement and differentiation, occurring in two stages. The first stage is referred to as primary or undifferentiated salt movement (Chorley, 1984 and Wilding et al., 1983).

The primary salt movement is assumed to occur during periods of limited precipitation and a consequent shallow moisture penetration, when an undifferentiated movement of all soluble salts takes place from the upper horizons to the lower B- or C-horizons. These salts accumulate and eventually precipitate in solid forms as the soils dry out.

During periods of uncommonly wet years, which are accompanied by deeper soil moisture penetration, secondary salt movement is assumed to occur. This involves the leaching away of the most soluble solid phase precipitates and leaving the least soluble salts/components such as calcite ($CaCO_3$). In this way, an horizon rich in $CaCO_3$ is formed, whereas the more soluble salts of sodium, potassium and magnesium may accumulate at greater depth, or may be translocated vertically or laterally, or may be eventually leached away from the regolith (Wilding et al., 1983).

For the first mechanism to hold, there must be a readily available source of $CaCO_3$ either from a calcareous parent material (Flint et al., 1974; Ruellan, 1973; Wilding et al., 1983 and Young, 1976) or from a calcareous dust fall as in New Mexico (Wilding et al., 1983).

Objections to this first mechanisms are:-

(i) Origination of $CaCO_3$ from calcareous parent material is not wholly true as the horizons have been found to occur over non-calcareous parent material (Ruellan, 1973)

(ii) Weathering and ground lowering is a very slow process in dry regions and therefore the carbonates are not likely to have originated from rock weathering (Young, 1976).

(iii) Leaching of soluble materials downwards is minimal in dry regions because of the absence of percolating water and hence the quantities of $CaCO_3$ could not possibly have been leached (FAO, 1973 and Young, 1976).

(b) <u>Upward movement from a calcareous groundwater</u>

This second mechanism which seems to have more general support, assumes that the carbonates originate from groundwater rich in calcium (bi) carbonate (calcareous groundwater) by capillary rise. So long as this water is replaced by inward seepage then more and more carbonates will be transported and accumulated near the top of the capillary fringe (Chorley, 1984; Flint et al; 1974; Jackson & Erie, 1973; Wilding et al., 1983 and Young, 1976).

Chorley (1984), supports this mechanism by asserting that (petro) calcic layers (or $CaCO_3$ rich horizons) appear to be formed in areas of carbonate-rich groundwater where sheet floods dry out, capillary rise occurs and the watertable oscillates close to the ground surface.

c) Lacustrine sedimentation model

In this third mechanism, there is lacustrine edimentation and evaporation, possibly with some subsequent edistribution by leaching. This is supported by the fact hat many calcretes occur in basin like situations with very entle slopes (0.2-0.4%) according to Young (1976).

.5.2 Forms or types of the calcareous layer

The form of occurrence of the layer is important as t influences the movement of water through the soil vertically and laterally) and hence the drainage status of n area.

According to Ruellan (1973) and Wilding et al. (1983), he $CaCO_3$ accumulations have been noted to occur in ifferent forms or types although still falling under either Calcic (discontinuous) or a Petrolcalcic (continuous) orizon.

The different types are often related to the stage f the development process. According to Wilding et l.(1983), the development of the $CaCO_3$ rich horizons, in he presence of a ready source of $CaCO_3$, reportedly rogresses in two evolutionary morphological sequences of our stages each. One sequence occurs relatively rapidly in aterials of gravel and cobbles, the other occurs slowly in on-gravely, sandy or loamy material. Both sequences onverge on their fourth stage on an indurated petrocalcic orizon with a laminated, almost pure carbonate, upper ubhorizon. The stages of the development processes are as riefly discussed below;

Stage (i):

This consists of a diffuse accumulation with or ithout pseudo-mycellium. The calcareous profile may be escribed as weakly differentiated (Ruellan, 1973). For ravelly material, this involves coating of pebble bottoms ith carbonate and for non-gravely material, there exists an orizon with a few filamentary deposits or thin ped coatings f carbonate (Wilding et al.; 1983).

Stage (ii):

This is an horizon of soft concretions or nodules hard concretions) throughout the thickness of the profile or non-gravely material (Ruellan, 1973 and Wilding et al., 983). For gravely material, all pebbles are surrounded by arbonate and there exists a discontinuous or uncemented arbonate accumulation.

In this second stage, the horizon may be referred to s a calcic horizon (Wilding et al., 1983) or a moderately ifferentiated calcareous profile (Ruellan, 1973).

Stage (iii):

This stage consists of a cemented layer (continuous ccumulation) and is referred to as the Petrocalcic horizon Ruellan, 1983). The thickness of the layer varies from 10 m to more than 2 m. The calcareous profile at this stage can e said to be very well differentiated (Ruellan, 1973). The ayer may be:

1) non-platy;

) Platy, i.e. a crust normally surrounding a non-platy lime crusting; or

) a compact slab situated on a crust and on a non-platy lime crusting.

tage iv:

This is the final stage and involves the desposition one or more thick carbonate laminae on top of the trocalcic layer (Ruellan, 1973 and Wilding et al, 1983).

5.3 Calcium carbonate content of the horizons

The calcium carbonate content of the layers is riable. According to Ruellan (1973), the carbonate ntents are as given below:

weakly differentiated; the accumulation is diffuse with, sometimes pseudo-mycellium (carbonate content: < 40 %);

) moderately differentiated: there exists diffuse and nodular carbonate; nodules can be soft or hard (carbonate content: < 60 %).

i) very well differentiated: there exists a calcareous crust,(carbonate content: > 60 %).

3 METHODOLOGY

This chapter is divided into three sections. The first part (Sec.3.1), explains how it was intended to achieve each of the four project objectives as outlined in Chap.1, Sec.1.3. In Sec.3.2, details of the field investigations carried out are presented. The laboratory analyses of samples collected from the field are presented in Sec.3.3.

3.1 Plan of action

In the following parts (i) to (iv), the plan of action for each of the four project objectives is given.

(i) and (ii) - Drainage and salinity data

The two objectives required that data be provided to describe the existing state, extent and degree of the drainage and salinity problems in the project area. To provide the data, it was planned to carry out investigations on the groundwater and soil conditions.

The data on groundwater conditions of the area consist of ;-

- water-table position relative to the ground surface;
- fluctuations in the watertable levels ; and
- groundwater quality.

The depth to groundwater data help in identification of areas with drainage problems, i.e., they show where shallow groundwater tables occur. Data on groundwater table fluctuations help in identifying periods of high groundwater ble and thus show when drainage is required. The oundwater quality data are important with regard to soil linisation, especially when shallow groundwater table nditions exist.

The data on soil profile conditions included ;-

- soil salinity and sodicity status;
- soil texture;
- soil hydraulic conductivity; and
- the calcareous layer (caliche).

It is imperative to have data on the soil salinity d sodicity levels due to the effect of the two on crop oduction. Information on the hydraulic conductivity of the ils gives an indication of the subsurface drainability, e., a low hydraulic conductivity indicates poor or low tural subsurface drainage capacity of the soils. Soil xture data was required for three main reasons, (i) it fluences the rate of capillary rise from the groundwater ble and thus the rate of salt transport to the surface or otzone, (ii) the development of soil sodicity conditions influenced by the soil texture, and (iii) soil texture fferences down the profile have an influence on the vement of water through the soil i.e., vertical or rizontal drainage.

Information required on the calcareous layer was th respect to its depth below the ground surface, extent, ope, nature or form of occurrence and its thickness. These atures are likely to influence the drainage depth; rection and slope of possible (field) drains and water vement through the soil (vertical or horizontal).

In addition to the investigations on the groundwater nd soil conditions it was important to study the area's opography so as to :-

- provide a topo-map combining both Kimorigo and amleza schemes on which to reference the soils and ground ater data. The the existing topo-map at a scale of 1:10,000 nly covers a small part of Kamleza scheme;
- get present ground levels which would help in derivation f groundwater and caliche levels (a.m.s.l.). This was to nable the production of the groundwater and calcareous ayer contour maps;
- determine the location and adequacy of outlet conditions or evacuation of (possible) excess water and salts from the oject area; and
- obtain additional information regarding ground slopes; ocation of canals and drains; current scheme boundaries; epage areas, and relative levels between the Lumi river d the project area to check on the possible influence the ver may have on the on the area's drainage.

ii) Cause(s) of the drainage and salinity problems

The fulfillment of the third objective required at the possible cause(s) of the drainage problem (excess oundwater) and high soil salinity be quantitatively aracterised. To do this it was decided to assess the oundwater and salt balances of the area within the hemes. It is only after the cause(s) have been identified d quantitatively characterised that appropriate remedial easures can be recommended, e.g. if the source of excess ter causing the drainage problem is over-irrigation, the olution may involve education of the farmers on water the ource of salts rise from the groundwater, then lowering of he groundwater table or providing adequate water for eaching to counteract salts brought to the rootzone by apillarity flow may be the solution.

To determine the causes quantitatively meant the olution of the groundwater balance equation. As mentioned n Sec.2.4, the various terms of the equation which needed o be determined were :-

- (P − Cap),
- ($Q_{inf} - Q_{dr}$),
- ($Q_{up} - Q_{do}$),
- ($Q_{lsi} - Q_{lso}$), and
- ΔS_{grw}.

The (P − Cap) term i.e. the supply to the roundwater table from the unsaturated zone could be btained in two ways:

a) through solving the water balance equation of the nsaturated zone when all the other terms are uantitatively known (see sec. 2.4 eqn. 11), and

b) from the groundwater balance equation during periods hen the net groundwater flow, I'_{ss} and the change in roundwater storage Sgrw, are known (see sec.2.4 , eqn. 0).

The data to be collected for solving the two water alance equations above included :-

- daily precipitation data,
- daily evapotranspiration data,
- change in the groundwater table height, h, as a measure of the change in groundwater storage,

The water balance equations were to be solved for periods when only one of the components of the equations is unknown. The unknown components included :-

- net groundwater flow, I'_{ss} ,
- amount of irrigation water applied at predetermined times; this would lead to estimation of irrigation efficiencies,
- amount of infiltrated flood water, and
- the drainage pore space, μ .

The salt balance assessment is to be carried out assuming steady state conditions. The amount of extra irrigation water required to maintain favourable salt conditions in the rootzone will be used as an indicator of the possible salinisation without leaching (see Sec. 2.4.2). With information on the groundwater table and soil texture, it will be possible to determine the approximate rate of capillary rise and the leaching efficiency. Also the groundwater quality will be known from the groundwater quality investigations. Average rainfall and evapotranspiration figures are to be obtained from Table 2.1.

(iv) The appropriate remedial measures

With data on the drainage and salinity status in the area and after identifying and quantitatively characterising the possible causes of the drainage problem, then appropriate remedial measures could be recommended, thus fulfilling the final project objective.

2: Field work

Field work comprised topographic surveys, ground- d surface water investigations, and soil investigations as tailed in the following sub-sections.

2.1: Topographic survey

The survey was carried out in 5 months from eptember, 1988 to January, 1989 with the help of 3 - Survey sistants from the Ministry of Agriculture. The area was ivided into a grid pattern of 100 m x 100 m, using a heodolite, ranging rods and two tape measures of 50 m ength each. The elevations of the grid points were obtained the use of two automatic levels and levelling staffs. he collimation method was used to find the reduced ground evels of the grid points.

The total area surveyed was approximately 1500 ha see Fig. 4.1 for the survey boundary). The allowable isclosure during the topo-survey was 1 cm per Km. As a check uring the survey period, several cross - sections were drawn nd a comparison made with the ground topography as seen in he field. Where doubts were cast on the survey result, a epeat was done.

.2.2: Ground and surface water investigations

a) Groundwater investigations

Wells were set up in the field at a grid of 1000 m x 00 m, the longer side running to the parallel North-West to South-East road and the shorter length running perpendicular to this road from Kamleza Scheme towards the Lumi river as shown in Fig. 3.1.

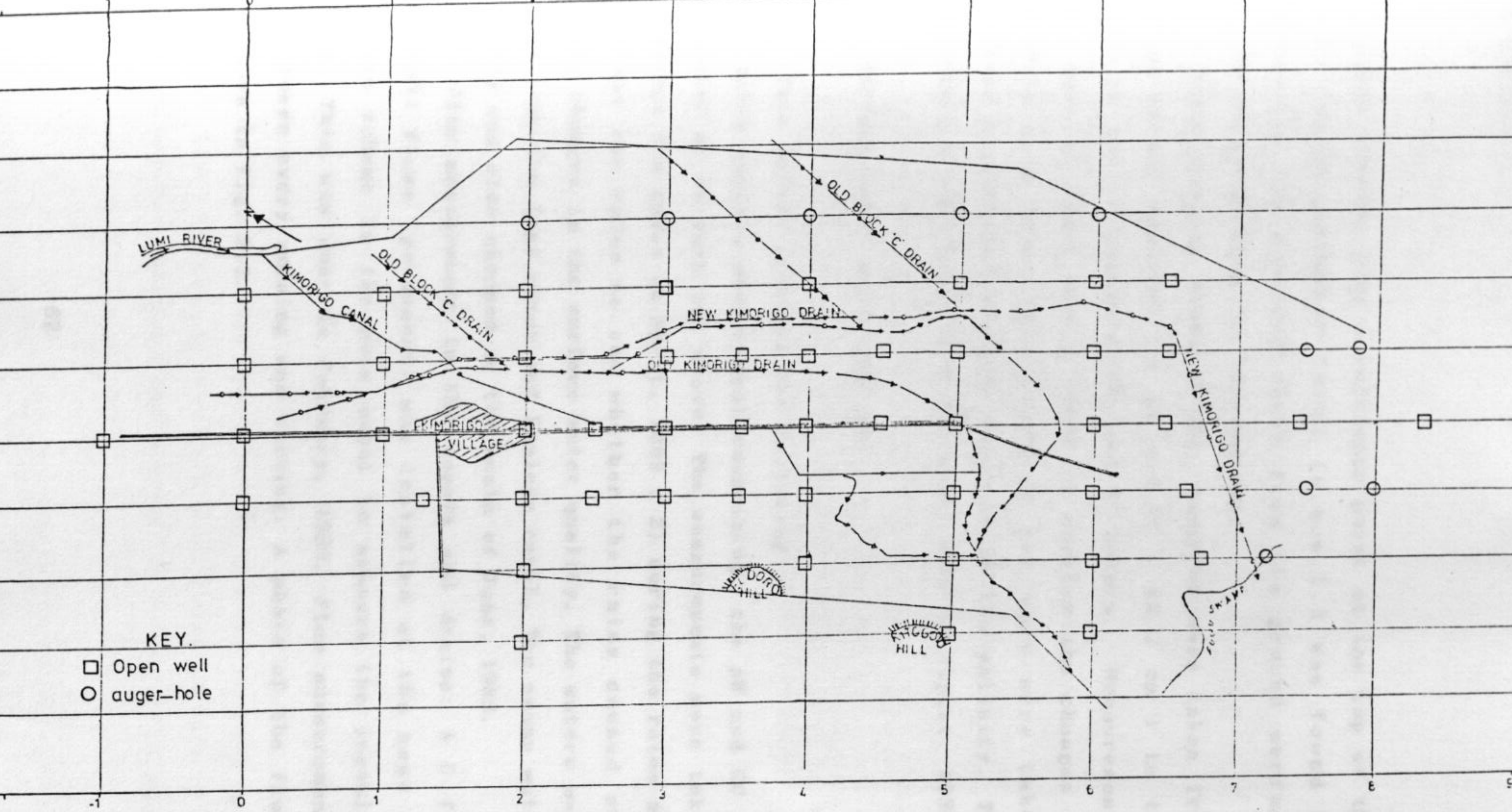
The wells were designated by a letter and a number e.g A2 as shown in Fig. 3.1. In a few cases, some wells do not fall under the grid of 1000 m x 500 m. This occurred when, (i) the well was previously existing, (ii) the well occurred towards the end of survey area and the distance remaining was less than 1000 m or 500 m , and (iii) when the well was set up later between two existing wells for further study of groundwater quality and depth.

A total of 50 open wells were dug in the area for the purpose of this study. In areas where the caliche layer was present, it was chiseled through. In addition to the open wells, 11 augerhole points were set up (5 along the G-line and the other 6 in the area close to the Ruvu swamp as shown in Fig. 3.1). The area covered by the wells and augerhole points in this study is approximately 2,250 ha. According to recommendations by De Ridder (1980), at least 40 wells should be set up for an area covering between 1000 - 10,000 ha and therefore the 61 measuring points are acceptable.

Most of the wells were set up between September, and December, 1988. The additional wells, in between the grid points, were set up at later dates.

Groundwater data collected from the wells were:-

1. Water level measurements:- these were measured on a weekly basis from 21/10/88 to 31/8/89, except during periods of rapid watertable fluctuations (rainy season or during heavy floods), when at least 2 measurements per week were taken. The depth to water level was measured in cm by use



ig.3.1: Well locations in the project area.

a tape measure from a reference point at the top of the ll. The groundwater level (a.m.s.l.) was found by otracting the measured depth from the ground surface evations known from the topo-survey.

Water quality measurements:- samples were taken from e wells and analysed for pH and EC (mS / cm) in the eld by use of portable pH- and EC-meters. Measurements re made at least once a month to monitor the changes of linity with time. More readings per week were taken enever significant changes occurred in the salinity. The asurements were taken from November, 1988 to August, 1989.

) Surface water investigations

This mainly involved the following :

) Water quality measurement comprising the pH and EC of e water as in part (a) above. The measurements were taken before the rains in April, 1989 ; 2) during the rains and after the rains to see whether the rains caused any rked changes in the surface water quality. The waters were ken from the Lumi river and Kamleza canal. The swamp water ality was also checked in the month of June, 1989.

i) Flow measurement in the canals and drains: A 5 ft-rshall flume (permanent) was installed at the head of mleza scheme in the main canal to measure the incoming ows. This was done in February, 1989. Flow maesurements re taken every morning and evening. A photo of the flume shown in Fig. 3.2.

Fig.3.3: 5-ft. Parshall flume constructed in the main Kamleza canal.

3.2.3 : Soil investigations

a) Investigation on the caliche layer:

Two sets of invesigations were carried out on the layer. First the depth to the calcareous layer from the surface was determined using Edelman soil augers (8 cm dia.). The augering was done at all the topo-survey grid points. The caliche level (a.m.s.l.) was obtained by subtracting the measured depth from the known grid point ound levels. This investigation covered the period tober, 1988 to January, 1989.

The second investigation involved noting the form of curence of the layer i.e., whether pervious, slightly rvious or impervious. This was done during well nstruction.

In addition to the above two investigations , a tal of 22 samples of the layer from 18 locations were llected for laboratory chemical analysis.

) Hydraulic conductivity measurement

Hydraulic conductivity, K, was determined in the eld using the auger-hole method (Van Beers, 1963, and edema and Rycroft, 1983). The equipment used for termination of the K-value in the field was obtained from jkelkamp Agrisearch Equipment, Netherlands.

The investigations were carried out in May-June 1989, en high groundwater tables existed in the area after the avy rains and floods in April. The sites at which the asurements were taken are presented in Fig. 3.3.

) Soil sampling for laboratory analysis:

The soils in the area have been investigated at a mi-detailed level by Kanake (1982). However, for this udy further investigations were carried out to ecifically note:-

) the influence of groundwater depth and quality on soil linity at various locations;

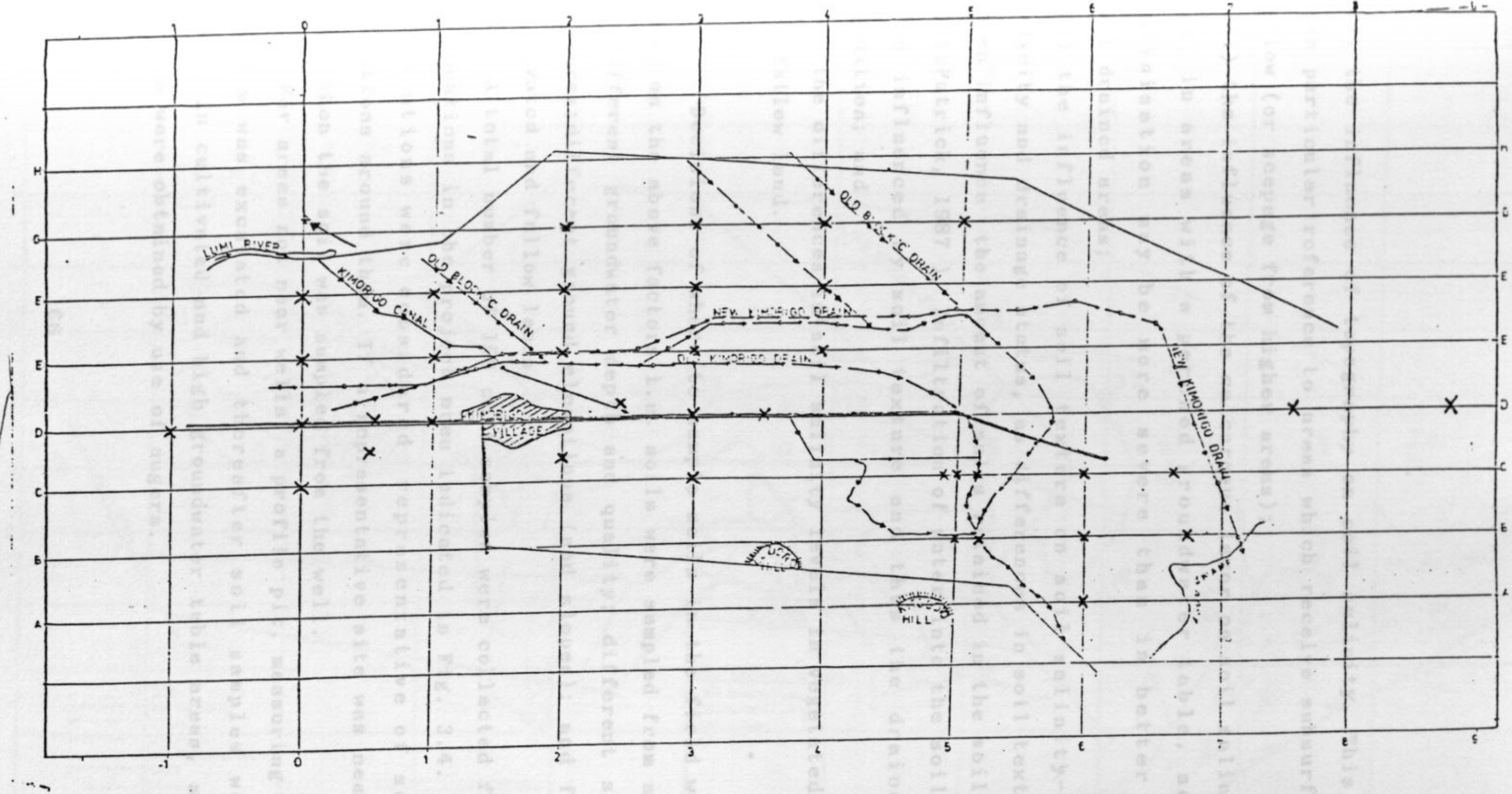


Fig.3.3: Hydraulic conductivity points.

ii) the influence of topography on soil salinity. This is ith particular reference to areas which receive subsurface nflow (or seepage from higher areas);

iii) the influence of the calcareous layer on soil salinity .g. in areas with a perched groundwater table, soil alinisation may be more severe than in better or ell drained areas;

iv) the influence of soil texture on soil salinity-odicity and drainage status, as differences in soil texture ften influence the amount of salts retained in the soil FitzPatrick, 1987). Infiltration of water into the soil is lso influenced by soil texture and thus the drainage ondition; and

v) the differences in soil salinity levels in vegetated nd fallow land.

Decisions of where to sample soils in the field were ased on the above factors i.e. soils were sampled from areas f different groundwater depth and quality; different soil extures;different ground elevations (and slopes); and from ultivated and fallow lands.

A total number of 150 soil samples were collected from 24 locations in the project area indicated in Fig. 3.4. The 24 locations were considered representative of soil conditions around them. If a representative site was near a well, then the soil was sampled from the well.

For areas not near wells, a profile pit, measuring 1.5 x 1.0 m was excavated and thereafter soil samples were taken. In cultivated and high groundwater table areas, soil samples were obtained by use of augers.

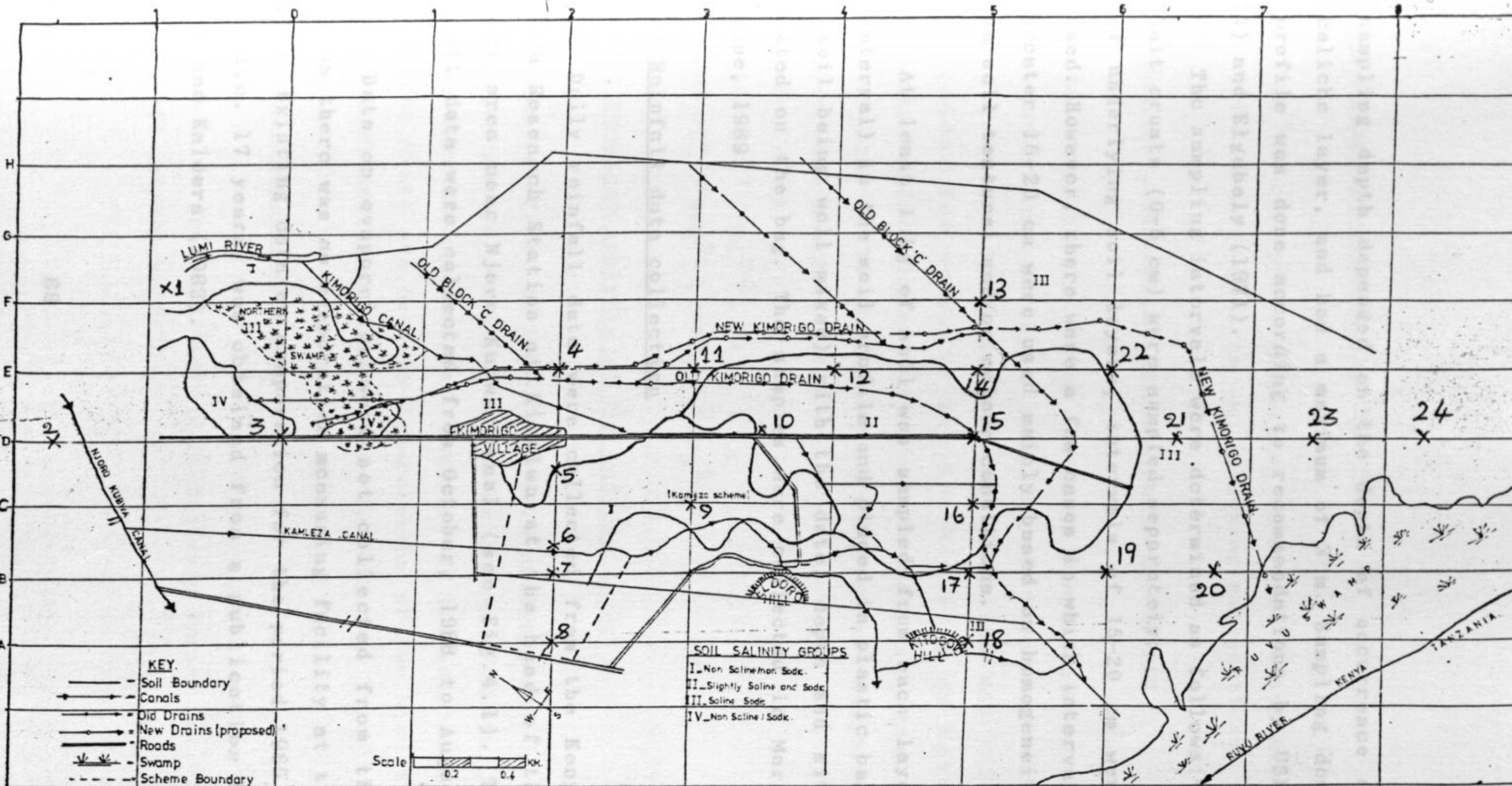


Fig.3.4: Soil sampling locations.

sampling depth depended on the depth of occurrence of caliche layer, and had a maximum of 3 m. Sampling down profile was done according to recommendations by USDA 54) and Elgabaly (1971).

The sampling intervals were determined as follows:-

Salt crusts (0-5 cm) were sampled separately;

For underlying soil layers, intervals of 15-20 cm were used. However, there were a few cases in which intervals greater 15-20 cm were used mainly based on homogeneity in soil textural and/or colour conditions.

At least 1 kg of soil was sampled from each layer interval) in the soil profile and placed in plastic bags e soil being well mixed) with the date, depth and site icated on the bag. The samples were collected in March June, 1989.

.4: Rainfall data collection

Daily rainfall data were collected from the Kenya aria Research Station at Kivalwa at the head of the ject area near Njoro Kubwa canal (see Fig.4.1). The nfall data were collected from October, 1988 to August, 9.

Data on evaporation were not collected from the ld as there was no evaporation measuring facility at the tion. Existing data on evaporation for the period 1965 - 2, i.e. 17 years, was obtained from a publication by ger and Kalders (1983).

.3: Laboratory investigations

The laboratory investigations comprised water and oil analysis as presented in the following sub-sections.

.3.1: Chemical analysis of surface and groundwaters

To determine the cation and anion composition of the urface and ground waters, samples of 3 litres were ollected from the field in November, 1988 and May, 1989 after rains) for analysis at the Ministry of Water evelopment Quality Laboratories at Industrial Area in airobi. A total of 36 samples were collected and analysed. he samples were analysed for :

- pH , EC (mS/cm) ;
- Cations Ca^{2+} , Mg^{2+} , Na^{+} , K^{+} ;
- Anions Cl^{-}, SO_4^{2-}, HCO_3^{-}, CO_3^{2-}.

3.3.2: Chemical analysis of the caliche layer

Samples of the caliche layer were analysed mainly to ind the percentage content of Ca.The contents of Na, K, g, and Fe were also determined. Analysis of the samples was one at the Mines and Geology Laboratories of the Ministry f Environment and Natural Resources, Nairobi.

.3.3: Soil chemical analysis

he soil samples from the field were analysed for:-

pH and EC (mS/cm) at 25°C ;

Exchangeable cations Na^+, K^+, Mg^{2+}, Ca^{2+} (in me/100g soil);

CEC (in me/100g soil).

i) EC - determination:

The electrical conductivity, EC, was measured using conductivity meter Bridge. A soil suspension of 1:2.5 soil:water ratio) was prepared and EC readings taken after t least 15 minutes of settling. The reading obtained was ecorded and the room temperature noted. The EC-value was hen converted to the standard temperature of 25°C by a orrection factor as recommended by USDA (1954).

ii) pH-determination:

Soil pH-values were obtained from suspensions of oil samples in water (1:1 soil:water ratio) and in 0.01M aCl_2 (1:2 soil:solution ratio). A Metrohm Herisan pH-eter, model E350B was used. Readings were taken after the ixture had been allowed to settle for 30 minutes.

iii) Exchangeable cations

Samples weighing 5 g were leached with 100 ml of mmonium acetate at pH 7.0, in stages of 25 ml each (4 eachings of 25 ml each).

A 100 ml of the soil leachate was then taken for the nalysis of the exchangeable cations at the Mines and eology Laboratories, Ministry of Environment and Natural esources at Industrial area in Nairobi, with an Atomic

Absorption Spectrometer. The determinations of the exchangeable cations was done for single leachates only , i.e. not in duplicate.

(iv) CEC - determination

Since most of the soils in the area are alkaline, as found by Kanake (1982), the CEC of the soils was determined by leaching of 5 g soil samples with 100 ml of 1N sodium acetate at pH 8.2 as recommended by USDA (1954). During this leaching exchangeable cations are replaced by Na^{+}-ions. This initial leaching was then followed by a second leaching with 100 ml of 96% ethyl-alcohol to wash out excess sodium ions from the soil. Finally the soil was leached with 100 ml of 1N ammonium acetate at pH 7.0 during which the Na+-ions in the exchange complex are replaced by NH_4^{+}-ions.The amount Na^{+}-ions in the final leachate was then determined using the same AAS machine as for the exchangeable cations above. The CEC equals the Na-content determined in me/100g soil.

3.3.4: <u>Soil textural analysis</u>

This involved the analysis of the texture of the soil samples for the % clay, % sand, and % silt using the hydrometer method (Brady, 1984).

4 TOPOGRAPHICAL RESULTS

4.1 Topographical features and ground contours

Based on the topographical data collected, a topographical map of the project area has been prepared as shown in Fig. 4.1. The map covers the area stretching from the Njoro Kubwa canal in the north-west to the Jipe and Ruvu swamps in the south. The Lumi River runs along the Eastern side to the swamps in the South. On the Western side of the schemes lie the Eldoro and Kitogoto Hills and along the Kenya-Tanzania border, flows the Ruvu River from the swamps to Tanzania.

Between the Njoro Kubwa canal and Kimorigo village there occurs a swampy area shown by the dotted lines in the map. The size of the swamp varies, reaching a maximum during the rainy season and approximating the dotted area.

On the topo-map are shown ground contours with a vertical interval of 1.0 m covering an area of around 1200 ha. The area is nearly flat with ground slopes varying from under 0.1 % in the Kimorigo, Block C and Ngutini areas to slightly over 1% in parts of Kamleza scheme on the hillslope of Eldoro and Kitogoto hills.

The contours show that the general direction of groundslope and hence surface drainage is from the hilly areas and the upper areas in the North-West towards the Block C area and eventually to the Jipe and Ruvu Swamps in the South.

The longitudinal profile in Fig. 4.2 also illustrates the variations in ground topography in the project area from the Njoro Kubwa canal (point N), along the North - West to South - East road to the edge of Ruvu swamp

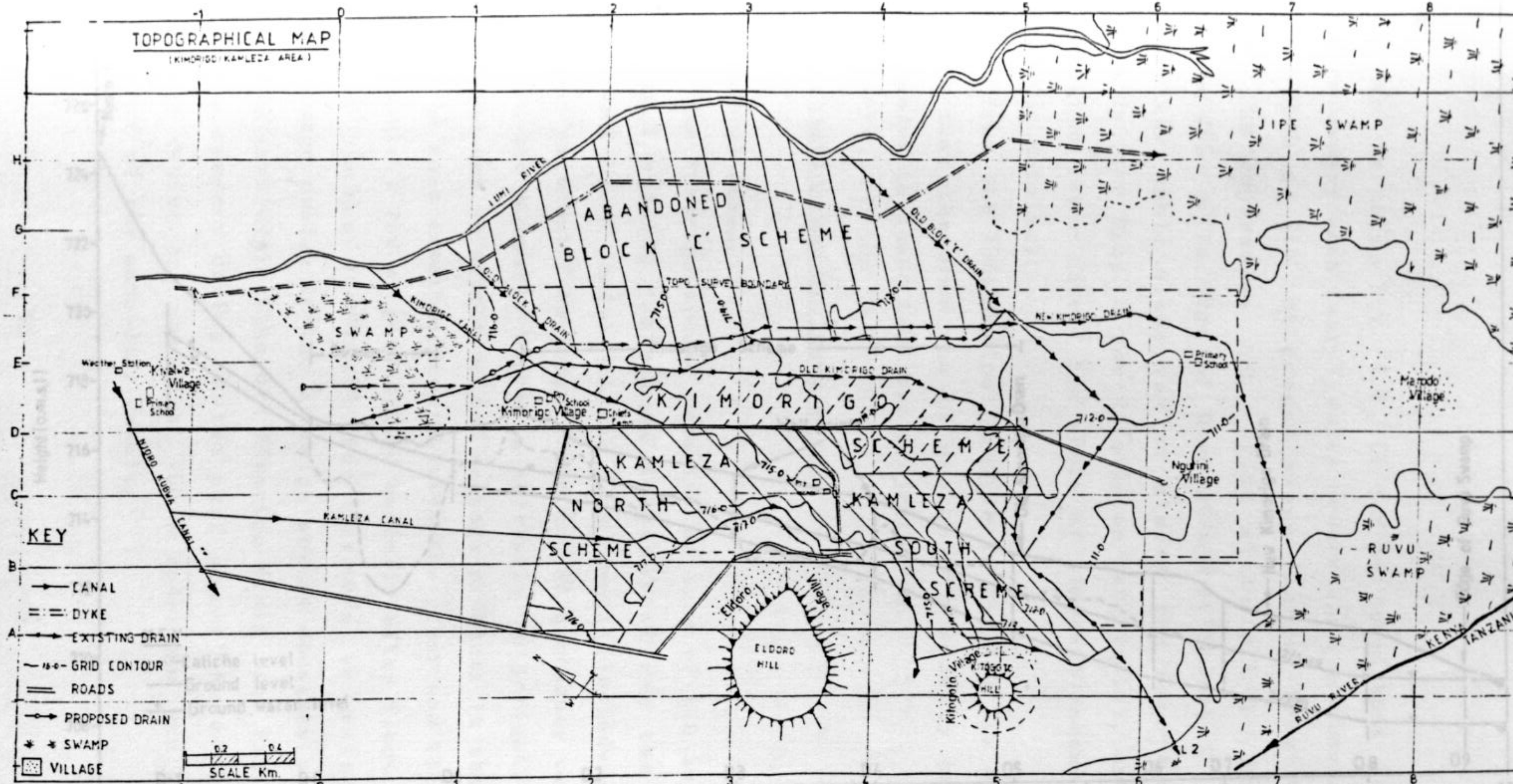


Fig. 4.1 Topographical Map of the project area.

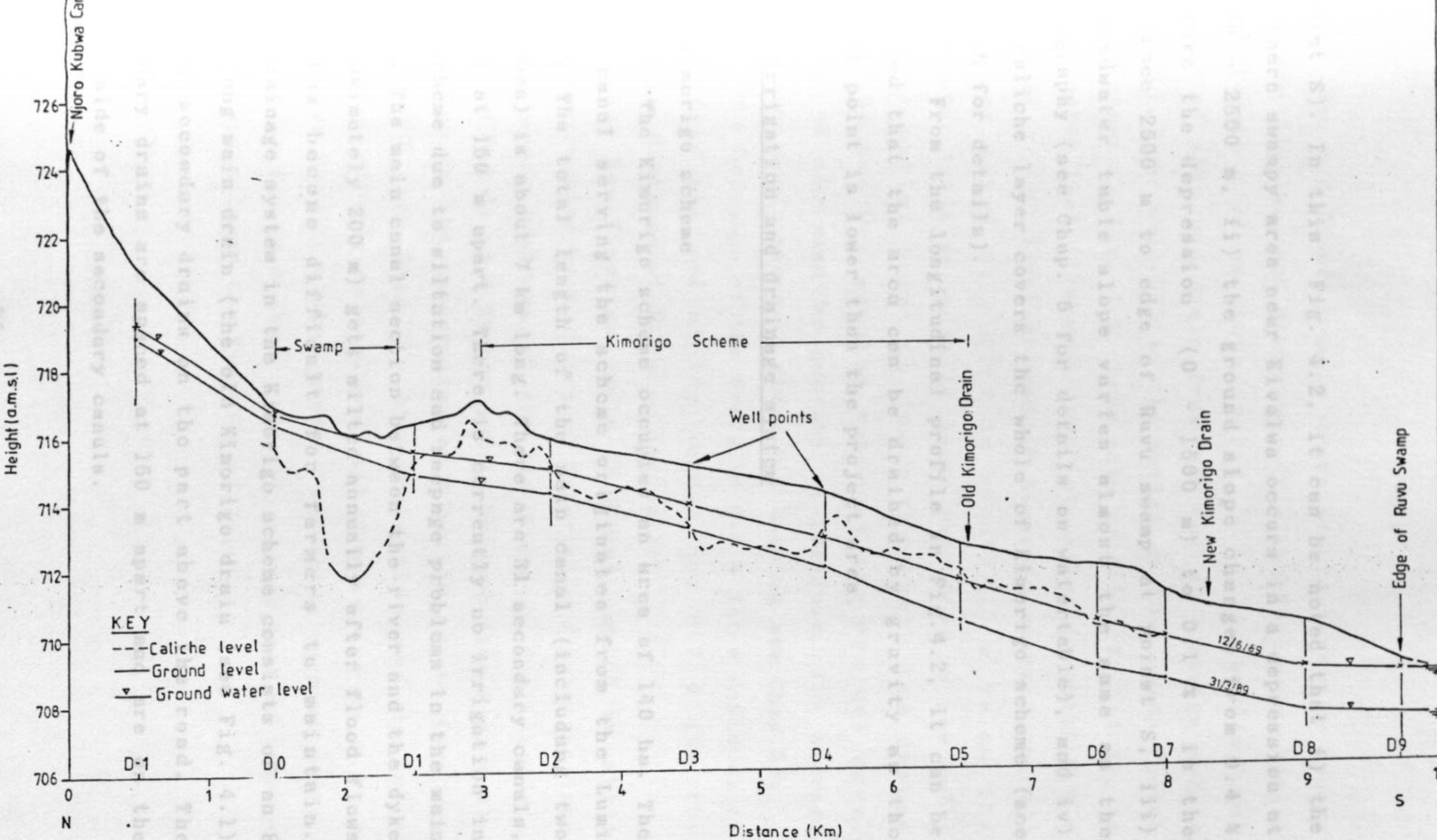


Fig.4.2: Longitudinal profile from Njoro Kubwa Canal (point N) to the edge of the Ruvu swamp (point S).

point S). In this Fig. 4.2, it can be noted that i) the northern swampy area near Kivalwa occurs in a depression at 1500 - 2500 m, ii) the ground slope changes from 0.4 % before the depression (0 - 1500 m) to 0.1 % in the distance 2500 m to edge of Ruvu swamp at poinst S, iii) groundwater table slope varies almost the same as the topography (see Chap. 5 for details on watertable), and iv) the caliche layer covers the whole of Kimorigo scheme (see Chap.6 for details).

From the longitudinal profile in Fig.4.2, it can be deduced that the area can be drained by gravity as the outlet point is lower than the project area.

4.2 Irrigation and drainage system

a) Kimorigo scheme

The Kimorigo scheme occupies an area of 140 ha. The main canal serving the scheme originates from the Lumi river. The total length of the main canal (includung two branches) is about 7 km long. There are 31 secondary canals, spaced at 150 m apart. There is currently no irrigation in the scheme due to siltation and seepage problems in the main canal. The main canal section between the river and the dyke (approximately 200 m) gets silted annually after flood flows and has become difficult for farmers to maintain. The drainage system in the Kimorigo scheme consists of an 8 km long main drain (the old Kimorigo drain (see Fig. 4.1) and 21 secondary drains on the part above the road. The secondary drains are spaced at 150 m apart and are on the upper side of the secondary canals.

The old Kimorigo main drain starts from the swampy rea near Kivalwa and discharges into the Ruvu swamp behind he Kitogoto hill as shown in Fig. 4.1. A longitudinal rofile of this old drain from the end of Kimorigo scheme point L1, near well D5) to the outlet at Ruvu swamp (point 2) is shown in Fig. 4.3. From this profile (Fig. 4.3), it an be noted that i) ground level at outlet is about 6.0 m elow the ground level at end of Kimorigo scheme, and ii) he water level at outlet is about 4.0 m below the roundwater table at point L1 (near well D5). As the water evel at outlet point is lower than both the ground levation and groundwater table of the project area, rainage of the area by gravity is possible. The average roundwater table slope is about 0.1 % (also see Chap.5).

The bedslope of the drain is 0.1 % for a distance of 600 m from the end of the scheme and 0.7 % for the emaining distance of 400 m to the outlet.

The New Kimorigo drain (8.9 Km), which is still nder construction by Ministry of Water also discharges into he Ruvu swamp upstream of the old Kimorigo drain outlet. ut of the 8.9 Km, 3.4 Km are yet to be done (see Fig. 4.1).

Due to the inoperation of Kimorigo scheme for long since 1966, see Chap.2), the irrigation and drainage ystems are rarely maintained. All drains are in a poor tate being heavily silted and/or vegetated in most parts. he photo in Fig. 4.4 shows a heavily silted part of the old imorigo drain (near the Kimorigo village).

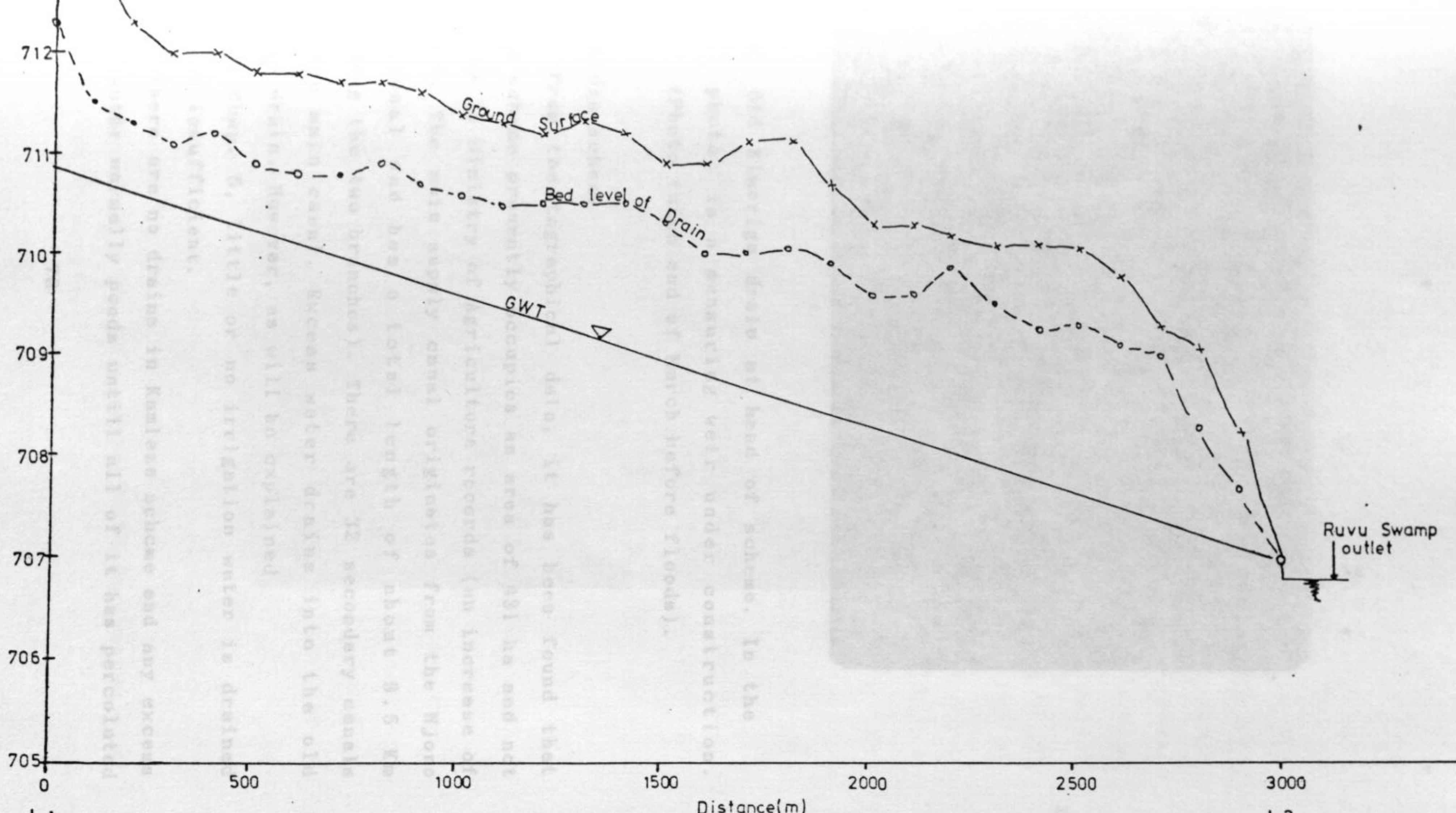


Fig.4.3: Longitudinal profile from end of Kimorigo Scheme

Fig.4.4: Old Kimorigo drain at head of scheme. In the photo is a measuring weir under construction. (Photo taken end of March before floods).

(b) Kamleza scheme

From the tographical data, it has been found that Kamleza scheme presently occupies an area of 431 ha and not 314 ha as in Ministry of Agriculture records (an increase of 117 ha.). The main supply canal originates from the Njoro Kubwa canal and has a total length of about 9.5 Km (including the two branches). There are 32 secondary canals along the main canal. Excess water drains into the old Kimorigo drain. However, as will be explained later in Chap. 5, little or no irrigation water is drained as it is insufficient.

There are no drains in Kamleza scheme and any excess surface water normally ponds untill all of it has percolated the groundwater table. Any excess irrigation water in Njoro Kubwa canal often results in high flows in the leza canal, especially if it occurs at night and the trol gate is not closed. The high flows overtop the main leza canal and together with increased seepage losses, ult in surface water ponding in the Kmaleza North scheme a (see Fig. 4.1). Such an incident was witnessed during period December, 1988 to January, 1989 and this is as wn by the Photo in Fig. 4.5. This caused a lot of age to crops as can be seen in the photo.

.4.5: Flooding of farms in Kamleza North due excess flow in the main canal.

There is a lot of surface runoff from around the
doro and Kitogoto hills into the Kamleza scheme. However,
is surface runoff does not cause any damage as it gets
to the main canal and is subsequently discharged into the
d Kimorigo main drain.

:) Block C area

This is a formerly rice irrigated area of 400 ha.
ne irrigation and drainage infrastructure are still
ident, only that they are silted and vegetated in most
arts. However, during the flood flows, they channel
oodwater into the Block C and Kimorigo area and are thus a
enace. In Fig. 4.1, only two main drains have been
ndicated. The irrigation canals and other drains are not
nown.

3: Flood problem

There exists a serious flood problem in the project
rea. The floods, as mentioned in Chap.2, originate from the
. Kilimanjaro area and occur during the short and long
ains. The short rain floods are of low magnitude and do not
ause much damage. However, the floods which occur during
he long rainy season cause a lot of damage. These floods
ormally occur between the months of March and May, and for
few days only (flash floods). While there exists a flood
ontrol dyke on the project side of the river (see Fig.
.1), this dyke is ill-maintained and so are the flood and
torm drains on the river and landside of the dyke
espectively. The floodwaters affecting the schemes pass
hrough a breach (broken area) of the dyke in the upper

areas around Kivalwa (near Njoro Kubwa canal) as shown by the photo in Fig. 4.6. The whole Kimorigo scheme and the lower parts of Kamleza scheme are affected by these floodwaters. The floodwaters affecting the Block C area also originate from breaches in the lower parts of the dyke and are led into the area by existing old drainage canals and the storm water drain on the landside of the dyke (See Fig. 4.1)

Fig.4.6: Flood flow through a breach near the head of the dyke (Photo taken on 5/4/89 on the day of floods).

As the old Kimorigo main drain is silted, its charge capacity is reduced. The drain therefore overflows the floodwaters spread onto the adjacent lands as seen Fig. 4.7. These floodwaters cause a lot of damage as cussed later in Sec.4.5.

. 4.7: Overflow of the old Kimorigo drain during floods. (5/4/89)

Relative elevation difference between the river and project area

From the topograhical data, it was found that the ver lies at higher elevation than the adjacent lands of project area as shown by the two longitudinal profiles

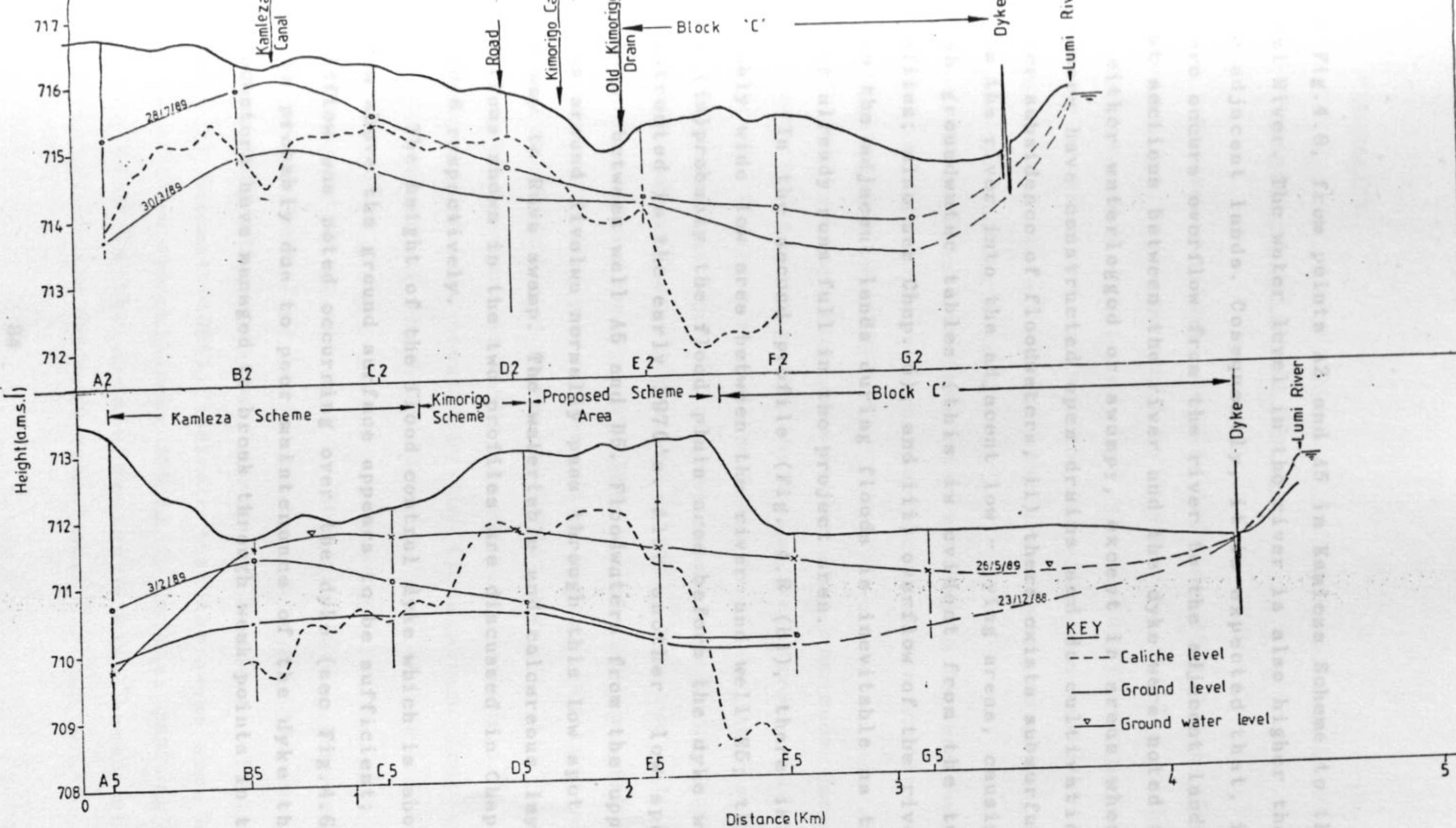


Fig.4.8: Longitudinal profiles from Kamleza Scheme to the Lumi river.

Fig.4.8, from points A2 and A5 in Kamleza Scheme to the mi River. The water level in the river is also higher than e adjacent lands. Cosequently, it is expected that, i) ere occurs overflow from the river to the adjacent lands; st sections between the river and the dyke were noted to either waterlogged or swampy, except in areas where rmers have constructed open drains and do cultivation 'ter subsidence of floodwaters, ii) there exists subsurface om the river into the adjacent low - lying areas, causing gh groundwater tables (this is evident from the two ofiles; also see Chap. 5), and iii) overflow of the river to the adjacent lands during floods is inevitable as the ver already runs full in the project area.

In the second profile (Fig. 4.8 (b)), there is a tably wide low area between the river and well E5; this s (is)probably the flood plain area before the dyke was nstructed in the early 1970's. Also another low spot curs between well A5 and D5. Floodwaters from the upper eas around Kivalwa normally pass through this low spot on e way to Ruvu swamp. The watertable and calcareous layer sitions shown in the two profiles are discussed in Chaps. and 6 respectively.

The height of the flood control dyke which is about .0 m above the ground surface appears to be sufficient; no oodflow was noted occurring over the dyke (see Fig.4.6). is probably due to poor maintenance of the dyke that oodwaters have managed to break through weak points in the yke.

4.5: Discussion

4.5.1 Drainage situation in the area

The topographical results indicate that (i) surface drainage from the area would be low due to the low ground slopes (around 0.1 %), and (ii) the natural subsurface drainage or gravitational outflow from the area would be low as the drainage base is high (the area drains into the Lake Jipe and surrounding swamps).

The prolonged surface water ponding in Kamleza North scheme highlights the serious surface drainage problem in the project area (see Fig.4.5).

Another important observation that was made during the study is the change in the swamp boundary. In the profile in Fig. 4.2 from Njoro Kubwa canal to the swamp edge, it was found that the current swamp edge is about 600 m further inland (point S instead of S1). This can only be true if the water levels in the lake are rising, encroaching on adjacent land (and encouraging swampy vegetation). Underhill (1955) and Farrant (1966) have in the past reported that water levels in the Lake are rising, due to high amounts of silt brought by the flood waters from the catchment areas of the Lumi River in the slopes of Mt. Kilimanjaro.

According to a report by Kalders (1986), the water level in the Lake Jipe has risen by 1.0 m in the period 1954 to 1986 (32 years); an average of 3 cm/year. Further reports by Farrant (1966), indicate that the swamp area has increasesd from approximately 259 ha in 1906 to 3627 ha in 1965. A rise in the area's drainage base level will adversely affect the drainage situation.

5.2 Causes of surface drainage problems in the project area.

The sources of excess surface water in the project rea include i) floodwater, ii) irrigation water, and iii) recipitation. Overflow from the river onto the adjacent and between the river and the dyke can also be considered s a source of excess surface water. By far floodwater can e considered as the major causative factor of the drainage roblems, firstly, due to the wide area affected by floods nd secondly, the amount of floodwater flowing over the area.

The flood results in siltation of canals and drains, estroys or washes away canals, and causes damage to farms nd crops in the schemes. The roads in the project area also et destroyed. Villagers in Kimorigo often have to emigrate o higher ground in severe flood incidences as their houses ecome flooded (some get destroyed and have to be rebuilt).

After the flood flow over the farms which occurs n early part of the cropping season (mid-March to mid-pril), replanting has to be done in most of the farms. here the crops have not been washed away, the resulting aterlogged soil conditions retards growth and yellowing of rops occur as shown by the photo in Fig.4.9.

In conclusion, the investigations have shown the nadequacy of the existing surface drainage and flood ontrol facilities in the project area and there is need to:

i) Maintain and repair the dyke and the existing drains so s to improve the control of floodwater and any surface flow from either rainfall and/or irrigation. Improvement of the urface drainage status will also reduce amount of percolated water to the groundwater table and thus a reduced

Fig. 4.9: Yellowing of cotton crop under waterlogged conditions in Kamleza South (May, 1989).

burden for subsurface drainage requirement. The completion of the remaining 3.9 km of the New Kimorigo main drainage canal, with a discharge capacity of 2.5 m^3/s will greatly alleviate the drainage problems in the area.

(ii) look into ways of improving the channel capacity of the Lumi river, especially in its lower reaches where the water level is at a higher elevation than the adjacent land (See Fig. 4.5). With continued siltation, both the lake and river water levels are bound to rise to even higher levels n the future worsening the drainage problems in the area. here will be more flood incidences even at low flows and ncroachment of adjacent land by swampy vegetation is bound o increase.

iii) Improve soil conservation measures in the catchment f the Lumi River in the lower slopes of Mt. Kilimanjaro so s to reduce surface runoff. This may require the co-operation between the two neighbouring governments of Kenya nd Tanzania.

5. SURFACE AND GROUNDWATER RESULTS

5.1 Surface water investigation results

Investigations on the surface waters of the project area consisted of (i) monitoring of the variation of the pH and EC in (mS/cm) with time, (ii) determination of the cation and the anion composition of the waters, and (iii) flow measurement in the Kamleza canal (see Chap.3).

5.1.1: Variation in pH and EC of the surface waters

The pH and electrical conductivity of the irrigation water (EC) in Kamleza canal and the Lumi river were monitored between March and June, 1989 to check on any variations due to annual occurrence of heavy rains and floods in April.

The results obtained are presented in Table 5.1 and indicate that no major variation occurred in the salt content of the waters during the period March to June, 1989. Floods occurred on 5 - 4 - 1989 and lasted 3 - 5 days.

The EC of the water sample from the Lumi river on the day of the floods was found to be lower than in the periods before and after the rains; this could be attributed to dilution of the river water by the flood waters with a lower salt concentration.

5.1: Variation of pH and EC (mS/cm) in the Kamleza canal and Lumi River.

	Date	EC at 25°C	pH	Comments
	27/3/89	0.25	8.3	before floods in April.
	5/4/89	0.23	8.2	day of floods
	22/5/89	0.32	8.7	after floods, light rains.
	30/6/89	0.24	8.2	dry season (no rains)
ver	20/3/89	0.22	7.9	before floods
	27/3/89	0.20	8.1	before floods
	5/4/89	0.15	8.2	day of floods
	30/6/89	0.23	8.3	dry season (no rains)

.1.2 Chemical analysis results (laboratory)

The results of the laboratory analysis of the surface aters are as shown in Table 5.2. The waters from Njoro Kubwa anal, Kamleza canal and Lumi river have medium salinity and ow sodicity hazards according to the US Salinity Laboratory lassification System (Chap.2, Table 2.4). The RSC-value for ll the waters is zero, hence there is no danger of odification from the use of the waters (Chap.2, Tab.2.7).

The swamp water has a high salinity hazard but a ow sodicity hazard. Although the sodicity hazard is low, the SC-value of 9.3 me/l is high (see Chap.2, Tab.2.7) ndicating that there is a danger of sodification should the ater be used for irrigation.

Table 5.2: Chemical analysis results of various surface waters.

Parameters	Njoro Kubwa canal	Lumi River	Kamleza canal	Ruvu swamp	Kimorigo Drain
pH	7.5	7.4	7.4	8.6	9.2
EC, mS/cm	269	254	268	1696	2642
Ca, me/l	0.9	0.9	0.9	2.2	0.6
Mg, ,,	1.3	1.3	1.3	1.3	0.4
K, ,,	0.3	0.5	0.6	12.3	16.3
Na, ,,	0.1	0.09	0.1	0.2	0.7
TH, ,,	2.0	2.1	2.1	3.4	1.0
TA, ,,	2.1	2.0	2.0	12.8	17.4
Cl, ,,	0.1	0.3	0.08	2.5	8.3
SO_4 ,,	0.09	0.1	0.1	0.9	0.5
SAR	0.3	0.5	0.6	9.3	23.1
RSC, me/l	0	0	0	9.3	16.4
Class	C2-S1	C2-S1	C2-S1	C3-S1	C4-S4

NB: TH = Total Hardness TA = Total Alkalinity

The water from Kimorigo drain is of the poorest quality of all the surface waters, with a very high salinity hazard (C4) and a high sodicity hazard (S4); this shows that the drain helps in removing salts from the area. The RSC-value is also high, indicating the potential sodification danger.

5.1.3: Quantity of irrigation water in the main Kamleza canal

Water flows in the main Kamleza canal at the head of the scheme were measured by means of a 5 ft. Parshall flume. Flow data were collected from the second week of March, 1989 to end of July, 1989. The water depth measurements at the flume were converted into discharge units (l/s) by use of standard tables for a 5 ft. Parshall flume. The flows btained in l/s as average (from 2 daily readings) for a 24 hour duration are given in Table 5.3.

5.3 : Discharge in the main Kamleza canal at head of scheme (l/s) - 1989.

MAR	APR	MAY	JUN	JUL
-	156	43	136	236
-	146	43	72	250
-	146	< 43	63	242
-	112	55	0	243
-	457	68	0	235
184	43	68	0	263
112	97	104	57	221
82	205	57	205	270
82	241	(71)	35	245
82	385	(316)	68	270
0	174	(145)	75	250
0	81	(184)	54	213
0	157	(87)	243	203
165	188	(62)	252	224
302	165	96	165	290
146	179	(84)	201	174
204	179	(47)	296	163
235	128	(145)	296	236
184	(125)	(238)	224	300
256	(110)	(47)	< 43	276
184	128	(110)	< 43	301
184	(140)	(158)	49	301
184	(140)	(84)	< 43	285
184	(145)	(174)	341	311
146	(124)	(174)	266	238
146	96	0	238	250
165	0	0	212	305
165	0	0	168	285
156	< 43	0	205	250
174	< 43	0	247	224
174		0		186

47) = Flow determined assuming 96 % submergence, otherwise actual submergence is 100 %. For all other cases without the brackets, the submergence ratio is less or equal to 96 %.

The bracketed flows correspond to periods of 100 % submergence as a result of heavy growth in the canal causing water back-up upto the flume structure (see footnote at end of Table 5.3).

Irrigation mainly takes place in the months of June to October when there is very little or no precipitation (see Table C-1, Appendix C). Cotton, maize and vegetables are the main crops grown under irrigation between March to July/August. From September to December, only maize and vegetables are cultivated. From the data in Table 5.3, normal water flow in the canal occurred during the month of July, the average daily flow being 250 l/s. In the months of January to Mid-March, farmers carry out land preparation and any water in the canal is mainly for domestic and livestock consumption. From mid-March there is some irrigation but this halts with the onset of heavy rains in late March to May.

The graph in Fig. 5.1 shows the variations in the daily flows in the main canal. Peak flows of around 400 l/s occurred when there were floodflows in the main Kamleza canal. Two other high flows of around 350 l/s in May and June are due to excess flow in the canal, possibly as a result of high water levels in the Njoro Kubwa canal from where Kamleza scheme gets its water. Periods of zero flow in the canal correspond to times when there is canal maintenance and/or repairs.

The total scheme area of Kamleza was found to be 431 ha. However, the area under irrigation is lower than this due to either salinity or absentee farmers (see Chap.6 for details on areas affected by salinity). The average discharge of 250 l/s is not sufficient for the 431 ha. Considering the month of October with the highest evapotranspiration of 4.8 mm/day (see Table C-2, App.C), during the irrigation seasons, the scheme water requirement for a 24 hour daily irrigation with an average crop factor of 0.9 and overall irrigation efficiency of 50 % is 0.9 l/s/ha. For 431 ha., the discharge required would be 388 l/s. The 250 l/s would be sufficient for 278 ha. Farmers normally complain of insufficient water, especially those at the tail end of the scheme, and the flow measurement results prove that this is so.

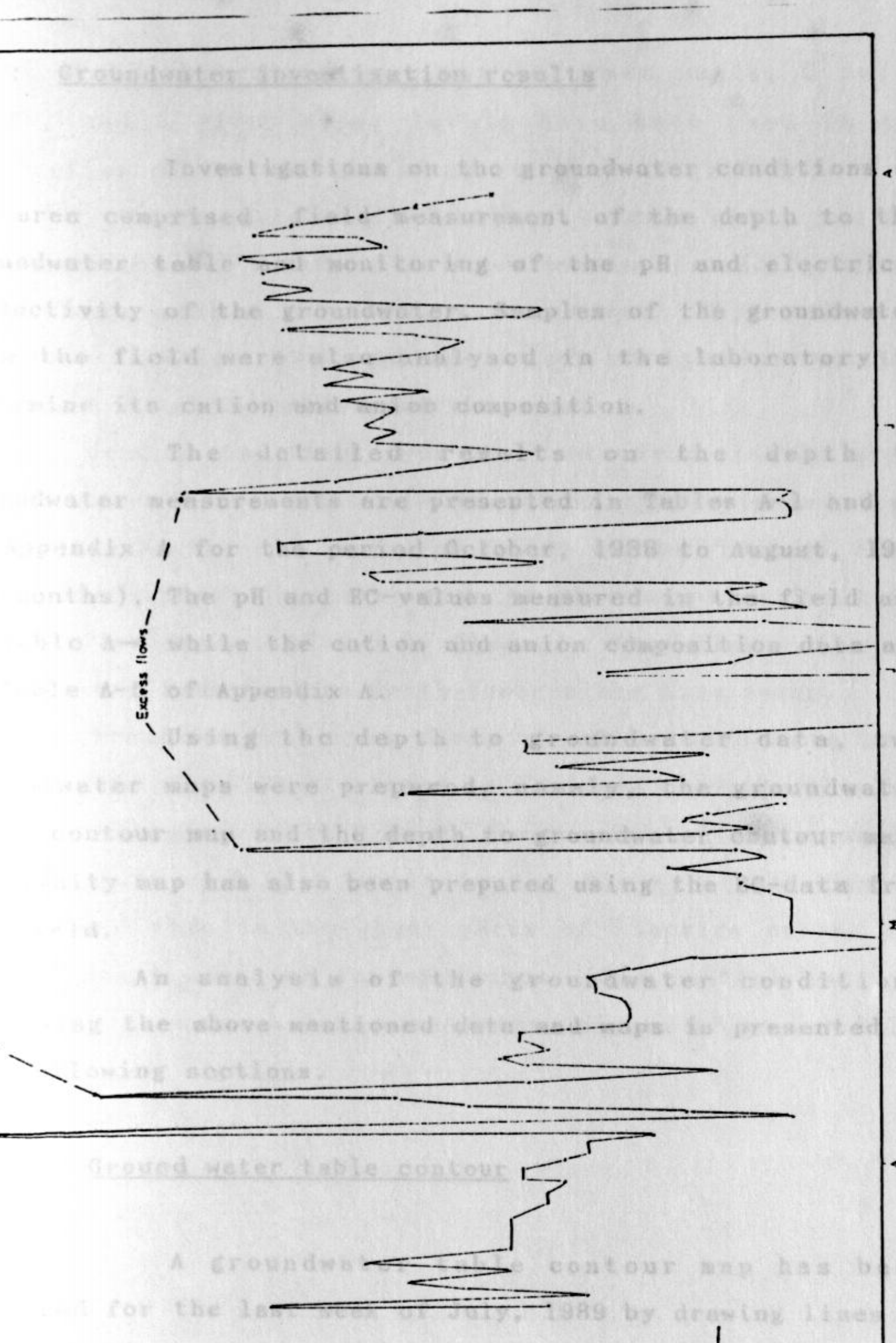


Fig.5.1: Variations in canal flows at the head of Kamleza scheme.

.2 : Groundwater investigation results

Investigations on the groundwater conditions of he area comprised field measurement of the depth to the roundwater table and monitoring of the pH and electrical onductivity of the groundwater. Samples of the groundwater rom the field were also analysed in the laboratory to etermine its cation and anion composition.

The detailed results on the depth to roundwater measurements are presented in Tables A-1 and A-, Appendix A for the period October, 1988 to August, 1989 10 months). The pH and EC-values measured in the field are n Table A-4 while the cation and anion composition data are n Table A-5 of Appendix A.

Using the depth to groundwater data, two roundwater maps were prepared, namely, the groundwater able contour map and the depth to groundwater contour map. salinity map has also been prepared using the EC-data from he field.

An analysis of the groundwater conditions employing the above mentioned data and maps is presented in he following sections.

5.2.1 Ground water table contour

A groundwater table contour map has been prepared for the last week of July, 1989 by drawing lines of equal watertable elevation. The water table levels (a.m.s.l.), were obtained by subtracting the depth to water level measurements of 28/7/89 from ground surface elevations at the observation points (see Table A-3, Appendix A). A otal of 52 observations points (41 open wells, 6 auger noles, and 5 river water levels have been used in the preparation of the watertable contour map (Fig. 5.2).

The date of 28/7/89 was chosen as it had the naximum number of water table measurements. In addition, the date falls within the irrigation season; this makes it possible to see the influence of irrigation on the groundwater table contours of the area.

Groundwater flows from the Lumi river, higher areas around Njoro Kubwa canal and also from the irrigated areas of Kamleza North, and converges in the central part of Block C and thereafter flow southwards to the swamps as indicated by the flowlines in Fig.5.2. There is also direct flow of groundwater from Kamleza North towards the Ruvu swamp.

Groundwater slopes along the flowlines have been calculated, the highest slopes being found close to the Lumi River, averaging 0.4%. Lowest groundwater slopes, ranging between 0.08 - 0.12 % occur in the Block C and Ngutini areas, and also in the upper parts of Kimorigo scheme and the adjacent areas of Kamleza scheme. The central to lower areas of the schemes have groundwater slopes of around 0.2 %.

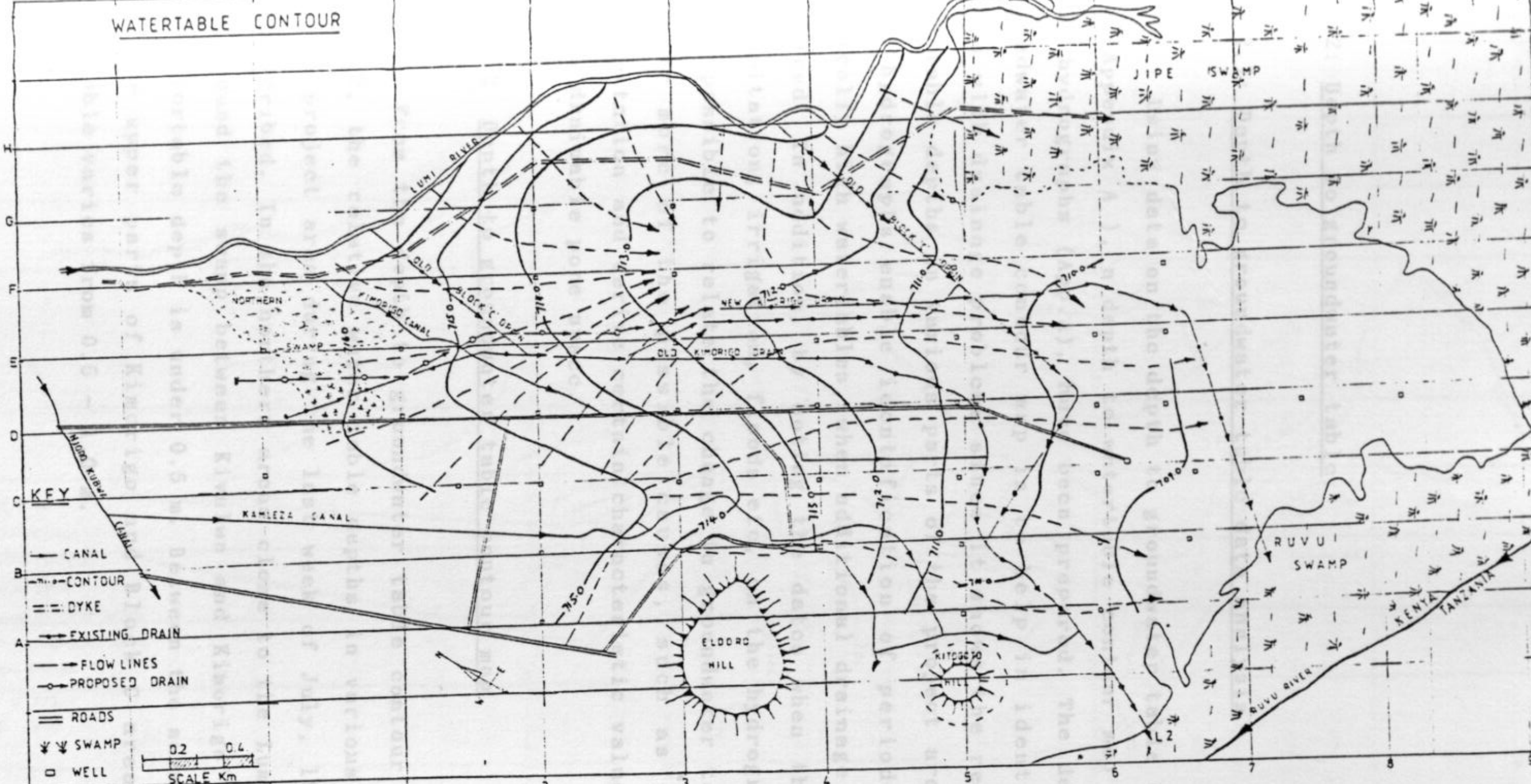


Fig. 5.2 : Watertable Contour Map (July, 1987).

.2.2: Depth to groundwater table

.2.2.1: Depth to groundwater table data analysis

Using data on the depth to groundwater table (Table -1, Appendix A), a depth to watertable contour map and 10 ıell hydrographs (App.A), have been prepared. The depth to roundwater table contour map is to help in identifying ıreas with drainage problems since it shows the relative ıatertable depths in various parts of the project area. The ıell hydrographs enable identification of periods with ritically high watertables, when additional drainage may be required. In addition, by noting the dates when there is precipitation, irrigation, floods etc, on the hydrographs , it is possible to relate the change in groundwater table to one or more of the possible causes, such as excess precipitation and derive certain characteristic values such ıs the drainable pore space.

5.2.2.2 Depth to groundwater table contour map

From the depth to groundwater table contour map in Fig.5.2, the relative water table depths in various places in the project area during the last week of July, 1989 can be described. In the northern areas close to the Lumi river and around the swamp between Kivalwa and Kimorigo scheme, the watertable depth is under 0.5 m. Between the swampy area and the upper parts of Kimorigo and Block C areas, the watertable varies from 0.5 - 1.0 m.

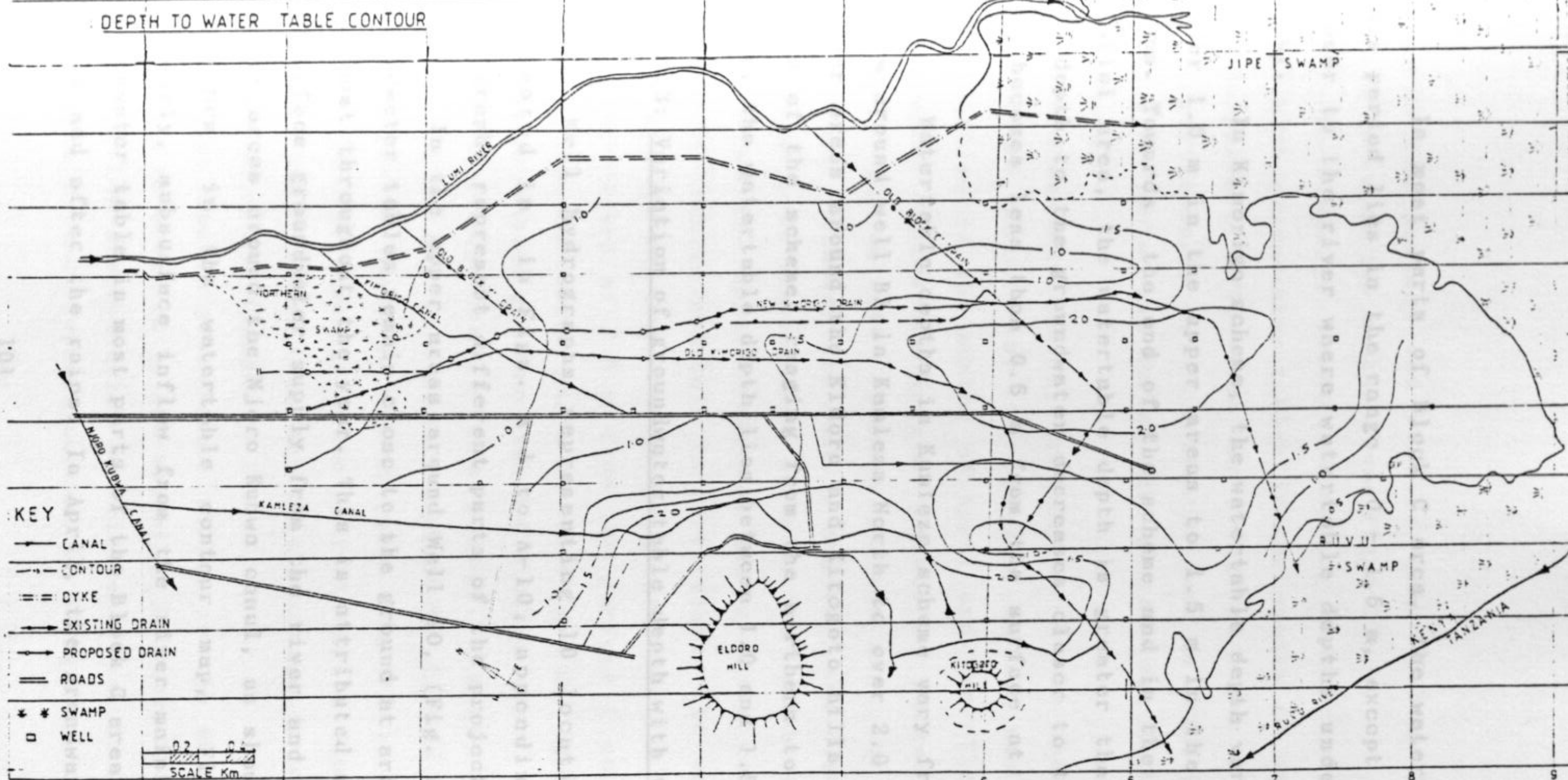


Fig.5.3: Depth to groundwater table contour map.

In most parts of Block C area, the watertable at this period lies in the range 1.0 - 1.5 m, except in areas closer to the river where watertable depths under 1.0 m occur.

In Kimorigo scheme, the watertable depth varies from under 1.0 m in the upper areas to 1.5 m in the central areas. Towards the end of the scheme and in the adjacent Ngutini area, the watertable depth is greater than 2.0 m. The depth to the groundwater decreases closer to the swamps and becomes less than 0.5 m from the surface at the swamp edge.

Watertable depths in Kamleza scheme vary from under 0.5 m around well B2 in Kamleza North to over 2.0 m in the higher areas around the Eldoro and Kitogoto hills. In most parts of the scheme, ranging from the northern to southern areas, the watertable depth lies between 1.0 and 1.5 m.

5.2.2.3: <u>Variation of groundwater table depth with time</u>

Well hydrographs representing 10 locations are presented in in Figs. A-1 to A-10, appendix A. The hydrographs represent different parts of the project area.

In the upper areas around Well EO, (Fig. A-1), groundwater tables remain close to the ground at around 0.25 m almost throughout the year. This is attributed mainly to subsurface groundwater supply from the river and from the higher areas around the Njoro Kubwa canal, as shown by the flowlines in the watertable contour map, Fig. 5.1. Similarly, subsurface inflow from the river maintains the groundwater table in most parts of the Block C area at 1.0 m before and after the rains. In April, the grondwater table rises to the surface and remains under 0.5 m from the surface for upto two months (see Fig.A-10).

In Kimorigo scheme, flooding and precipitation cause high groundwater tables in the months of April and May. Subsurface inflow from the irrigated areas of Kamleza North, particularly in the months of June to August, causes a groundwater table rise during this period (see Figs. A-2 and A-3, App.A).

In Kamleza scheme, groundwater table changes are influenced mainly by irrigation water and excess precipitation in the months of April and May. The highest groundwater tables are however caused by percolation of excess irrigation water. Notable periods are the months of December - January and June to August (see Figs. A-6 to A-9, App.A). In the southern parts of the scheme, subsurface inflow from the upper irrigated areas often causes high groundwater tables and this is particularly the case in the months of July and August when the groundwater table stays at a constant level of 1.0 m from the surface (see Fig.A-8, App.A). In the lower parts of Kimorigo and Ngutini, deep groundwater tables greater than 2.0 m often occur. Changes in the groundwater table are mainly caused by excess precipitation and to a lesser extent by floods as in the lower parts of Kimorigo scheme (see Fig.A-4). The partly constructed New Kimorigo drain prevents flood flow over the areas in Ngutini and thus the little change in water table position after the floods.

The lowest groundwater tables in the whole of the project area occurred in the months of February and March, a period of low precipitation and little if any irrigation as it is mostly land preparation that is being undertaken.

Groundwater quality

Groundwaters from different parts of the project
ere sampled and analysed for the salinity level (EC);
tion and anion contents of Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-.
HCO_3^- and CO_3^{2-}); and also the total hardness (TH).
s of the data obtained is presented in the next two
aphs.

The groundwater salinity data monitored at different
ls (times) are presented in Tables A-4 and A-5,
lix A. A study of these tables reveals the wide
ions in salinity occurring in the project area. The
ne varies from 0.34 mS/cm at well B2 in January, 1989
za Scheme) to 88.6 mS/cm at well E4 in July, 1989
en Kimorigo Scheme and Block "C" area).

The relative variation in salinity with place is
rated by the groundwater salinity map (Fig.5.4).
e salinity values for the period Oct.,1988 to July,
ave been used in preparing the salinity map. Low
water salinities under 2 mS/cm occur in most parts of
a scheme and also in areas close to the Lumi river.
s Kimorigo and the Block C areas, there is a notable
se in the groundwater salinity level. The groundwater
ty level in most parts of Kimorigo for the period
es 8 mS/cm and above with extremely high salinity
of above 30 mS/cm around well E4 between the Block C
morigo area. The higher salinity of the groundwater in
morigo and the Block C area can be attributed to a
le net inflow of groundwater (and salts). The water
contour map in Fig.5.1 shows that the two areas (Block
Kimorigo) recieve groundwater inflow from the Lumi

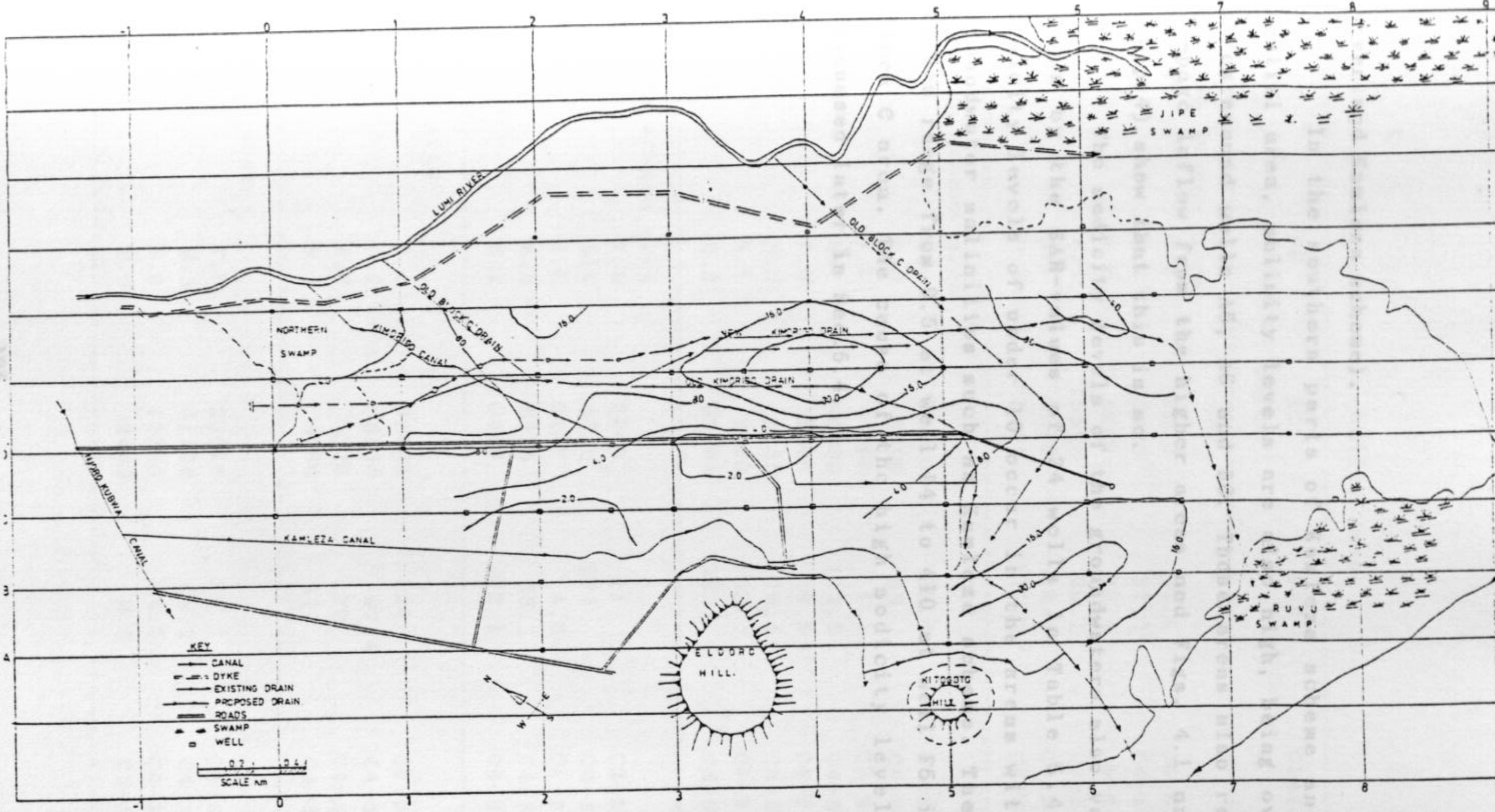


Fig. 5.4: Groundwater Salinity Map

river and Kamleza scheme).

In the southern parts of Kamleza scheme and the Ngutini area, salinity levels are also high, being over 30 mS/cm around wells A5, A6 and B6. These areas also receive seepage inflow from the higher areas and Figs. 4.1 and 4.5 (Chap.4) show that this is so.

The sodicity levels of the groundwaters also vary as shown by the SAR-values of 24 wells in Table 5.4. Low sodicity levels of under 10 occur in the areas with low groundwater salinities such as Kamleza scheme. The SAR-values range from 0.5 at well D4 to 410 at well F5 in the Block C area. The cause of the high sodicity levels are discussed later in Sec.5.4.

Table 5.4 : Groundwater quality data

	pH	EC uS/cm	SAR	CLASS
Northern swampy area				
DO	8.2	2332	20.5	C4-S3
EO	9.8	3420	37.1	C4-S4
D1	8.2	2880	30.4	C4-S4
D1	8.0	15548	20.2	C4-S4
C1	9.1	6240	48.3	C4-S4
E1	8.8	5400	112.2	C4-S4
Kimorigo scheme area				
D2	8.4	14400	59.4	C4-S4
E2	8.8	6480	59	C4-S4
D3	7.6	768	1.1	C3-S1
E3	8.7	15600	111.5	C4-S4
D4	7.9	2040	0.5	C4-S1
D5	8.0	5400	16.5	C4-S2
E4	9.1	9120	162	C4-S4
E4	8.2	69944	183	C4-S4
Kamleza scheme area				
C2	7.8	2040	11	C3-S2
C3	9.0	3720	271	C4-S4
C4	7.6	2487	4.5	C4-S1
C5	8.0	6720	36.1	C4-S4
B5	8.5	6480	72.1	C4-S4
Block C area				
F2	8.4	32400	121	C4-S4
F3	9.2	6000	97.4	C4-S4
F4	8.6	5520	122	C4-S4
F5	9.1	9360	410	C4-S4
Ngutini area				
B6	7.9	36000	36	C4-S4
E6	8.3	11000	46.3	C4-S4
D6	8.0	11760	44.6	C4-S4
F6	8.0	2040	9.5	C3-S1

5.3: Discussion

5.3.1 Irrigation water and possible influence on soil salinity in the project area.

Investigations on the quality of the canal and river waters reveal that the waters have low salt content and are therefore suitable for irrigation. Provided that there is sufficient leaching and drainage in the irrigated areas, no salinity problems associated with the river and canal waters are expected in the long run. However, leaching and drainage are inadequate as has been mentioned in the literature review (Chap.2). It is therefore possible that since the inception of the Kimorigo and Kamleza schemes, salinisation due to irrigation could have occurred. An estimate of salt deposited by irrigation water can be estimated once the cropping pattern, crop water requirement and effective rainfall in the project area are known. This has been done below as follows:

(a) Cropping pattern :

Crop production is mainly in the months of March - July when mainly cotton and maize are cultivated. During August, there is harvesting and land preparation for the second season, which starts from September - December and the main crops grown are maize and vegetables. January and February are periods of harvesting and land preparation.

) Crop water requirement:

c potential evapotranspiration can be obtained from Table
l through multiplication of the potential evaporation by
8. For the cropping seasons, the ETP's are:

rch - July : 974 mm
ptember - Dec. : 1120 mm
otal ETP : 2094 mm

onsidering an average crop factor of 0.9, the crop water equirement becomes 1885 mm for the two cropping seasons. he effective rainfall as calculated by Berger and Kalders, 1983), for Taveta are given in Table 5.5 below:

le 5.5: Effective rainfall for Taveta.

onth	J	F	M	A	M	J	J	A	S	O	N	D
ff.R	31	34	70	99	51	7	5	4	6	26	68	38

Taking into account the effective rainfall for the two ropping seasons, the irrigation water requirement after pplying an efficiency of 0.5 becomes:

rop water requirement - Eff. rainfall = (1885 -370)/0.5 = 030 mm.

The amount of salts brought by irrigation water per year can thus be estimated. Considering irrigation water ality of 0.25 mS/cm (= 160 ppm = 160 mg/l), the amount of lts deposited in the soil per ha. is 4848 kg (4.848 nnes). If these salts are not removed from the soil, then ey will accumulate and eventually result in salty soil nditions unfavourable for crop growth. Kamleza irrigation heme has been in existence for 27 years (1963 - 1990). The tal amount of salts brought by irrigation water over this riod and deposited in the soil approximates 130 tonnes/ha.

From field investigations at different sites of the hemes, it was found that the rootzone depth never exceeds) cm, whether for cotton or maize. Considering an average lk density of the soil as 1400 kg/m^3, the increment in salt ntent over the 27 years in the 50 cm depth would be 1.8 %.

According to reports by Elgabaly (1971), and El-jaili and Ismail (1971), salt content of 1 % in the soil is uivalent to 23.1 mS/cm. Therefore, a salt content of 1.8 % uld be equivalent to 42 mS/cm and this salinity level would unfavourable virtually for all crops. This is supported by rar (1971), who mentions in the same report that a salt ontent of 0.5 % in the soil rootzone is too high for most rops. The soil results presented in Chap.6 indicate that igher soil salinity levels do actually exist in the scheme.

.3.2 Causes of high groundwater table in the project area.

From the results on groundwater table conditions, it an be said that most parts of the project area are poorly rained. Groundwater tables remain high or close to the round for long durations indicating that natural subsurface rainage outflow from the area is low. The low groundwater lopes of around 0.1 % in most parts of the area confirm the low natural or gravitational outflow from the area.

The sources of excess water supply to the groundwater able in the project area are precipitation, irrigation, loodwater and seepage inflow from the Lumi river and also rom high to low groundwater table areas. Groundwater supply rom precipitation and floodwater occurs mainly in the months f April and May. Supply from irrigation happens normally uring the irrigation seasons, with a peak in the months of une and July when there is very little precipitation.

Subsurface inflow from the river occurs throughout he year to all the adjacent low lying areas on the project ide. This inflow from the river is the cause of the swampy onditions between Kivalwa and Kimorigo (the northern wamp). Fig.4.4 shows high groundwater table conditions tarting at around well DO, the edge of the swamp. The water able contour in Fig.5.2 also shows flowlines from the river nto this swampy area. In Fig.4.5, the water elevation at he river is seen to be higher than the watertable elevation of the adjacent lands in the Block C area, confirming that here is subsurface inflow from the river. In Chapter 2, it was reported that the failure of the Block C scheme was due o waterlogging and salinity problems. Knowing that there exists seepage inflow from the river, waterlogging was nevitable in the absence of adequate drainage.

Groundwater balance assessment presented in Chap.7, gives an estimate of the net subsurface inflows, especially within the Kimorigo and Kamleza schemes. The influence of floodwater on the groundwater water table can be said to most pronounced. Immediately after floodwater flow over the area, groundwater tables remain high for long durations as already reported. Flood control is therefore important to reduce its influence on the areas groundwater system.

3: Causes of high groundwater salinity in project area

As mentioned in Chap.2, high groundwater salinity rrigated areas is often associated with i) low rainfall high evapotranspiration and thus little percolation to c groundwater refreshment, ii) seepage inflow which itably brings with it some salts, and iii) poor drainage itions which result in low salt efflux. In the project , low rainfall and high evapotranspiration conditions t, thus promoting the development of high groundwater nity conditions. Differences in groundwater salinity in project area can be attributed to differences in seepage ows, amount of leaching by irrigation water and drainage itions (rainfall and evapotranspiration being the same).

In the irrigated areas, relatively low groundwater nities occur and this is due to regular refreshment by olating irrigation water and also sufficient groundwater harge away from these irrigated areas causing evacuation xcess salts. Similarly, low groundwater salinity in the ions closest to the river can be attributed to constant h sufficient groundwater discharge from the river and ce excess salts (see Fig.5.2, watertable contour). ever, with increasing distance away from the river rds the low-lying and nearly flat area of Block C area, re is a notable increase in the groundwater salinity. As be seen from the watertable contour map in Fig.5.2, re is seepage inflow into the Block C area and this ibly brings in more salts than what is discharged away, ulting in the noted high salinity levels. The relatively er groundwater slope in the Block C area than at the er, is an indication that the outflow from the area is than the inflow, high capillary rise occurs and salts accumulate on the surface and in the groundwater. Similarly, the low groundslope in the Block C area also indicates low natural drainage outflow and would encourage accumulation of salts in the groundwater.

In the central part of Kimorigo scheme between wells and D4, groundwater salinity is relatively lower than in adjacent areas which also receive seepage inflows e.g., the upper areas of Kimorigo scheme (see sec.5.3). This means that the drainage discharge from the central area is better than in the other adjacent areas. On the other hand, there could be some fresh groundwater supply from below (a deeper aquifer). This is possible as the groundwater salinity remains low whether or not there is precipitation or seepage from the irrigated areas of Kamleza North.

The high groundwater salinity around well C3 in the central part of Kamleza scheme, despite regular refreshment from excess irrigation water, can only be true if there is impeded drainage. The underlying calcareous layer is impervious and perched groundwater occurs (see Chap.6). Accumulation of salts in-situ is therefore possible resulting in high groundwater salinity. Similarly, in the southern areas of Kamleza scheme around wells B5 and C5, the high grounwater salinities can be attributed partly to accumalation of salts in-situ due the occurrence of an impervious calcareous layer at shallow depth (see Chap.6), and partly to seepage inflow from higher irrigated areas bringing with it salts. In the Ngutini area around wells A6 and B6, the high groundwater salinities can be attributed to seepage inflow from higher areas and to poor drainage conditions, and thus low salt efflux from the area (see Fig. 2).

.4: Possible influence of high groundwater table and salinity on soil salinisation in project area.

As the salty groundwaters occur at shallow depth, pillary salinisation is expected to be substantial, pecially in unirrigated areas where for most parts of the ar there is very little rainfall and thus minimal leaching. ter the rains and floods, groundwater tables remain at high vels for long durations and thus re-salinisation from oundwater may occur, negating the leaching effect of the ins. A salt balance assessment, incorporating capillary se from the groundwater is presented in Chap.7.

In Chap.2, it was mentioned that salty groundwater ould not stay in the rootzone for more than 48 hours to event injury to crops. The results on the watertable depths ow that it takes upto 2 months for the watertable to fall low 0.5 m as shown by the well hydrogaphs. Injury to crops ll therefore be inevitable. While it was mentioned in ap.2, that the critical salinity for groundwater should between 2.3 - 4.7 mS/cm, it can be seen from the results esented that higher groundwater salinities do occur and at pths less than the critical depth of between 2.5 - 3.0 m. is for certain that substantial capillary salinisation curs.

3.5: Factors promoting capillary salinisation in project area.

Among the factors which can be considered as fluencing capillary salinisation include seepage inflow, aching and drainage and the high evapotranspiration over infall in the area. Seepage inflow from the river into the ow-lying adjacent areas on the project side ensure aintenance of high groundwater tables for most parts of the ear, promoting upward capillary flow and hence alinisation. Inadequate leaching, especially in unirrigated arts as in Kimorigo scheme allows accumulation of salts in he soils. Poor or inadequate drainage result in low salt fflux from the area, and this is evident from the high roundwater salinities in various parts of the project area. igh groundwater table conditions for long durations are lso indicative of poor or inadequate drainage. Re-alinisation is therefore certain to occur in the area under he prevailing drainage conditions.

The high evapotranspiration rate over rainfall (1900 m and 600 mm respectively), certainly ensures a net upward alt movement by capillary rise, especially in areas with igh groundwater tables as already mentioned, thus promoting apillary salinisation.

5.3.6 Possible remedial measures

In order to improve the drainage conditions in the project area, it is important that measures to either reduce he groundwater recharge and/or increase the discharge of excess groundwater from the project area should be ndertaken. The groundwater recharge components include) subsurface inflow from higher areas, ii) percolating rain, ii) percolating floodwater, and iv) percolating irrigation vater.

Of the four mentioned groundwater recharge components, influence of floodwater on the groundwater table s the most widespread, covering many parts of the project

a (see sec. 5.2). The resultant high groundwater tables
r long durations promote capillary salinsation. This calls
 the need to control the floodwater flow over the area to
duce the recharge to the groundwater table as mentioned in
ap.4. Surface drainage in the project area is also
adequate, with ponding surface water being common, thus
using high recharge to the groundwater system. The need to
stall additional surface drainage canals to enable quick
scharge of excess surface water from the area is thus
commended. The completion of the main Kimorigo drain will
eatly help in alleviating the surface drainage problems.

Measures to improve the subsurface drainage
nditions in the schemes include provision of adequate
bsurface drainage facilities for rapid removal of excess
oundwater, and also to lower the groundwater table to below
e critical water table depth. A means of demineralisation
 the groundwater to lower its salinity level can also be
nsidered.

The depth to which the groundwater table in the
hemes can be lowered depends on the water level at the
tlet (Ruvu swamp). For the month of November, 1988, the
ter level at the outlet was found as 706.8 m (a.m.s.l.).
 well B5, the water level was 708.8 m (a.m.s.l). The
stance between the two points is 1800 m, and the
oundwater slope then was 0.1 %. As the groundwater levels
 well B5 are known for all the other months upto August,
89 (see Tables A-1 and A-2, App.A), the water levels at
e outlet can be approximated by subtracting 1.8 m from the
oundwater levels of well B5. The results are as shown in
ble 5.6 (also see watertable contour map in Fig.5.2 for
cation of well B5 and the outlet point, L2). The surface
levation of well B5 is 711.55 (see Table A-3, App.A).

ble 5.6: Average monthly watertable levels at well B5 and Outlet (L2).

onth	Watertable depth at B5	Watertable elevation at B5	Water elevation at outlet.
n	0.92	710.6	708.8
b	0.89	710.7	708.9
r	1.24	710.3	708.1
r	0.63	710.9	709.1
y	0.12	711.4	709.6
n	0.6	711.0	709.2
l	0.7	710.8	709.0

The highest water level at the outlet occurred during e month of May, 1989 and was 709.6 m (a.m.s.l.). This water vel can be compared with the desired water levels in the in drain for parts of Kimorigo and Kamleza schemes at ints D5 (end of Kimorigo scheme), D2 (start of Kimorigo heme). The ground surface elevations at wells D5 and D2 are 2.94 and 715.77 m respectively. Applying the minimum slope 0.05 % , water levels in the drain can be determined. The sults are shown in Table 5.7.

The water elevations in the drain become 3.27 m at te D2, 1.94 m at D5 and 1.05 m at B5. The results indicate at it is possible to have deep field drains greater than 5 m depth around site D2 in the upper areas of Kimorigo d Kamleza schemes. In the lower areas, the field drain pth will be less than 1.9 m around well D5 and less than e 5.7 : Water levels in main drain along D2 to L2

ation	Distance (m)	Elevation m(a.m.s.l)	Slope %
et(L2)	0	709.6	
			0.05
	1800	710.5	
			0.05
	2800	711.0	
			0.05
	5800	712.5	

m around well B5. Control of capillary rise through allation of deep drains in the lower areas of Kamleza me is therefore difficult due to lack of sufficient head. recommended water table depth for preventing capillary into the rootzone lies between 2.5 - 3.0 m. (D5) and m (B5).

The recharge to the groundwater table due to essive irrigation can be reduced through improved water ribution and application. Only the correct amount of er at the right time should be applied to avoid over-gation and thus high recharge to the groundwater table. ugh water should also be applied to ensure that sufficient hing of salts occurs.

6. SOIL ANALYSIS RESULTS

Results of soil investigations in the field are
nted here in three sections. The first section is on
calcareous layer, the second on the soil chemical and
ral analysis and the third section is on hydraulic
ctivity.

The calcareous horizon

Investigations on the calcareous layer comprised
ermination of the nature of the layer (whether
ocalcic or calcic (see Chap.2). A chemical analysis of
layer was also carried out to give indications of the
onate content and relate to the percentages represented
Sec.2.5.3, Chap.2. In addition to determining the nature
the layer, the depth of occurence of the layer too was
ermined. The results are presented in the next two
sections.

1.1: Types of horizon in the project area

Two main types of the calcareous layer were found to
st in the project area, namely, calcic and petrocalcic
rizons. The calcic horizon occurs mostly outside the
heme areas, especially in areas towards the swamps and
ver Lumi, and in the Block C and Ngutini areas. However,
ose to the river and near the southern swampy areas, no
lcic or petrocalcic horizon exists.

The petrocalcic horizon is found in almost all parts
Kamleza and Kimorigo schemes, occurring in different
rms. Some horizons are pervious while others are

cly impervious.

In the areas around Kitogoto hill, no calcic or lcic horizon was found at depths of 3 - 4.5 m (around). However, calcareous nodules and small concretions r in the profile.

Eight different forms were distinguished. In Table e wells at which the various forms occur are given.

.1: Types of the calcareous horizons in the project area.

.	Form of occurrence	Well no.
	discrete nodules	D3 , D4
	cemented nodules with holes	B2
	cemented layer of nodules (impermeable)	A2, B5, C3
	massive encrustation with fine pores (single layer), semi-permeable	C2, DI, D2, E2
	massive encrustation with fine pores of 2-3 distinct layers, s-permeable	Cl, C4, C6, D5
	massive encrustation with no pores (single layer), impermeable	B4, C5
	earthy $CaCO_3$ layer (calcic horizon)	D6, D7, E4, F
	earthy $CaCO_3$ horizon underlain by a layer of sands and pebbles	E5, E6, E7, F5

: Discrete nodular layer (Form I)

This type of $CaCO_3$ accumulation is found in the
tral part of Kimorigo scheme from well D3 to D4. It
sists of discrete calcareous nodules (hard
centrations). These nodules resemble calcareous
faceous grits obtained around the lower slopes of Mt.
imanjaro. Fig.6.1 shows the nodules obtained from well D3
a depth of about 1.7 m.

The nodules have holes in them. The shape can be
cribed as botryoidal (bears resemblance to a bunch of
pes).

Porosity of the layers is very high at the two wells
to the discontinuity of the nodular horizon. As can be
n in Fig 6.1, the nodules have minimal earth between them
within the holes. Deepening of well D3 to find out what
urs further down the profile was prohibited by too much
er at shallow depth (=1.0 m).

At well D4, the nodules were coated with more earth,
opposed to the nodules found at well D3 mentioned above.
nodules started at a depth of about 1.0 m and as the
th increased to 2.4 m, there was a notable increase of
t concentrations of $CaCO_3$ or nodules. In addition, the
portion of sand and gravel particles increased between
– 2.4 m.

The $CaCO_3$ content of the nodules is 49 % at well D3
55 % at well D4. The general carbonate contents for nodular
centrations was mentioned in Chap. 2 as less than 60 %,
ch agrees with the contents obtained.

Fig. 6.1. Discrete nodules, obtained from well D3 (Type I).

(B) : Nodular layer with holes (Form II)

This form was found at depths of around 1.0 m at well B2 in Kamleza scheme. It consists of a cemented layer of nodules with holes in them. The porosity of the layer is as high as for Type I. Pieces of the layer also bear ressemblance to those of Type I. As at well D3, it was not possible to investigate what lies at greater depths due to too much water below 1.0 m.

The $CaCO_3$ content of this layer is 67 % which is in agreement with other values for a cemented layer, which are normally greater than 60 % (see Chap.2).

(C) : Nodular layer with no holes (Form III)

This type occurs in Kamleza scheme around wells A2, C3 and B5. It consists of nodules cemented together forming a continuous impermeable crust (nodular encrustation). Perched water occurs on top. At well A2, the layer started at a depth of 2.1 m; at C3, 1.5 m and at B5, 1.8 m. Fig. 6.2 shows pieces of the chisselled layer from well C3 in Kamleza scheme. From the photo, it can be seen that some reddish earth appears on the surfaces of the nodules. This is an indication that previous to the development of the cemented layer, some earth was present and this was not completely displaced during the cementation process.

The thickness of the layers varied; 50 cm at well A2; 75 cm at well C3 and 65 cm at well B5. The $CaCO_3$ contents were 64 % at well A2 and 55 % at well B5.

Concretions and nodules occur both above and below the layer. The ones above the layer are covered by a mixture of whitish $CaCO_3$ and reddish brown earth. Underneath, the nodules are coated with whitish $CaCO_3$. Water occurs immediately underneath the cemented layer in all these wells. Deeper down the profile, smaller and softer nodules are more abundant as are gravel and sand particles.

Fig.6.2: Pieces of the nodular cemented calcareouslayer from well C3 in Kamleza scheme (Form III).

(D) : Massive encrustation with fine pores (Forms IV and V)

Types IV and V are similar in that they are both massive encrustations with fine continuous pores filled with soil. Type V occurs in layers of 2 or 3, while Type IV occurs as a single continuous horizon. Fig. 6.3 shows chiselled pieces of the encrustation from well D5 in Kimorigo scheme.

Due to the fine pores filled with soil, these two types of layers are pervious, though not as pervious as types I and II. In places where the layer occurred within the water-table zone such as in the upper areas of Kimorigo scheme and the adjacent parts of Kamleza scheme, water was observed to ooze as the layers were chiselled through.

This type of layer was found to occur at depths [b]een 0.8 m at well C1 to 1.75 m at well C6. The thickness [of t]he Type IV petrocalcic layer varied from 45 cm at C2 to [..] cm at wells D1 and D2. Each layer of the layered [petr]ocalcic horizon (Type V) was betweem 10 - 30 cm thick.

Below the layer there is a discontinuous accumulation [of n]odules in a thick paste of whitish $CaCO_3$. Deeper down the

[Fig.] 6.3: Pieces of massive encrustation from well D5 (Form IV).

[wh]ile softer concretions, sand and gravel particles are [foun]d, as e.g. at wells C4 and D5.

The $CaCO_3$ content was 65 % at well D1 and 59 % at [wel]l D5.

) : Massive encrustation with no pores (Form VI)

This type occurs around well C5 in Kamleza scheme ose to the main drain. This is a massive encrustation with pores and is therefore impervious. When chiselling rough, it breaks into large pieces of solid rock as shown Fig.6.4.

There are nodules occurring above and below the ayer, those below being covered with a thick whitish ating of $CaCO_3$. The nodules above also have coatings of aCO_3 but not as much.

ig.6.4: Pieces of massive the encrustation from well C5

Due to the impermeability of the layer, a perched atertable is often found (see Chap.5), Immediately below he layer there exists confined groundwater. The $CaCO_3$ ontent was 62 % at well B4 and 44 % at well C5.

G) : Earthy $CaCO_3$ (Calcic horizon) -Type VII

This type of calcium carbonate accumulation consists f discontinuous soft and hard concentrations (nodules) in a ayer of whitish - yellowish - brown earth as shown in Fig. .5.

Fig.6.5: Whitish-yellowish-brown calcareous earth (Type VIII).

The top soil in most places with such calcic horizons black heavy clay. The earthy layer starts at about 1.0 m wells E4 and F2. The thickness of these layers was 75 (E4) and 100 cm (F2). An indurated nodular layer of out 10 cm occurs at the bottom of the calcic horizons at pths of 1.5 m at E4 and 2.9 m at F2. A water table often curs within this calcic horizon.

Similar horizons are found around wells D6 and D7 th an indurated layer of nodules below the horizon. The ickness of the calcic horizon at the two wells is 120 cm d 70 cm, respectively.

Below the indurated nodular horizon, discontinuous cumulations of nodules are found which give way to a ofile with more sand and gravel, particularly around wells and D7.

): Earthy $CaCO_3$ horizon underlain by a sandy /pebbly layer (Form VIII)

This type bears resemblance to type VII in that both ve a similar calcic horizon. The only difference is that e calcic horizon is not underlain by an indurated nodular yer. Instead, this calcic horizon gives way to a zone mposed of sand particles and smooth rounded pebbles which e mainly black in colour at wells E5 and F5 and whitish at lls E6 and E7.

Groundwater mostly occurs in this pebble and sandy rizon. The overlying soil is predominantly black heavy clay wells E6, E7 and F7 with deep cracks of upto 50 cm below e surface. Around well E5, the soil overlying this calcic rizon has a dark grey colour and is loamy.

The presence of the smooth rounded pebbles is an dication that at one time in the past sediments or rock agments were transported from some other location, either water or wind, and deposited here. In the process of ansportation, the rock fragments became smooth and rounded lint et al., 1974).

1.2: Depth to the calcareous horizon

The depth to the calcareous layer was determined at e grid of 100 m x 100 m mentioned in Chap. 3. From the llected data, two maps were prepared; firstly, a contour p of the elevation of the layer and, secondly, a contour p shpowing the depth to the calcareous layer below the ound surface. It should be noted that:

): In some places, there was no petrolcalcic horizon or liche, but an accumulation of discontinuous nodules as D3 and D4 (See Sec. 6.1.1).

i): In some other places also, the layer of discontinuous dules occurred above a petrocalcic (caliche) horizon. ere the nodules were large or close together, the ecorded depth was less than the actual depth. At lls A2, C3, and C5, the recorded depths were found be less by 0.45, 0.50 and 0.35 m, respectively. rge nodules measured upto 30 cm long x 20 cm wide. would have been therefore fitting to add these to corded depths; but; (a) the auger may miss hitting such dules, and hence get actual depth, and (b) there was no y to find out whether the auger had hit a nodular layer or uch cases.

Outside the Scheme areas, most parts were observed to ave a calcic horizon (an earth layer composed mainly of oft concentrations and relatively few nodules or hard oncentrations). While augering, it was assumed that there ould be a petrocalcic horizon underneath. However, this was nly found to occur around wells F2 and E4 as mentioned in ec.6.1 (F). The depths measured in most places were herefore erroneous and only presented the depth to which he auger could penetrate depending on the hardness or ompactness of the underlying layers. The maximum augered epth at which no hard layer was struck was 4.26 m. The reas with calcic horizon have therefore been left out while aking a contour map.

The other area left out, but which occurs within the cheme is in Kamleza South around well A5 and other section lose to the two hills. At well A5, no hard layer was found t a depth of 4.3 m, although sparse nodules were found. The ugering depths, in most parts ranged from 2.5 - 3.5 m. reater depths were prevented by the hardness of the soil black clay soils). No petrolcalcic horizon was encountered t these depths.

Two contour maps have been drawn: (1) Depth to calcareous layer (Fig. 6.6) and (ii) the surface contour of he layer (Fig. 6.7). Longitudinal profiles in Fig.4.2 and 1.8 (Chap. 4) also show the relative depth of this layer at various points.

The depth to the calcareous layer contour map in Fig.6.6 revealS the following:-

(i) The layer is deepest in areas near the hills where depths of 2 m and above occur. Other places where the layer

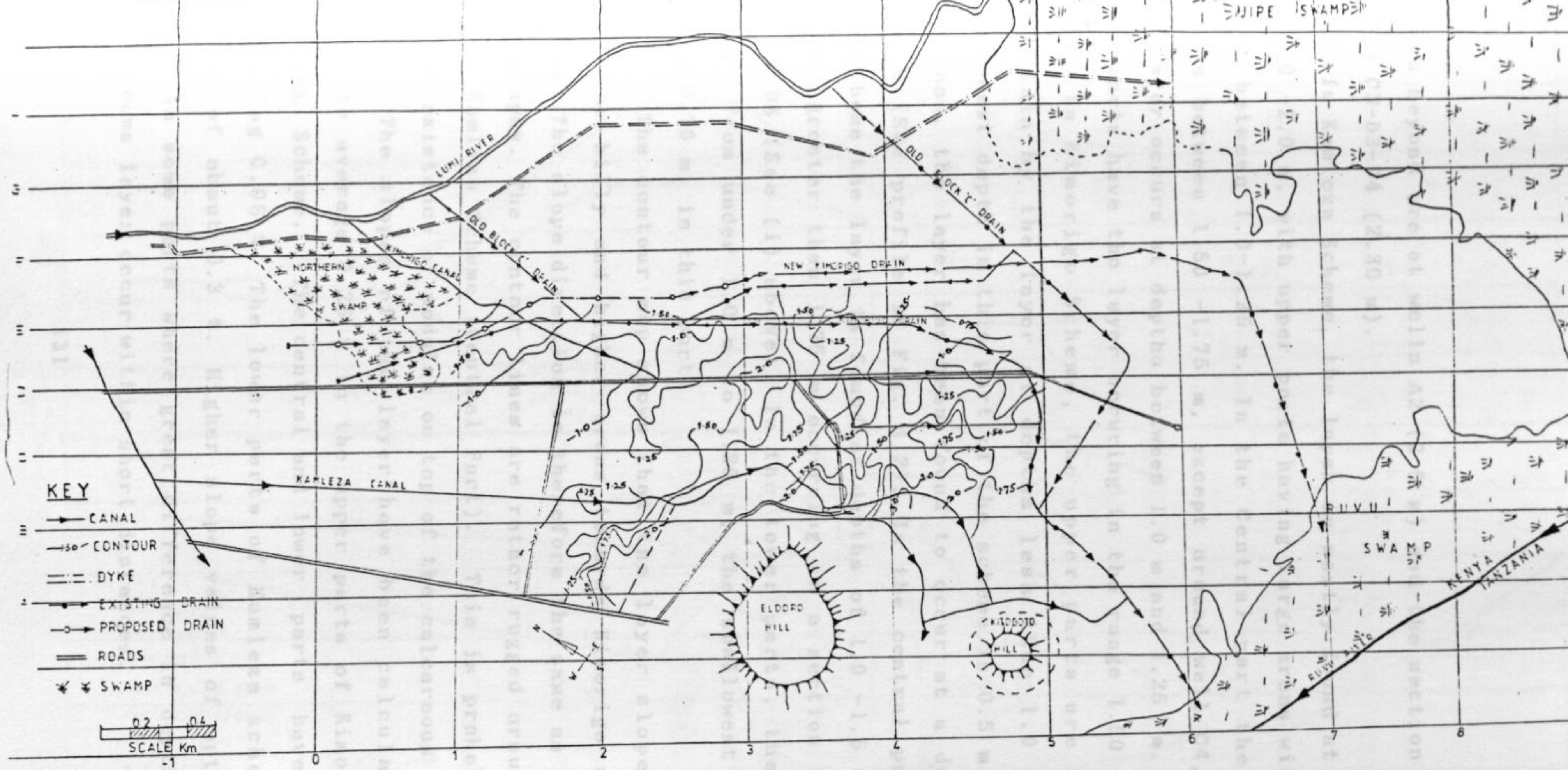


Fig.6.6: Depth to the calcareous layer contour.

ccurs beyond are at wells A2 (2.5 m) and the section between cells C3-D3-D4 (2.30 m).

ii) In Kamleza Scheme, the layer is mostly found at depths f 1.0 -2.0 m, with upper parts having large areas with the ayer between 1.0-1.25 m. In the Central part the layer aries between 1.50 -1.75 m, except around well C4, where he layer occurs at depths between 1.0 m and 1.25 m. The loer parts have the layer occuring in the range 1.50 - 1.75 m.

iii) In Kimorigo Scheme, the upper parts are mostly nderlain by the layer at depths less than 1.0 m. The hallowest depth in this part of the scheme is 0.5 m. Along he road, the layer has been found to occur at a depth of .35 m (See profile in Fig. 4.2). In the central parts of he scheme the layer is found at depths of 1.0 -1.5 m, with epths greater than 1.75 m occurring in a section between 3-D3-D4 (See (i) above). In the lower parts, the layer ccurs from under 1.0 m to 1.25 m, the shallowest depth eing 0.70 m, in this part.

The contour map shows that the layer slopes away from the hilly and higher areas towards Kimorigo and the swamps. The slope direction is therefore the same as for the topography. The contour lines are rather rugged around well 3 in Kamleza Scheme (Central Part). This is probably due to the existence of nodules on top of the calcareous layer.

The slopes of the layer have been calculated and found to average 0.25 % in the upper parts of Kimorigo and Kamleza Scheme. The central and lower parts have slopes averaging 0.06 %. The lower parts of Kamleza scheme have slopes of about 0.3 %. Higher slope values of upto 2.5 % occur in some parts where great difference in depth to the calcareous layer occur within short distances.

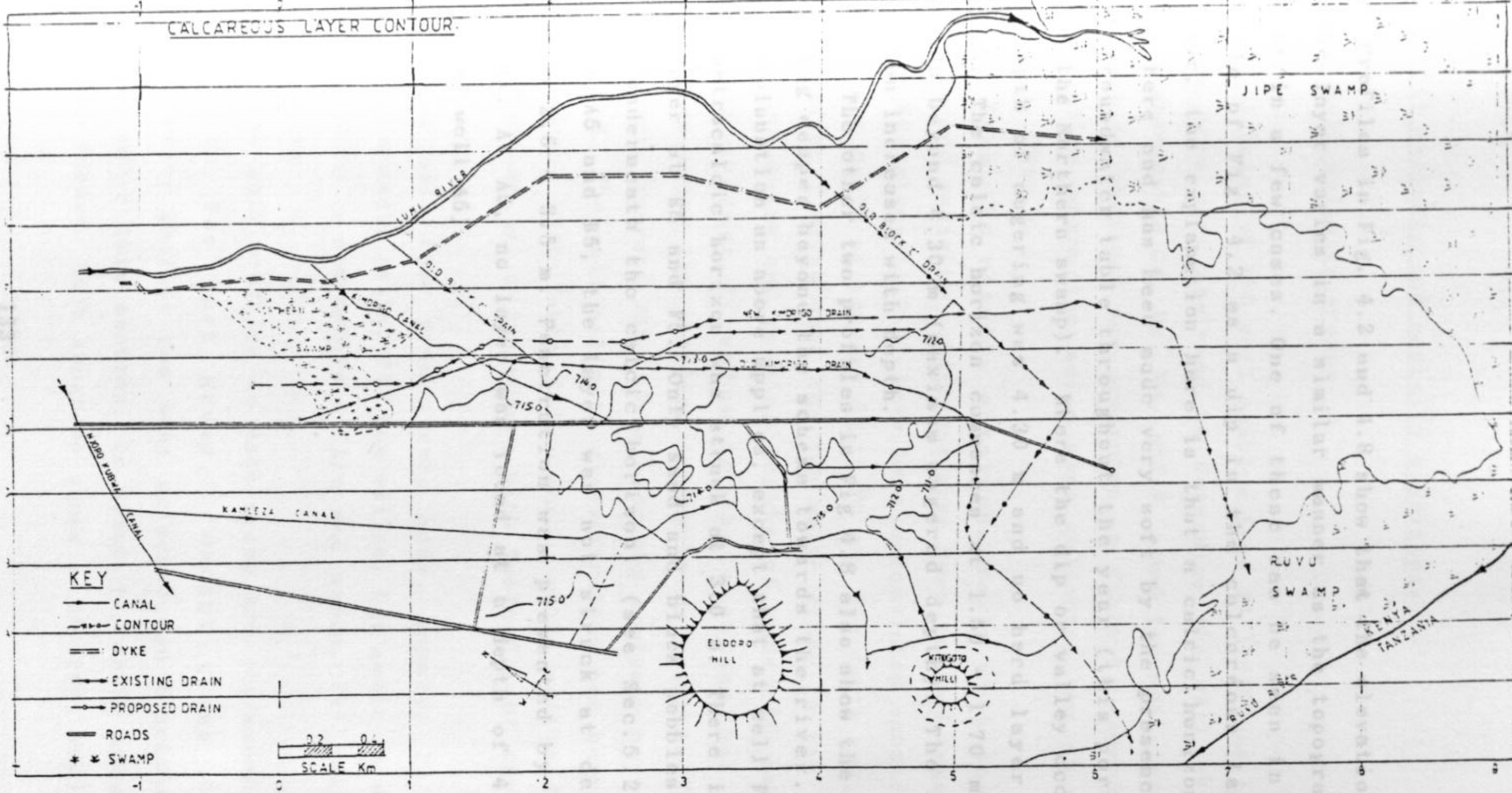


Fig.6.7: Calcareous layer contour.

Profiles in Fig. 4.2 and 4.8 show that the elevation f the layer varies in a similar manner as the topography, xcept in a few cases. One of these can be seen in the rofile of Fig. 4.2 as a dip in the calcareous layer. owever, the explanation here is that a calcic horizon is ound here and has been made very soft by the presence of igh groundwater table throughout the year (this portion orms the Northern swamp). Where the dip or valley occurs, he depth of augering was 4.30 m and no hard layer was truck. The calcic horizon commences at 1.50 - 1.70 m and xtends beyond 4.30 m (maximum augered depth). The sand raction increased with depth.

The other two profiles in Fig 4.8 also show the layer ccuring deeper beyond the scheme towards the river. The ame explanation as above applies, except that at well F2, a hin petrocalcic horizon was struck at 3.0 m. There is no ard layer at E5 and F5. Only sand and black pebbles are ound underneath the calcic horizon. (see Sec.5.2.1). etween A5 and B5, the layer was not struck at depths etween 2.5 - 3.5 m. Penetration was prevented by soil ardness. At A5, no layer was found at a depth of 4.3 m lepth of well A5).

Soil salinity and sodicity conditions

Soil salinity groups

A total of 150 soil samples from 24 locations in the ect area were analysed to determine the soil pH, EC, exchangeable Ca, Mg, Na, and K , and the soil texture. results obtained are presented in Table B, Appendix B. location where the soils were collected are shown in 3.5, Chap.3.

From the results obtained, soils with similar nity and sodicity conditions have been grouped together. ge EC-values (1:2.5) have been calcaulated considering tzone depth of between 50 to 70 cm. The depth range was en after finding that the two major crops in the area, on and maize had rooting depths of under 50 cm. The hted average EC-value in the rootzone has been ulated using the sampling intervals as weights. In the manner, average ESP-values over the rootzone have been ulated. The soil salinity classification has been done ccordance with Table 2.2, Chap.2, while soil sodicity sification is in accordance with Table 2.1 of the same ter.

In all, four groups were made, namely; I) Non-ne, non-sodic soils, II) Non-saline, but sodic in depth, Slightly - moderately saline and sodic, IV) Saline - c soils.

The soil profiles in each group are represented in e 6.2. For each group , except group IV, a esentative profile has been selected and discussed in text under this section. In group IV, three subgroups been formed. Each subgroup shows a distinct variation f salinity with depth down the profile. The first subgroup, a), consists of soils showing a maximum salt concentration t the surface followed by a sharp drop down the profile. he second subgroup, (b), consists of soils also depicting aximum salt concentration at the top ,but the decrease down he profile is gradual. The final subgroup, (c), consists of oils having a maximum salt concentration at mid-depth.

ble 6.2 : Soil salinity and sodicity groups.

il group no.	Soil profile pit no.	Representative profile
Non-saline, non-sodic	2, 6, 15	2
Non-saline, sodic in depth	1,7,8,18,20,23	8
I Slightly-moderately saline and sodic	10,14	10
Saline - sodic		
(a)	11,12,13,4,24	12
(b)	5,9,16,17	16
(c)	19,21,22	22

2.2 Non-saline, non-sodic soils - (group I)

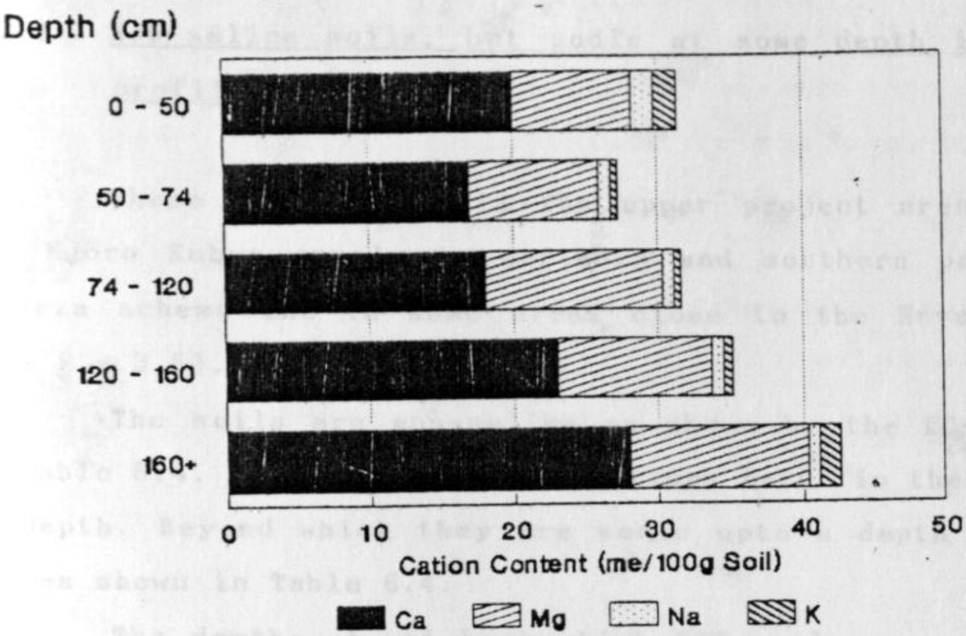
These soils occur close to the Lumi river (levee ils), in areas of Kamleza scheme close to the main rigation canal and in the southern parts of Kimorigo heme around well D5 (also see Fig. 3.5 for soil sampling cations). Both the EC- and ESP-values of the soils are , indicating non-saline, non-sodic soil conditions as own in Table 6.3.

Fig. 6.8 indicates that Ca^{2+}- and Mg^{2+}-ions are the ainant cations in these soils, a condition which is aracteristic of non-saline soils (See Chapter 2). These ls are intensively cultivated as shown in Fig. 6.9 , the in crop being bananas.

ble 6.3: Soil salinity and sodicity at profile No. 2 (close to Lumi River).

il depth n)	EC mS/cm	ESP %	pH 0.01 M $CaCl_2$
) - 50	0.3	5.3	8.1
0 - 74	0.2	3.1	7.9
4 - 120	0.2	2.2	7.7
0 - 160	0.3	2.4	8.0
0+	0.6	2.5	7.9

te: Groundwater depth at 1.5 m (March, 1989).



g.6.8: Exchangeable cations in soils close to the Lumi river (Profile no. 2).

ig. 6.9: Intensive cultivation of bananas and other crops close to the main Kamleza canal (Kamleza scheme).

2.3: <u>Non-saline soils, but sodic at some depth in the profile (group II)</u>

These soils occur in the upper project area around e Njoro Kubwa canal; in northern and southern parts of mleza scheme and in some areas close to the Ruvu swamp ee Fig.3.5).

The soils are non-saline as shown by the EC-values Table 6.4. Non-sodic soil conditions occur in the top 60 depth. Beyond which they are sodic upto a depth of 160 , as shown in Table 6.4.

The depths at which the high ESP -values occur have relatively higher clay content than the overlying soil yers, as shown in Table 6.4.

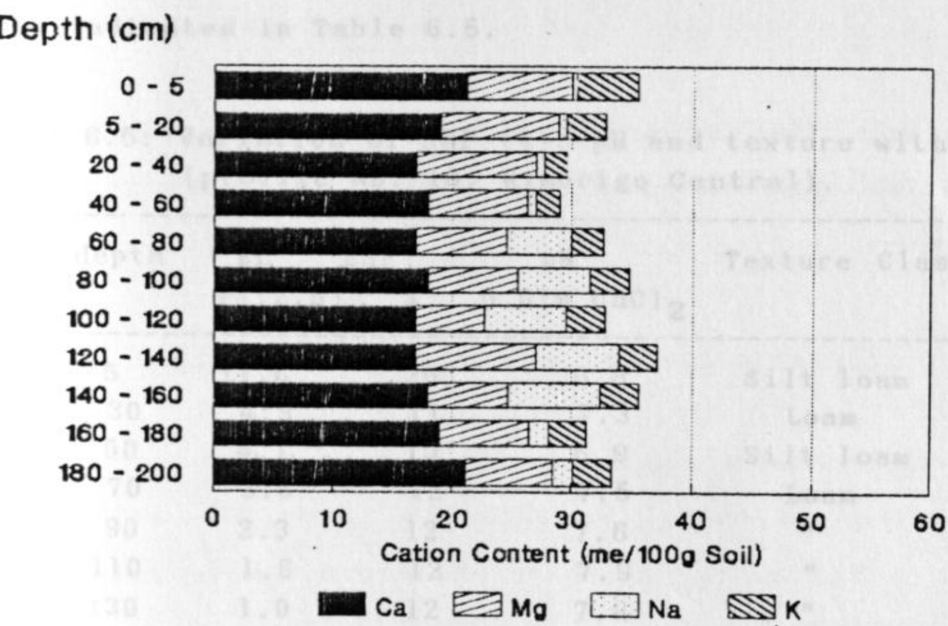
ble 6.4: Soil EC (mS/cm), ESP (%), pH and % clay for profile no. 8 (Kamleza North).

il depth cm)	EC mS/cm	ESP %	pH 0.01 M $CaCl_2$	% Clay
0 - 5	0.2	0.8	7.4	9
5 - 20	0.4	2.0	7.4	9
0 - 40	0.1	2.0	7.1	31
40 - 60	0.3	2.0	7.2	36
60 - 80	0.3	18	7.5	27
80 - 100	0.3	20	7.8	33
0 - 120	0.3	21	7.7	30
20 - 140	0.3	23	7.6	16
0 - 160	0.3	25	7.8	25
60 - 180	0.3	5	7.9	28
80 - 200	0.4	5	8.2	39

te: Groundwater: Average depth = 2.5 m and average EC = 0.7 mS/cm (Oct.1988 to July,1989).

A high clay content favours the accumulation of Na^{+}-ns (see Chapter 2). It is therefore possible that over the ars, Na^{+}-ions have been retained in the clay-enriched yers after coming into contact with either irrigation or oundwater.

The dominant cations are Ca^{2+} and Mg^{2+} as indicated Fig.6.10. As favourable soil conditions exist in the psoil (top 60 cm depth) , these soils are also tensively cultivated, like the soils of Group I above.



ig.6.10 : Exchangeable cations at profile no.8 (Kamleza North).

6.2.4: Slightly-moderately saline and sodic soils (III).

These soils occur in the unirrigated parts of central Kamleza and Kimorigo schemes, and also in Ngutini area adjacent to the lower parts of Kimorigo scheme. The representative soil profiles are nos. 10 and 14 in Fig.3.5.

In most of the central sections of the two schemes, strongly saline conditions exist in the top 10 cm layer of the soil below which slightly to moderately saline conditions are found. At profile no.10, the EC-value decreases from 11.6 mS/cm in the top 10 cm to under 5 mS/cm in the underlying layers as shown in Table 6.5. Similarly strong sodic conditions exist in the top 10 cm, which decrease to moderately sodic conditions in the subsoil, as also indicated in Table 6.5.

Table 6.5: Variation of ESP (%), pH and texture with depth (profile No. 10, Kimorigo Central).

Soil depth (cm)	EC (1:2.5)	ESP %	pH 0.01M $CaCl_2$	Texture Class
0 - 5	11.6	20	6.8	Silt loam
5 - 30	4.9	11	7.3	Loam
30 - 50	4.1	10	6.9	Silt loam
50 - 70	3.6	12	7.5	Loam
70 - 90	2.3	12	7.6	"
90 - 110	1.6	12	7.9	"
110 - 130	1.0	12	7.8	"
130 - 150	0.8	11	8.0	Clay loam
150 - 170	0.6	12	8.0	"
170 - 190	0.5	10	8.1	"
190 - 210	0.5	12	7.8	"

Groundwater : Av.depth = 1.1 m and Av.EC = 1.3 mS/cm (Oct.,1988 - July,1989).

The occurrence of a maximum salt concentration at the urface points at a net upward movement of salts towards the urface, which then get deposited as water is lost through vapotranspiration, i.e. there is salinisation from roundwater by capillary action (see Chap.2). The roundwater salinity is under 2 mS/cm in this central to ower area of the two schemes. With the groundwater table at n average depth of 1.1 m below the surface, it is possible or capillary rise to reach the surface for a loam soil (or a loam soil, maximum height of capillary rise is in the ange of 1.0 - 1.5 m; see Chap.2).

The cation composition in the soil profile is llustrated by the bar chart in Fig. 6.11. As in the previous wo cases both Ca^{+} and Mg^{+} ions are dominant, although there s a notable increase in the Na^{+}- ion content in the top ayer.

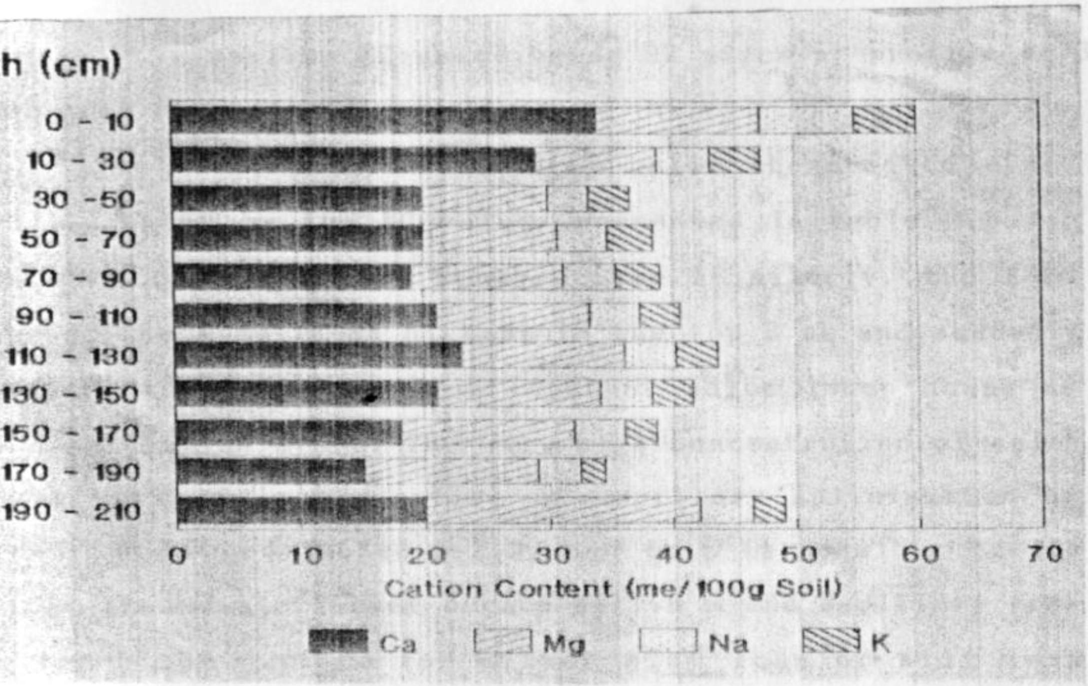
Patchy growth of cotton and white salt crusts are a ommon feature in these slightly-moderately saline/sodic oils as exhibited by the photo in Fig. 6.12.

.2.5: Strongly saline and sodic soils (group IV)

As earlier mentioned, these soils have been divided nto three subgroups of distinctly different salinity rofiles; they are presented below as (a) to (c).

a) Very high surface salinity only (maximum salinty at the surface followed by sharp a drop in the subsoil)

These soils occur in parts of Kimorigo and Kamleza chemes and at the swamp edges. The EC-value at the surface was found to be above 60 mS/cm for all the soil samples



.6.11: Exchangeable cations at profile no.10 (Kimorigo Central).

g. 6.12: Patchy and stunted cotton in central Kimorigo scheme (note the white salt crusts).

lysed, the maximum EC-value being 92 mS/cm at profile no.3 ar well DO at the swamp edge).

The sharp drop in salinity below the surface crust illustrated by the EC-values presented in Table 6.6 for file no.16 in Kamleza South scheme. Similarly, the ESP-ue of these soils is highest in the top 3 cm and suddenly reases to a more or less constant value lower down, as own in the Table 6.6. The very high concentration of salts the surface is indicative of capillary salinisation as ready mentioned in Sec.6.2.3, and this is possible as the erage groundwater level occurs at 1.0 m and capillary rise n reach the surface for either clay loam or silt loam xture for which the height of capillarey rise is greater an 1.0 m.

le 6.6: Variation of pH, ESP and soil texture with depth
(cm) (profile No. 16, Kamleza South).

				Texture			
h	EC (1:2.5)	pH	ESP	%S	%Si	%C	CLASS
3	63	9.2	100^+	17	46	37	SiL/CL
20	8.9	9.0	35	35	52	13	SiL
- 40	2.3	8.7	36	34	35	31	CL
- 60	2.1	8.9	42	34	35	31	CL
- 80	2.4	8.9	41	38	35	27	L
- 100	2.5	9.0	40	40	35	25	L
- 120	2.2	9.0	43	38	34	28	CL
- 130	2.4	8.9	38	34	27	39	CL

undwater: Av.depth = 1.0 m; Av.EC = 7.6 mS/cm and SAR = 36

The Na^+-ion content of these soils is much higher an in the soils already discussed. In Fig.6.13, the Na^+-ion dominant throughout the profile. This situation is true alues indicate the sodic or alkaline conditions of these oils (Table 6.8).

In all these areas with strongly saline and sodic oils, the groundwater salinity is greater than 2 mS/cm, eg. t profile no.16, the average EC-value of the groundwater was .6 mS/cm during the project period (see footnote in Table .6 above). With groundwater tables often occuring at hallow depth e.g. at an average depth of 1.0 m for profile o.16, capillary rise is able to reach the surface, resulting n considerable amounts of salt transport to the surface rom the salty groundwater and thus the high soil salinities esults can be easily understood (see Table B-3, App.B for oil analysis results).

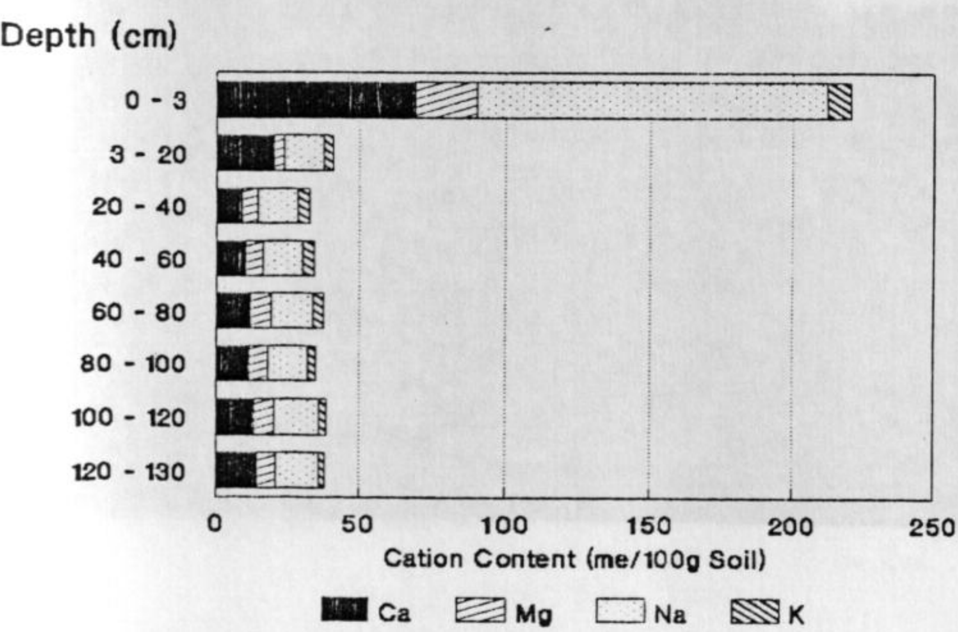


Fig.6.13: Exchangeable cations at profile no.16 (Kamleza South).

The result of the high saline and sodic conditions is arren patches covered with white salt crusts and exuberant alty vegetation, mainly Suaeda monoica (See photo in Fig. .14).

Cultivation is rare in these areas, although some armers try cultivating cotton, despite the stunted and atchy growth. There is no irrigation in this area, nd thus leaching of salts is only by rainfall and loodwater.

Fig. 6.14: Surface covered with white salt crusts. (near well C5, profile No. 16, Kamleza South).

b) <u>Saline-sodic soils with a gradual decrease in salinity down the profile.</u>

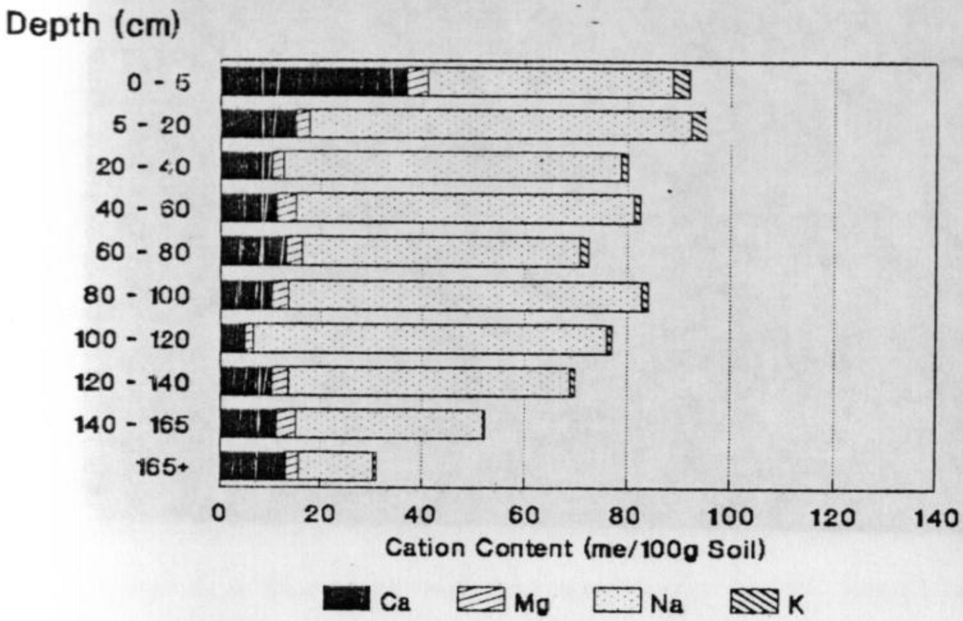
These are black heavy clay soils which occur mainly in he Block C area and in the adjacent areas of Upper Kimorigo cheme. In contrast to the saline-sodic soils discussed under a) above, these soils have relatively higher ESP-value, hich remain fairly constant throughout the profile (Table .7). The EC-value of the top layer is lower but still high nd it decreases gradually down the profile: from 26 mS/cm n the topsoil to 16 mS/cm at 120 cm depth as shown in Table .7.

ble 6.7: The ESP, pH and texture of soil sample from profile No. 12 (Block C, area)- Group IV(b) soils.

epth m)	EC(1:2.5)	ESP %	pH 0.01 M $CaCl_2$	Texture %S	%Si	%C	Class
0 - 5	26.0	98	8.5	23	48	29	CL
5 - 20	20.5	100^+	9.1	43	37	20	L
0 - 40	19.5	100^+	9.4	25	20	55	C
0 - 60	20.0	100^+	9.5	31	35	34	CL
0 - 80	17.0	100^+	9.6	42	22	36	CL
30 - 100	16.5	95	9.6	26	26	52	C
00 - 120	16.5	100^+	9.6	25	23	52	C
20 - 140	7.5	99	9.6	26	16	56	C
40 - 165	6.8	59	9.2	29	5	66	C
5^+	2.0	58	9.2	64	14	22	SIL

Groundwater : Av.depth = 1.2 m and Av.EC = 43 mS/cm and SAR = 162(Oct.,1988- July, 1989).

In Fig. 6.15, the dominance of Na^+-ion throughout the profile is evident. The likely source of the Na^+-ions is the sodic groundwater which has a high SAR-value as shown by the footnote below Table 6.7.



igure 6.15: Exchangeable cations at profile no.12 (Block C area) for group IV (b) soils.

The surface soil condition is often characterised y a puffy or fluffy crust of white salt. In some places hite salt crusts can be seen occuring between short grass as hown in Fig. 6.16. Soil pits also often have their sides overed with white salt crusts as illustrated by the photo in ig.6.17; this is a clear indication of the extreme salinity nd sodicity conditions in this area.

igure 6.16: White salt crusts in between short grass growth (Block C area).

igure 6.17: White salt crusts on the side of well E4 (Block C).

:) <u>Saline-sodic soils with maximum salinity at mid-depth depth.</u>

These soils are predominant in the Ngutini area to ne south of the schemes. The soils are characterised by a aximum salt concentration at some depth in the profile. This s shown by the EC-values in Table 6.8, for the soil from rofile No. 22. The ESP-values are relatively low in the top oil,as also indicated in Table 6.8. Similarly, the cation ontents are highest at this same depth of maximum salt oncentration (Fig.6.18).

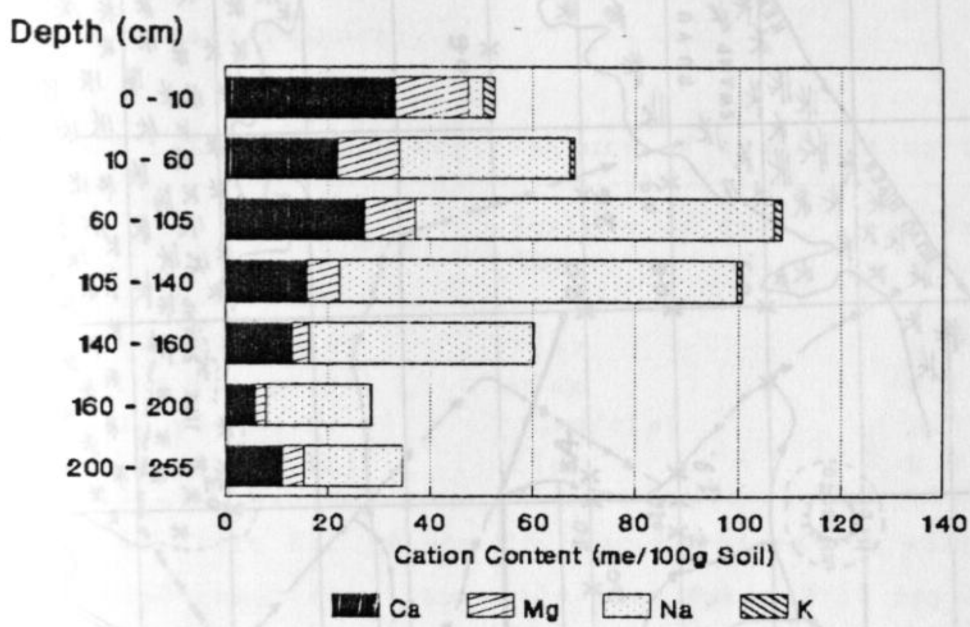
The occurence of higher salt concentration at a articular depth is normally an indication of the depth to hich salts are leached, or the depth to which capillary rise rom the groundwater reaches. In this Ngutini area, the roundwaters occur at depths between 2.0 - 3.0 m, except in reas close to the swamps (See Chapter 5, Section 5.2).

able 6.8: Variation of ESP, pH and texture for soil from profile pit No. 22 (Ngutini).

epth	EC(1:2.5)	ESP	pH	Texture			
cm)	mS/cm			%S	%Si	%c	Class
0 - 10	0.4	3.8	7.6	27	44	29	CL
0 - 60	4.0	79.0	8.0	29	28	45	C
0 - 105	14.	100^+	8.1	21	42	37	CL
05 - 140	8.3	100^+	8.5	21	12	67	C
40 - 160	3.8	100^+	8.4	37	25	38	CL
60 - 200	1.7	83.0	8.9	53	9	38	SC
00 - 250	1.2	100^+	8.6	73	19	8	SL

roundwater : Av. depth = 2.5 m; Av.EC = 8.1 mS/cm and SAR = 46 (Oct.,1988 - July,1989).

A height of capillary rise of 1.0 m will therefore
ssibly cause salt accumulation at around 1.5 m depth below
e surface.



g.6.18: Exchangeable cations at profile no.22 (Ngutini).

3: Hydraulic conductivity

The results of the hydraulic conductivity (K) tests rom 39 locations are presented in Fig. 6.19. Two sample lculations of how the K-values have been obtained are resented in App. D. The first sample calculation is for a mogenous soil profile while the second is for a layered oil (heterogenous). The augerhole and water table depths, pth of saturated layer and the depth to the impervious ayer indications are also given in Table D-1, App.D. gerhole depths varied between 100 cm at site D2-5 to 293 n at site D3 (see Fig.6.19).

In Fig. 6.19, the K-values can be seen to vary from s low as 0.009 m/day to 17.4 m/day at site D9. Low K-

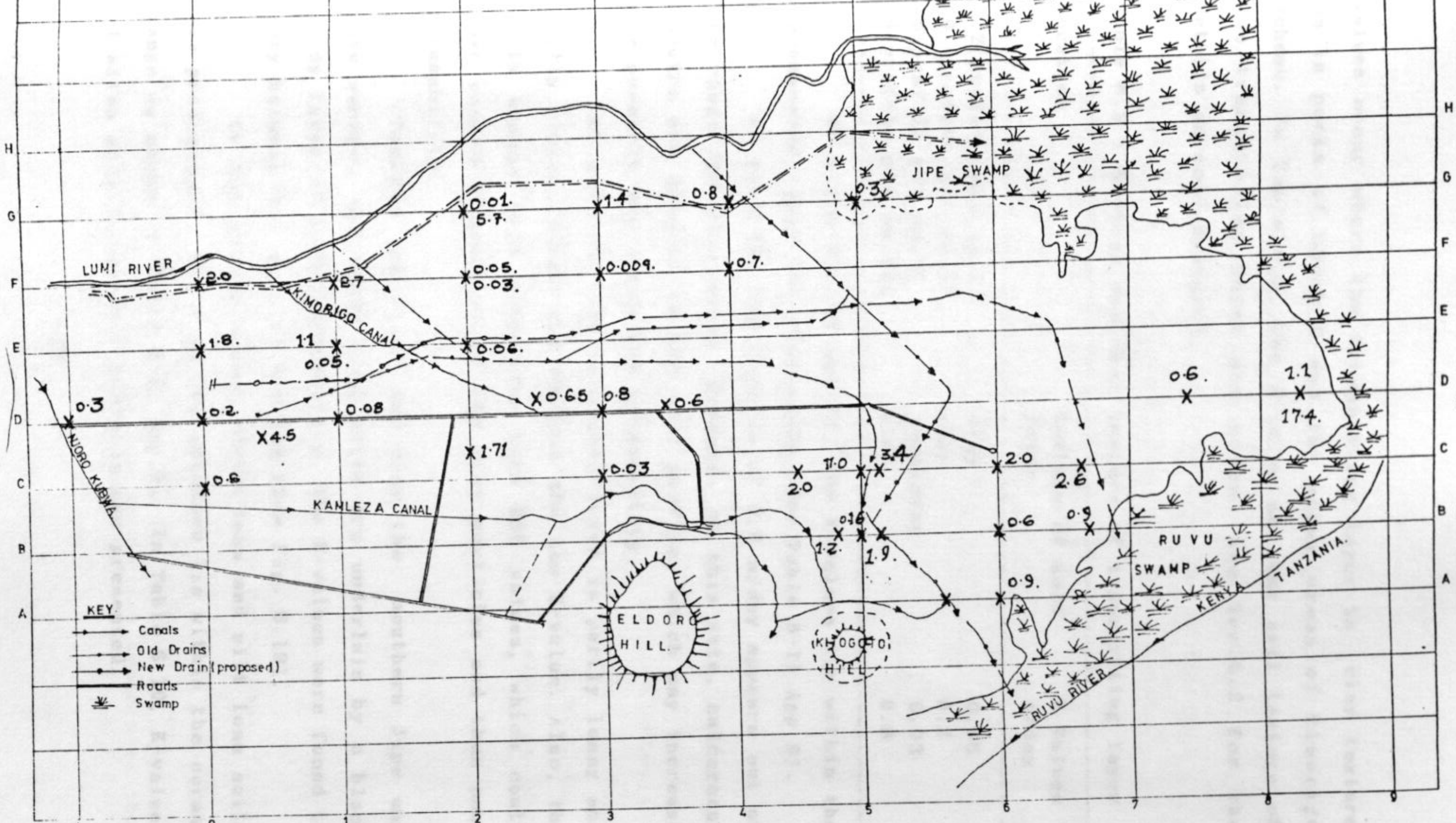


Fig.6.19: Hydraulic conductivity values.

ues occur where the transmitting layer is clay texture in parts of Block C and the upper areas of Kimorigo eme. In Table 6.9, the K-value and the soil texture of transmitting layer are given (see Sec.6.2 for the ails on soil texture).

le 6.9 : K-value and soil texture of transmitting layer

ation	Texture of salt layer	K-Values m/day
(profile pit no.4)	clay	0.06
(profile pit no.3)	clay	0.2
profile pit no.9)	loam/clay	0.03
profile pit no.12)	clay	0.8

At sites E2, D0 and C3, the K-values lie within the ommended range for clay soils (See Table D-11 App D).

At site E4, the K-value of 0.8 m/day appears out of range for clay soils. However, at this site, calcareous ules are present in the soil profile, which may increase porosity and hence the permeability.

At site C3, the saturated layer is partly loamy and rtly clayey, which may explain the low K-value. Also, the ls around this site have high ESP values, which could ve caused dispersion of the clay particles and thus poor rmeability.

Towards the river and near the southern Jipe and vu swamps, the heavy clay soils are underlain by a black dy layer of high permeability. The K-values were found to ry between 2.7 and 17.4 m/day (See Fig. 6.19).

In the scheme areas, where loam and silt loam soils predominant, the K-values obtained lie within the normal nge as shown in Table D-1, App D. In Table 6.10, K-values sites with known soil textures are presented.

The high K-value at site C5, which is out of range for either clay loam or loam soils, can be attributed to the presence of calcareous nodules in the soil profile above the impervious calcareous layer. The porosity of the soil around this area is therefore high (see Sec 6.1 also).

Table 6.10 : Soil texture and K-values at selected sites(in the schemes).

Location	Texture	K-Values (m/day)
D3-5 (profile no. 10)	loam	0.6
C2-D2 (profile no. 5)	loam	1.7
B5 (profile pit no. 17)	Clay/silt loam	1.2
C5 (profile pit no. 10)	Clay loam/loam	11

Differences in K-values within short distances can also be seen at site B5 in Fig.6.19. The K-value differed appreciably within a distance of 20 m e.g. 0.16 m/day at well B5 and 1.2 m/day. At 80 m away, the K-value was found as 1.9 m/day.

6.4: Discussion

6.4.1: The calcareous layer

From the presented data on the calcareous layer, some ideas can be formulated with respect to origin, influence on groundwater flow, and groundwater quality. In Chap.2, sec.2.2.6, three possible mechanisms explaining the ormation of the calcareous layer were given. Of the three, he second mechanism can possibly explain how the calcareous ayer in the schemes was formed. As summarised by Chorley 1984), calcareous layers can be formed in areas of arbonate rich groundwaters where sheet floods dry out, here capillary rise occurs and where the water table scillates close to the ground surface. From investigations n the surface and groundwater conditions in the Kimorigo nd Kamleza schemes it was noted that:

i) sheet floods do occur in the area,

i) the groundwaters are rich in the (bi)-carbonate salts,

ii) the groundwaters do occur at shallow depth and capillary rise can reach the surface as evidenced by pronounced capillary salinisation of the soils (see Sec. 6.2),

v) There is seepage inflow from higher areas which replaces water lost from the groundwater table by capillary rise.

The semi-arid climate in the area ensures that evaporation exceeds rainfall, so that there is, on the long run, a net upward flow of water and salts from the watertable below. In addition, as the area is close to the volcanic Kilimanjaro mountain, it is possible that calcareous dustfall has been a major source of $CaCO_3$, as was noted in New Mexico (Wilding et al., 1983).

Bear (1955), also supposed that the calcareous layers in the Taveta area originated from the groundwater through capillary rise. He further noted that the maximum thickness of the layers was between 2 - 3 ft, i.e. 60 - 90 cm. Our observations on the thickness of the layer in Sec.6.1.2 are within this range.

The influence of the layer on groundwater flow varies with the type of the layer. Where the layer is pervious, as in the central parts of Kimorigo scheme, drainage conditions are good and groundwater salinity is low (see Chap.5). Where the layer is completely impervious as in the central and lower parts of Kamleza scheme, perched groundwater is found. As drainage is restricted, the groundwater salinity in these areas is high (see Chap.5). Waterlogged conditions also result after heavy rainfall or floodflow as vertical drainage is restricted as shown by the hydrograph for well B5, in Fig. A-8, App.A.

It should be noted that while the layer is bound to restrict both vertical and horizontal groundwater flow and thus possibly result in shallow groundwater tables, groundwater depth position in the area is generally low even in areas without the petrocalcic horizon. This is because the drainage base is set mainly by the swamp levels.

Spacing of field drains is dependent amongst other factors, on the depth of the underlying impervious layer. The shallower the depth, the closer the drain spacing (Smedema and Rycroft, 1983). To avoid too close a spacing of drains, the impervious layer should occur at a depth of at least 1.5 m from the surface (MOA, 1984). In the schemes the layer occurs at depths of even less than 1.0 m and this may be an obstacle to the installation of field drains as a high number of drains will be expensive to construct and maintain (see Chap. 8).

.4.2: Salinity conditions and salinisation

Before carrying out investigations on soil salinity n the Kimorigo-Kamleza area, it was mentioned that the main bjective was not to show that salty soils exist, as this is lready known (see Chap.2), but to relate the soil alinity in different parts of the area to influencing actors like:

- groundwater depth and quality,
- rate of capillary rise,
- groundwater flow,
- soil texture,
- calcareous layer,
- leaching and internal drainage conditions.

The soil salinity conditions at the surface are given in Table 6.11 for various soil textures and under known groundwater conditions of depth and salinity (average watertable depth and salinity between Oct.1988 to July, 1989). The topsoil depths are shown in the table.

In Chap.2,Sec.2.2.5, it was mentioned that the extent of capillary salinisation and the depth at which salts accumulate is governed by the rate and height of capillary rise and the groundwater salinity, counteracted by the leaching intensity. In the non-irrigated areas, the very high salinity at the surface suggests that there is capillary salinisation (see Tables 6.5, 6.6, and 6.7). This shows that leaching by rainfall is insufficient and thus a net upward movement of salts occurs.

Table 6.11: Variation of soil salinity at the surface for various soil textures with groundwater table depth and salinity.

Profile no.	Soil Depth	Average GW depth (m)	GW salinity (mS/cm)	EC(1:2.5) at soil surface (mS/cm)	Texture
3	0-2	0.3	3.3	92	clay
5	0-2	1.0	8.0	72	loam
9	0-3	1.0	2.7	72	loam
10	0-10	1.4	1.3	12	loam
11	0-3	1.3	12.9	22	clay loam
12	0-5	1.2	45.0	26	clay
13	0-5	1.0	9.0	14	clay
15	0-30	1.9	3.2	0.4	loam
16	0-3	1.2	7.6	63	loam
17	0-5	1.0	3.6	68	silt/clay
22	0-10	2.5	9.0	0.4	clay loam

Where the groundwater table is less than 1.5 m from the surface, maximum salinity exist at the soil surface as shown in Table 6.11 or at least within the top 0 - 50 cm, indicating that capillary rise is able to reach the rootzone or the surface. As the groundwater table falls to beyond 1.9 and 2.5 m, soil salinity at the surface is considerably lower, as shown in the table. The zone of maximum soil salinity instead occurs deeper in the profile (see Table 6.10), showing that at the two depths of 1.9 and 2.5 m, capillary rise is not able to reach the surface or, if it does, the rate of rise is so small that insignificant amounts of salt get transported to the surface. These two depths are close to the recommended critical water table depth of 2.5 - 3.0 m (see Chap.2).

The highest salinity at the surface within the project area occurs where there is waterlogging, like in the wamp edges, and this can be attributed to relatively high ates of capillary rise and hence salt transport to the urface (see Table 6.11, profile no. 3). Soil texture also auses differences in capillary salinisation at the surface. t about the same groundwater table depths, medium textured oils exhibit higher soil salinity at the surface than fine extured soils, even with lower groundwater salinities. This an be seen by comparing soil salinity results of profile os.16 and 12, 11 and 10 and also 17 and 13 in Table 6.11. he higher salinities at the surface can be attributed to igher rates of capillary rise for medium textured soils han for finer textured soils.

For soils of the same texture, groundwater table epth, and hence the rate of capillary rise, appears to ontribute more to soil salinity at the surface than the roundwater salinity level (cf. results for profile nos.5, , 16 and 17). Differences in groundwater salinity do not ecessarily result in higher or lower salinity conditions at he surface. Similar results have been obtained by Elgabaly 1971).

High soil salinity in the area is generally ssociated with seepage inflows which maintain high roundwater tables for prolonged periods and thus enhance apillary salinisation. The Block C area, the Upper and entral parts of Kimorigo scheme and the southern areas of amleza scheme and the adjacent Ngutini areas, where high oil salinity conditions exist, all receive seepage inflow rom areas with higher groundwater tables.

Where the groundwater table is perched due to an mpervious calcareous layer, as at profile no.9 in Kamleza cheme, poor salt efflux conditions result in higher roundwater salinities than similarly irrigated areas in amleza scheme. Salinisation therefore occurs in between rrigations and this has led to high soil salinity despite ossibly sufficient leaching by irrigation water. Perched roundwater also occurs in the southern parts of Kamleza cheme (see Sec. 6.2).

Where non-saline soils occur, both leaching and nternal drainage can be said to be sufficient. This is the ase in the irrigated areas of Kamleza scheme where excess rrigation water causes sufficient leaching of salts. dequate internal drainage ensures evacuation of excess alts in the groundwater and, as reported in Chap.5, roundwater salinities in most parts of Kamleza scheme are ow. Under inadequate leaching, capillary rise from even ater of relatively low salinity, as at profile no.10 (imorigo Central), can lead to high soil salinity levels see Table 6.11). Where drainage conditions are poor, as in he Block C area, groundwater tables remain high for long urations after a sudden groundwater table rise. As noted in hap.5, the Block C area continually receives subsurface nflow from the river throughout the year, which ensures aintenance of high groundwater table conditions.

The soil salinity results obtained by Asol (1984), for the central part of Kimorigo scheme (near profiles no.10 nd 11), also reflect the presence of capillary alinisation, although his salinity levels are lower. This ndicates that salinity levels have risen, which could be rue as no measures have been taken since then to prevent alinisation, i.e. there have been no improvements in the leaching and drainage conditions.

The soil salinity boundaries drawn by Kanake (1982) longer hold, because some of the areas indicated as ing non-saline or slightly saline soils, particularly in southern parts of Kamleza scheme and the adjacent tini areas, now have strongly saline and sodic soils, as ustrated by profile nos. 16, and 17 (see map in Fig. 0). This too indicates that soil salinity levels have en. Similarly, in parts of Kimorigo scheme, like around file nos. 10 and and 12, the salinity levels are siderably higher. The rise in salinity levels can be ributed partly to irrigation and partly to upward ement of salts from the shallow and saline groundwater e Chap. 5).

.3: <u>Soil salinity/sodicity effects on crop growth</u>

EC-values in the rootzone can be obtained by tiplying the weighted averages in the rootzone by a factor 3 (see Sec. 6.2 and Chap.2). The rootzone depth sidered is in the range 50 - 70 cm. Tables 6.12 and 6.13 ve the ECe- and ESP-values in the rootzone depth. The scussion on the effects of the soil salinity and sodicity nditions on crop growth is presented in two parts :-

) Kimorigo and Kamleza Schemes;

i) Ngutini, Block C and swamp edges.

) Kimorigo and Kamleza Scheme

The ECe-and ESP-values for Kimorigo Scheme in Table 12 reveal that only in the lower areas the salinity and dicity levels are low enough to enable cultivation of a

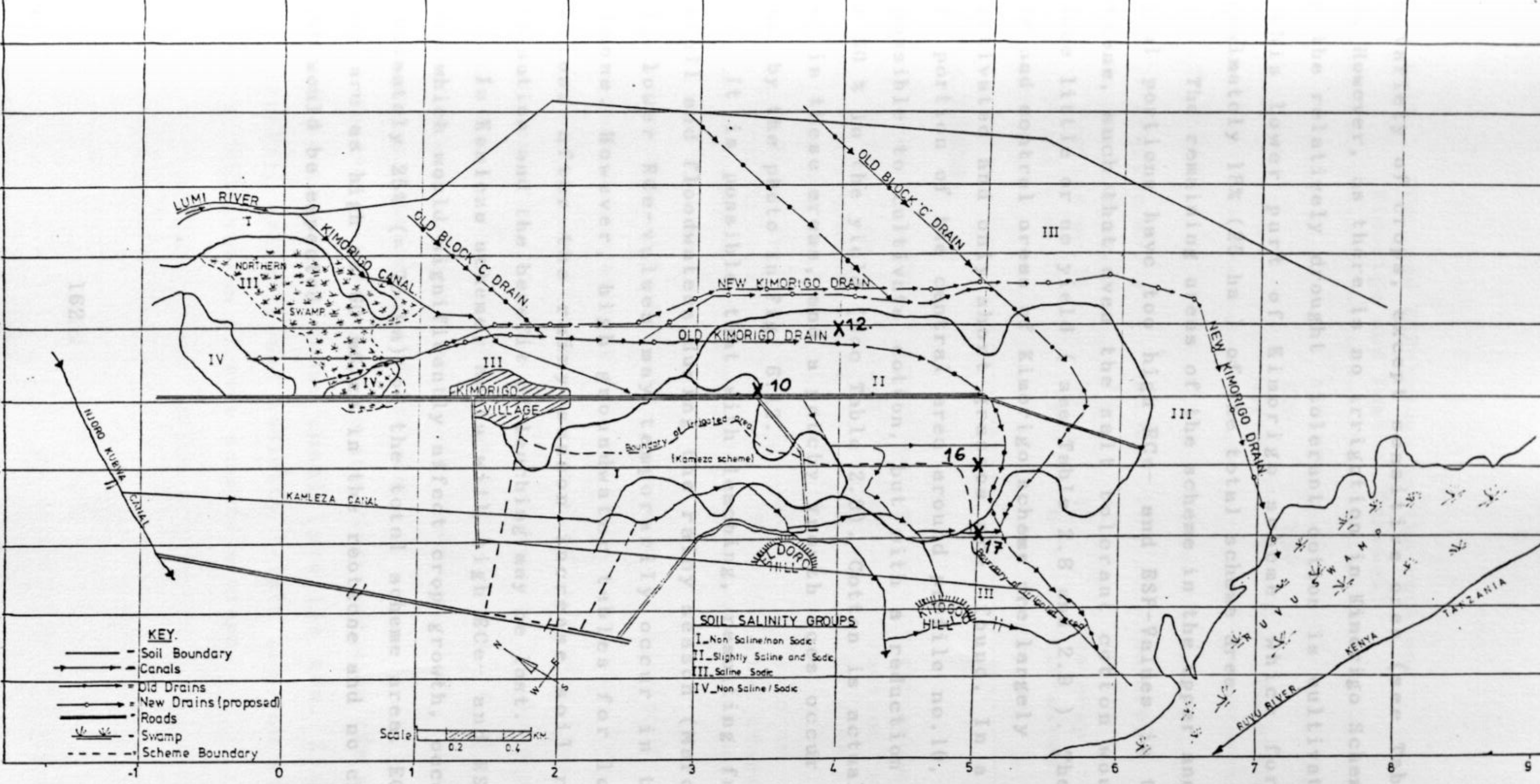


Fig.6.20: Soil salinity changes indicated on the soil salinity map..

de variety of crops, except sensitive ones (see Table 9). However, as there is no irrigation in Kimorigo Scheme, ly the relatively drought tolerant cotton is cultivated this lower part of Kimorigo scheme, which forms proximately 18% (25 ha) of the total scheme area.

The remaining areas of the scheme in the upper and ntral portions have too high ECe- and ESP-Values in the otzone, such that even the salt tolerant cotton would oduce little or no yield (see Table 2.8 and 2.9). These per and central areas of Kimorigo scheme are largely cultivated and only short grasses are found. In a all portion of the central area around profile no.10, it possible to cultivate cotton, but with a reduction of me 50 % in the yield (see Table 2.8). Cotton is actually own in these areas, and a patchy growth does occur as own by the photo in Fig. 6.12.

It is possible that with leaching, resulting from infall and floodwaters during the rainy season (March-y), lower ECe-values may temporarily occur in the otzone. However, high groundwater tables for long rations after the rainy season increase soil re-linisation and the benefit of leaching may be lost.

In Kamleza scheme, areas with high ECe- and ESP-lues which would significantly affect crop growth, occupy proximately 25% (= 75 ha) of the total scheme area. ECe-lues are as high as 60 mS/cm in the rootzone and no crop owth would be expected.

ble 6.12: ECe- and ESP-Values in the rootzone
(Kimorigo and Kamleza Schemes)

ea	Average ECe mS/cm	ESP %	Possible crops
morigo Scheme			
per : Profile No. 4	24.6	77	No crop
ntral: Profile no.10	18	12	cotton
Profile no.11	35	47	No crop
wer : Profile no.15	3	6	All except sensitive crops
mleza Scheme			
rth : Profile no.8	0.8	2	All crops
Profile no.5	14.3	43	cotton with
ntral: Profile no.9	42	39	no crop
uth : Profile no.16	21	41	no crop
Profile no.17	60	58	no crop
Profile no.18	1.3	9	all crops

Salt tolerant bushes and grasses are predominant in hese areas. The remaining 75% of the scheme area have low Ce- and ESP-values in the rootzone such that even sensitive rops can be grown. Crops which were observed in these areas nclude fruit crops (lemon, avocado, mango), food crops maize, bean, cowpea); vegetable (cabbage, kale, onions, omatoes) and cotton as a fibre crop.

In the section close to the river and also the areas djacent to the Njoro Kubwa canal (profile nos. 2 and 1 espectively), salinity and sodicity levels are low enough o enable cultivation of even sensitive crops.

(ii) <u>Ngutini, Block C and Swamp Edges</u>

In the upper areas of Ngutini cotton can be cultivated as the ECe-value in the rootzone is 10 mS/cm. However, the high ESP-Value of 66% may cause stunted growth. Fig. 6.21 shows stunted cotton and maize growth in a saline and/or sodic patch.

The areas abounding Kimorigo Scheme have similar soil conditions as in the lower areas of Kimorigo and cotton does very well (see Table 6.12).

Fig.6.21: Stunted maize and cotton growth in a salt affected patch in Marodo.

The lower parts of Ngutini adjacent to Kamleza
cme have soils with very high ECe- and ESP-values which not allow any crop growth. Salt bushes and grasses inate in these lower areas of Ngutini.

The Block C area also has soils with very high ECe- l ESP-values in the rootzone that would prohibit tivation of crops. As in the lower areas of Ngutini, the dominant vegetation are salt bushes and grasses.

On the swamp edges, extreme salinity and sodicity ditions also exist and the waterlogged condition appear to our the growth of Wild date and Doum palms.

le 6.13: ECe-and ESP-Value and influence on crop growth (other areas).

ea	Average ECe	ESP	Comments
UTINI			
er: Profile no.22	10	66	cotton can be grown
ver: Profile no.19	55	80	no crop
ck C			
per: As for Upper Kimorigo Scheme			
ntral: Profile no.12	61	100	no crop
per :			
VAMP EDGES			
:Profile no. 3	60	86	no crop

6.4.4: Hydraulic conductivity discussions

The data in Sec. 6.3 on hydraulic conductivity give a pointer to the varying internal drainage conditions in the area. In the Block C area, the low hydraulic conductivities of less than 0.1 mm/day reflect poor internal drainage conditions. The salty conditions of the soil and groundwaters in the Block C area can be attributed to the poor internal drainage (due to low hydraulic conductivity) coupled with the low groundwater slope in the area, leading to low salt efflux. In terms of reclamation of the soils in the Block C area and the upper parts of Kimorigo scheme, the low K-values would result in i) very close spacing of drains, and ii) low leaching efficiency and thus very high amounts of water required for leaching.

In the central parts of Kimorigo scheme and most parts of Kamleza scheme, the K-values are higher than in the Block C and the upper areas of Kimorige scheme, indicating relatively better internal drainage conditions.

7 GROUNDWATER BALANCE CALCULATIONS

7.1: Introduction

Groundwater balance calculations in this chapter are to enable quantification of the various sources of excess groundwater in the project area. The theory and pertinent formulas have been considered in Chap. 2. Once the sources are quantitatively known, then appropriate remedial measures can be recommended as earlier mentioned in Chap. 2.

Four areas within the two schemes have been selected for the groundwater balance assessments, namely; Central and Southern areas of Kamleza scheme around wells C3 and B5 and the Upper and Lower areas of Kimorigo scheme around wells E2 and D3.

The main sources of groundwater supply in the area, which are often the causes of high groundwater tables or drainage problems, are excess irrigation and precipitation, floodwater and seepage inflows (see Chap. 5). Changes in watertable levels, Δh , for the four selected areas are represented by well hydrographs in Figs. 7.1 to 7.4 at wells C3, B5, E2 and D3, respectively.

In order to relate the groundwater table changes either rainfall or irrigation, 10 - day rainfall totals have been plotted above the hydrographs. Arrows have been included in the figures to illustrate dominant percolation or capillary rise.

The precipitation data used in the waterbalance calculations are in Table C-1, App.C and the evapotranspiration data in Table C-2, App. C.

The unknowns to be determined from the water balance calculations are net subsurface inflows (I_{ss}), amount of percolated water (Perc), amount of irrigation water (Irr) and the drainable pore space (μ). Irrigation efficiency estimates have been made by comparing the expected crop water requirement for a given period with the amount of irrigation water calculated from the water balance for the same period.

For none of the four selected areas, there is direct interaction between the water level in the Lumi river and the groundwater table. Consequently, the discharge term, (Q_{inf} - Q_{dr}) in the Groundwater Balance Equation (eqn. 10), is zero. Also, due to the nearly flat topography (low groundslope) surface runoff is considered negligible in the following calculations.

A sample calculation has been presented for the area around Well C3 in Central Kamleza scheme. For the other areas, calculated values or results have been given in tables. However, for every area, a brief explanation is given of how the results have been obtained.

7.2: Sample calculation for Kamleza Central

Five different cases of groundwater balance assessment, using the indirect method, have been selected. The first case involves the determination of the net subsurface inflow, I_{ss}, and the drainable pore space, u, which are both unknown. In the next three cases, the calculated values of I_{ss}, and u are substituted in the groundwater balance equation to enable determination of the other unknowns as explained later. In the final case, the net subsurface inflow, I_{ss}, is determined from the groundwater balance equation, all other terms being known.

Case 1 : <u>Calculation of net subsurface inflow, I'_{ss} and the drainable pore space, μ.</u>

The net subsurface inflow and the drainage pore space have been calculated for two periods during which the supply (Perc - Cap) and the change in water table (Δh) are known. The two periods are 10/4 - 14/4/89 and 8/5 - 15/5/89. The groundwater table at the start of the two periods is at a depth of 90 cm below the surface (see Fig. 7.1).

For the two periods there is percolation due to excess precipitation over evapotranspiration causing a groundwater table rise. The soil is supposedly at field capacity, hence there is no change in the soil moisture content (ΔS_{sm} = 0). Capillary rise is zero as there is percolation of water to the groundwater table. There is no irrigation, hence Irr = 0 and runoff is negligible as already mentioned.

For the first period of 4 days from 10 / 4 - 14 / 4/ 89, the amount of percolation can be found by using eqn. (8) or (9) and substituting Pr = 37.5 mm (from Table C-1, App. C) and Et = 16 mm (from Table C-2, App.C). One thus obtains; <u>P = R - ET = 21.5 mm.</u>

Applying eqn. (18), and substituting Perc = 21.5 mm, Δh = 225 mm and Δt = 4 days from Fig. 7.1, one finds ;

$I'ss = 225\ \mu /4 - 21.5/4$ .... (i)

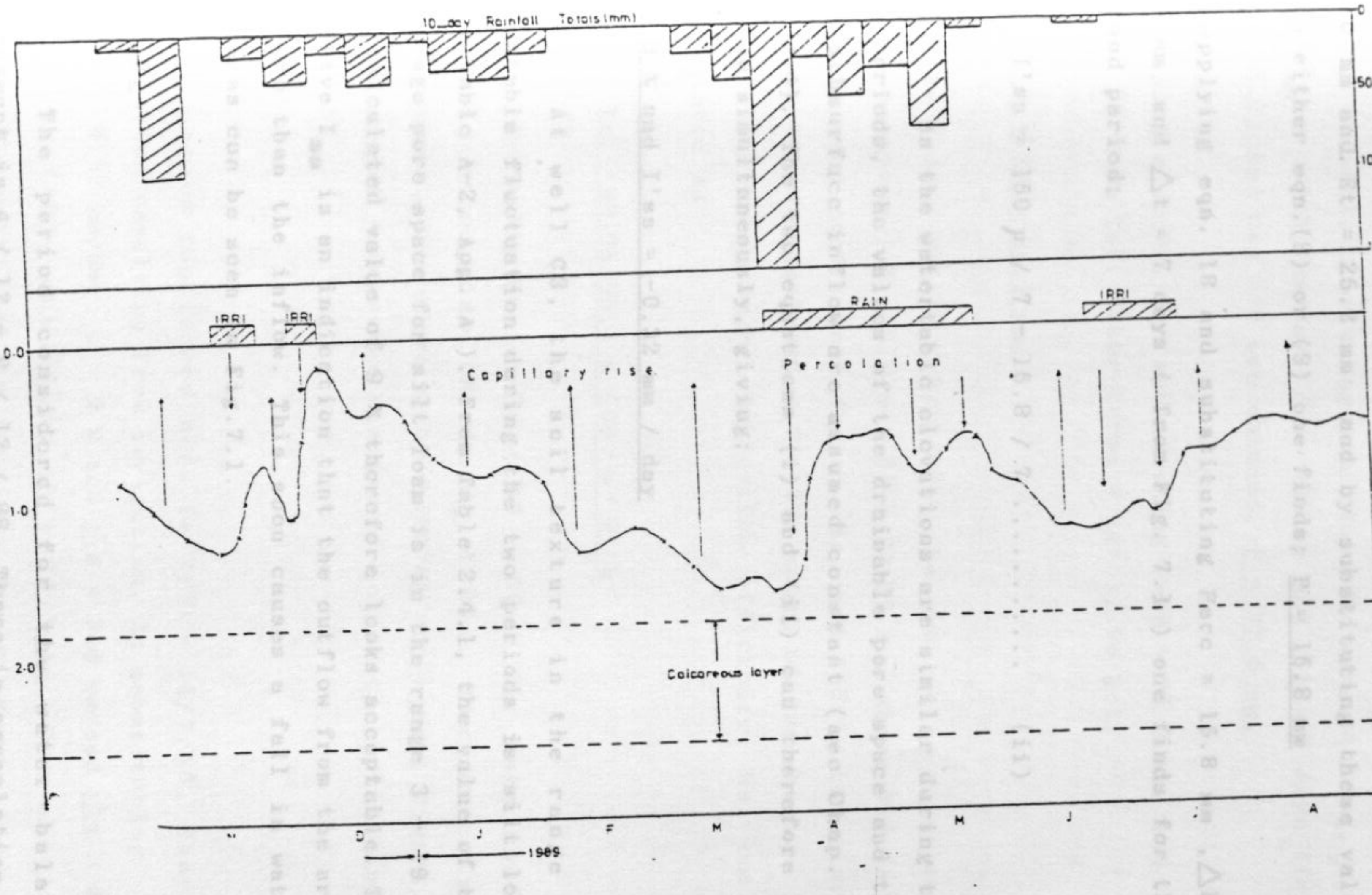


Fig.7.1: Hydrograph for well C3 (Kamleza central).

For the second period of 7 days from 8/5 - 15 / 5 / 89, Pr = 41.0 mm and Et = 25.2 mm and by substituting these values into either eqn.(8) or (9) one finds; <u>P = 15.8 mm</u>

By applying eqn. 18 and substituting Perc = 15.8 mm , $\triangle$h = 150 mm and $\triangle$t = 7 days (from Fig. 7.1) one finds for this second period;

I'_{ss} = 150 μ / 7 - 15.8 / 7 .... (ii)

As the watertable elevations are similar during the two periods, the values of the drainable pore space and the net subsurface inflow are assumed constant (see Chap. 2, Sec.2.4). The two equations (i) and (ii) can therefore be solved simultaneously, giving;

<u>μ = 9 % and I'_{ss} = -0.32 mm / day</u>

At well C3, the soil texture in the range of watertable fluctuation during the two periods is silt loam (see Table A-2, App. A). From Table 2.4.1, the value of the drainage pore space for silt loam is in the range 3 - 19 %. The calculated value of 9 % therefore looks acceptable. The negative I_{ss} is an indication that the outflow from the area is more than the inflow. This soon causes a fall in water table as can be seen in Fig.7.1.

<u>Case 2:</u>

The period considered for the water balance assessment is 4 / 12 - 9 / 12 / 88. There is percolation due o excess irrigation. The amount of percolated water, Perc, can be determined by using eqn (15). By substituting, μ = 9 %, I'_{ss} = - 0.32 mm/day, Δh= 800 mm and Δt = 5 days (from Fig. 7.1) and Cap = 0 one obtains, P = 73.6 mm.

Applying eqn.(8), and substituting Perc = 73.6 mm, and ET = 22.5 mm (all other terms = zero), we get,

I_i = P + ET = 96.1 mm.

For the 5 days (4/12 - 9/12/89), the crop water requirement would be about (5 x 0.9 x 4.5) = 20.25 mm, where 0.9 is the average crop coefficient factor, Kc, and 4.5 is the average monthly evapotranspiration for the month of December.

The irrigation application efficiency, Ea, can be calculated as

Ea = 20.25/96.1 x 100 = 21 %

Normally Ea is about 40 - 50 % for many surface irrigation methods (Michael, 1983). The calculated efficiency is therefore about half of the normal figure, an indication of poor water management (or excess irrigation).

Case 3:

The period considered here is 7/7 - 14/7/89. There is percolation resulting from irrigation. By substituting I_{ss} = - 0.32 mm/day, μ = 9 % and Δh = 350 mm and Δt = 7days into eqn.(12), one finds, P = 33.7 mm. The amount of irrigation water can be found by applying eqn (11), and ubstituting P = 33.7 mm and ET = 24.5 mm (all other terms oeing zero) and one finds, $\underline{I_i = 58.2 \text{ mm}}$

The calculcated irrigation efficiency in this case is 38 %.

Case 4 :

The period considered here is 21/7 - 4/8/89, and similar conditons apply as in case (3), except ET = 49.6 mm and $\triangle h$ = 150 mm and $\triangle t$ = 14 days. The calcualted, Perc and Irr - terms and the application efficiency, Ea, are presented in Table 7.1 using eqs. 8 and 12, respectively.

Case 5:

This covers the period from 4/8 - 31/8/89. The groundwater table is constant, ($\triangle h$ = 0). The lateral subsurface inflow, I'ss , must therefore be equal to the capillary rise which in turn equals the ET - rate (all other terms being zero), which is 3.7 mm /day for the month of August.

able 7.1: Summary of results of groundwater balance calculations (Kamleza Central).

Period	μ %	I'ss mm/day	P mm	Cap mm/day	(P - Cap) mm/day	I_i mm	Ea %
0/4 -14/4/89	9	-0.32	21.5	0	5.4	0	-
/5/-15/5/89	9	-0.32	15.8	0	2.3	0	-
/12-9/12/88	9	-0.32	73.6	0	14.7	96.1	23
/7-14/7/89	9	-0.32	33.7	0	4.8	58.2	38
1/7-4/8/89	9	-0.32	18	0	1.4	68.3	65
/8-31/8/89	-	3.7	0	3.7	-3.7	0	-

7.3: Groundwater balance calculations (Kamleza South).

In Kamleza South (around well B5) marked changes in groundwater table occured due to irrigation and precipitation, as illustrated by hydrograph of well B5, Fig. 7.2.

The values of the drainable pore space, u and the net subsurface inflow, I'ss, have been estimated for periods 7/4 - 10/4/89 and 9/12-23/12/88. These two values have subsequently been used in groundwater balance calculations for other periods, where they are assumed to be about the same. The results are presented in Table 7.2.

Table 7.2: Groundwater balance calculation results (Kamleza South)

Period	μ (%)	I'ss mm/day	P mm	Cap mm/day	(P - Cap) mm/day	I_i mm	Ea %
7/4-10/4/89	9.1	0	100.5	0	33.5	0	-
9/12-23/12/88	-	1.7	0	1.7	-1.7	0	-
13/1-27/1	9.1	1.7	69.5	0	5.0	100.5	56
11/8-18/8/89	9.1	1.7	24.5	0	3.5	50.4	47
23/6-3/7	-	3.6	0	3.6	-3.6	0	-
14/7-28/7	9.1	5.3	0	3.5	-3.5	-	-

(a) Estimation of the drainage pore space u.

To calculate the drainable pore space, u, a period of heavy rainfall, 7/4 - 10/4/89 was selected. Eqn. 16 applies

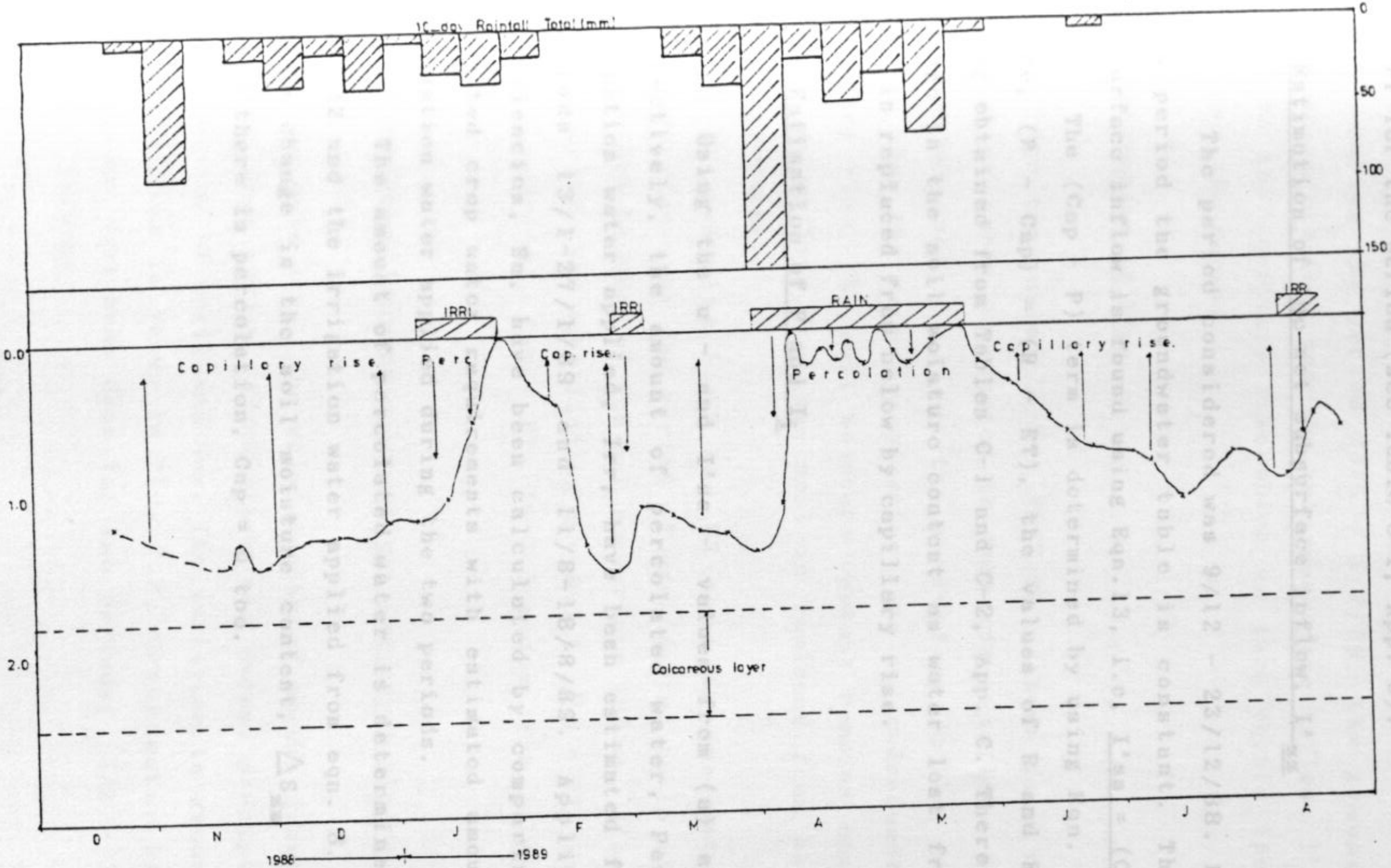


Fig.7.2: Hydrograph for well B5 (Kamleza south).

and, u = P /$\triangle$h, where $\triangle$h = 1025 mm (from Fig. 7.2), and P = Pr for the period (see Table C-1, App. C).

(b) Estimation of the net subsurface inflow, I'_{ss}

The period considered was 9/12 - 23/12/88. During this period the groundwater table is constant. The net subsurface inflow is found using Eqn.13, i.e, I'ss = (Cap - P).

The (Cap - P) term is determined by using Eqn. 9 where, (P - Cap) = (R - ET), the values of R and ET being obtained from Tables C-1 and C-2, App. C. There is no change in the soil moisture content as water lost from the soil is replaced from below by capillary rise.

(c) Estimation of P and I_i

Using the u - and I'ss - values from (a) and (b) respectively, the amount of percolated water, Perc and irrigation water applied, Irr, have been estimated for the periods 13/1-27/1/89 and 11/8-18/8/89. Application efficiencies, Ea, have been calculated by comparing the expected crop water requirements with estimated amounts of irrigation water applied during the two periods.

The amount of percolated water is determined from Eqn. 12 and the irrigation water applied from eqn. 8. There is no change in the soil moisture content, $\triangle S_{sm}$ = 0 and since there is percolation, Cap = 0 too.

(d) Estimation of I'ss

During the period 23/6 - 3/7/89, the groundwater table stays constant and the net subsurface inflow, I'ss, is equal to the capillary rise which in turn equals the ET - rate over the period.

(e) Estimation of I'ss

For the period 14/7 - 28/7/89 , there is a rise in groundwater table attributed to subsurface inflow. For the groundwater table to rise, the subsurface inflow must be greater than the evapotranspiration rate and consequently the capillary rise. The soil moisture content remains unchanged as any water lost from the soil is replaced from below by capillary water.

By assuming that the ET-rate approximates the capillary rise over the period of groundwater table rise, an estimate can be made of the net subsurface inflow, I'ss by using eqn. 12, and substituting u = 9.1 %, $\triangle$h = 275 mm (from Fig. A-7, App. A), Cap = ET (= 3.5 mm/day for July) and P = 0.

7.4: Groundwater balance calculations for upper Kimorigo

In this area, the main sources of excess groundwater are subsurface inflow, floodwaters and excess precipitation in the months of April and May. The variation in groundwater table position is shown in Fig. 7.3. Groundwater balance calculations have been done for two periods; 3/2 - 24/2/89 and 4/8 - 15/9/89.

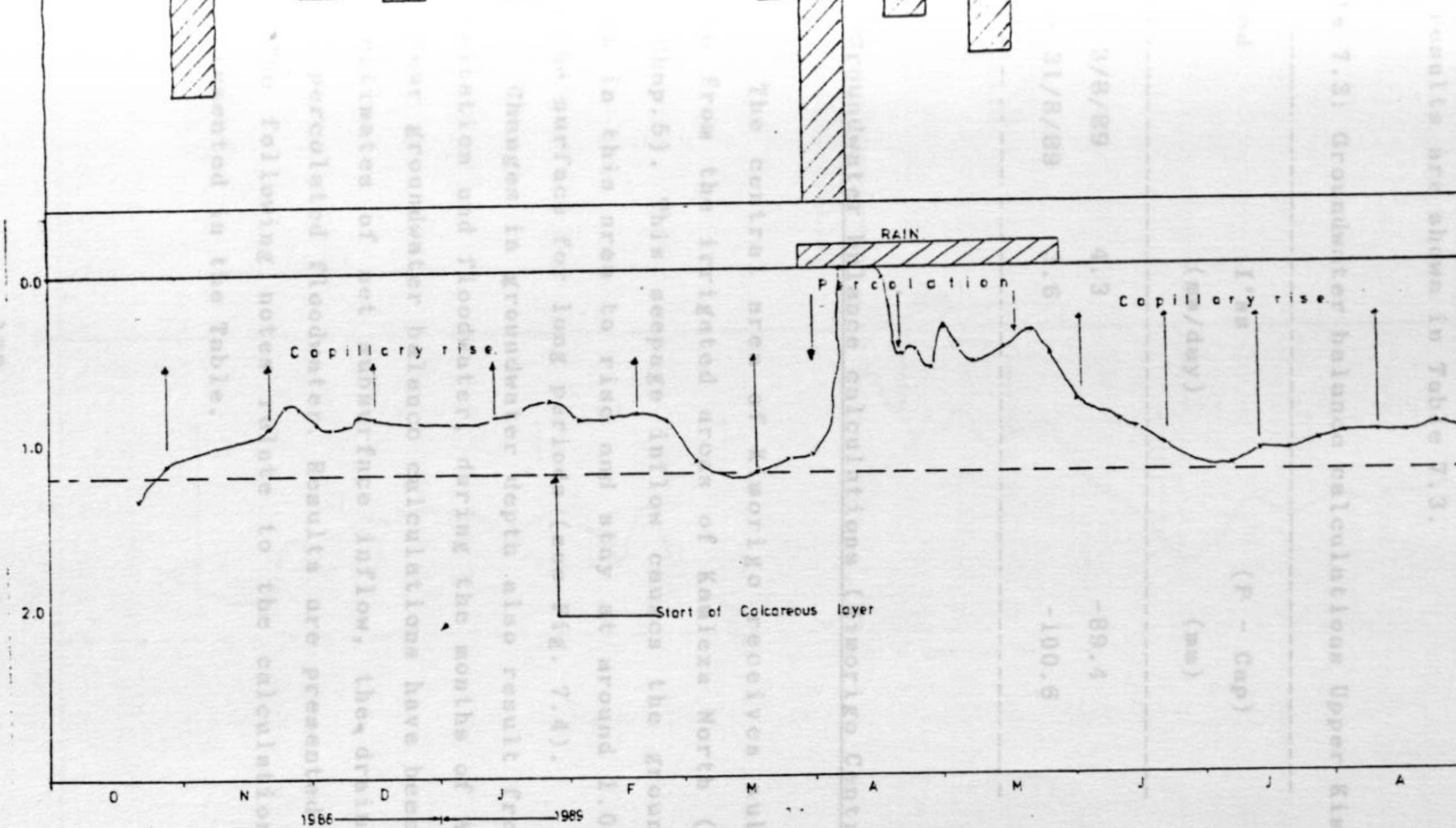


Fig.7.3: Hydrograph for well E2 (Upper Kimorigo scheme area).

For both periods, the net subsurface inflow equals the difference between precipitation and evapotranspiration. The results are shown in Table 7.3.

Table 7.3: Groundwater balance calculations Upper Kimorigo

Period	I'ss (mm/day)	(P - Cap) (mm)
3/2 - 3/8/89	4.3	-89.4
4/8 - 31/8/89	3.6	-100.6

7.5: <u>Groundwater balance calculations (Kimorigo Central)</u>

The central area of Kimorigo receives subsurface inflow from the irrigated areas of Kamleza North (See Fig. 5.1, Chap.5). This seepage inflow causes the groundwater tables in this area to rise and stay at around 1.0 m depth from the surface for long periods (see Fig. 7.4).

Changes in groundwater depth also result from excess precipitation and floodwater, during the months of April and May. Four groundwater balance calculations have been done to find estimates of net subsurface inflow, the drainage pore space, percolated floodwater. Results are presented in Table 7.4. The following notes relate to the calculation of the data presented in the Table.

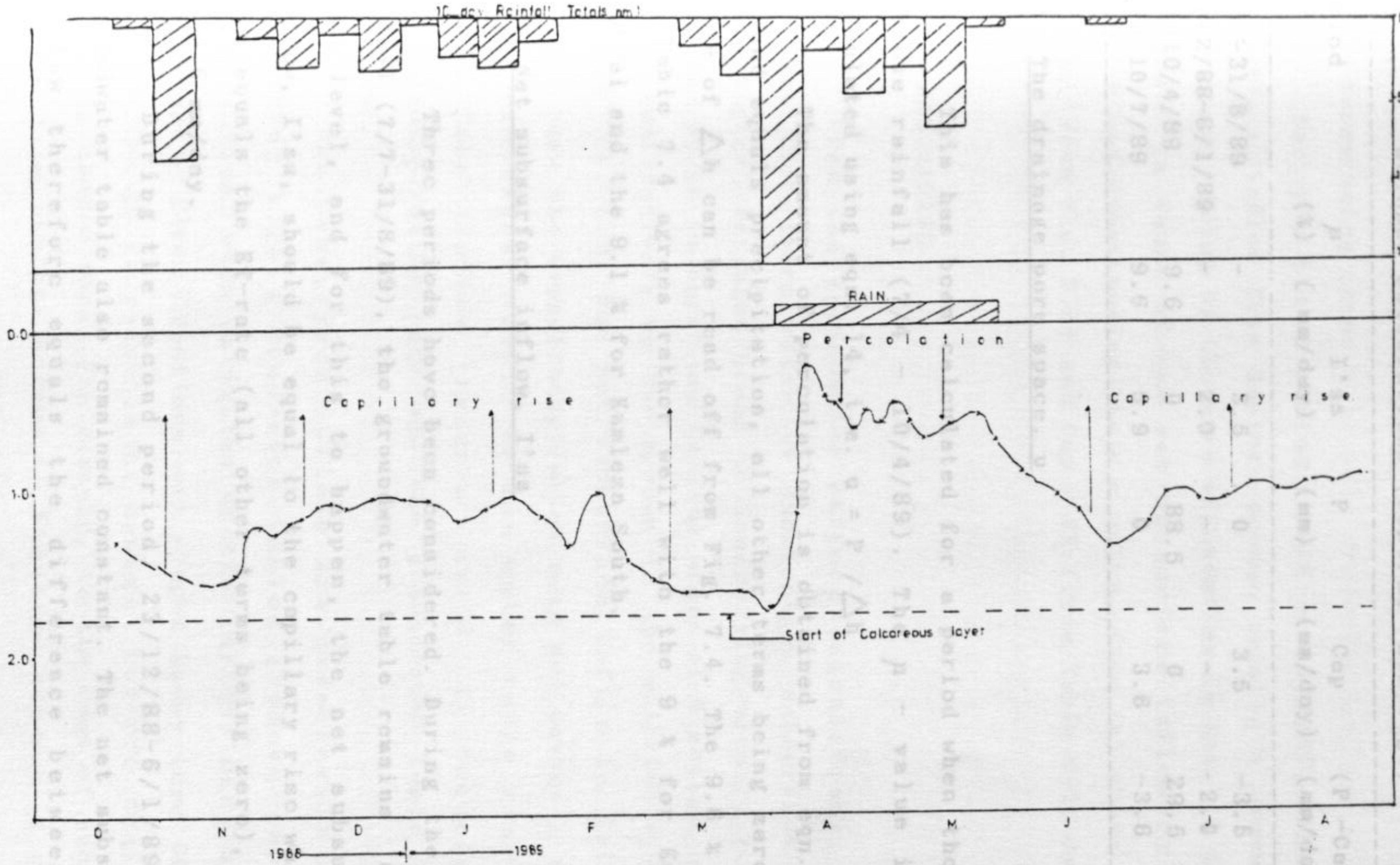


Fig.7.4: Hydrograph for well D3 (Kimorigo Central).

Table 7.4: Summary of results on groundwater balance calculations (Central Kimorigo)

Period	μ (%)	I'ss (mm/day)	P (mm)	Cap (mm/day)	(P -Cap) (mm/day)
7/7 -31/8/89	-	3.5	0	3.5	-3.5
23/12/88-6/1/89	-	2.0	-		-2.0
7/4-10/4/89	9.6	0	88.5	0	29.5
23/6-10/7/89	9.6	5.9	0	3.6	-3.6

(a) The drainage pore space, u

This has been calculated for a period when there is intense rainfall (7/4 - 10/4/89). The μ - value is calculated using eqn. 14, i.e. $u = P / \triangle h$

The amount of percolation is obtained from eqn. 8 or 9 and equals precipitation, all other terms being zero. The value of $\triangle h$ can be read off from Fig. 7.4. The 9.6 % shown in Table 7.4 agrees rather well with the 9 % for Kamleza Central and the 9.1 % for Kamleza South.

(b) Net subsurface inflow, I'ss

Three periods have been considered. During the first period (7/7-31/8/89), the groundwater table remains at the same level, and for this to happen, the net subsurface inflow, I'ss, should be equal to the capillary rise which in turn equals the ET-rate (all other terms being zero), which is 3.5 mm/day.

During the second period, 23/12/88-6/1/89, the groundwater table also remained constant. The net subsurface inflow therefore equals the difference between the percolation and capillary rise, (Perc - Cap), which in turn equals the precipitation minus evaporation (R - ET), all other terms being zero.

For the third period, 23/6 - 10/7/89, there is subsurface inflow from Kamleza scheme causing a groundwater table rise. Going by the same argument as in Sec.7.3 (e), an estimate is found of the net subsurface inflow by using eqn. 12 and substituting the u - value, from (a) above, $\triangle h$ = 400 mm (from Fig. 7.3) and Cap = ET (from Table C-2, App. C).

7.6: Discussion

From the groundwater balance calculations, it is evident that there often is substantial subsurface inflow from higher irrigated areas to lower lying areas i.e., from Kamleza North to Upper and Central areas of Kimorigo, as also shown qualitatively by the arrows in the watertable contour map in Fig. 5.2. The net subsurface inflow is initially higher than the evapotranspiration rate and causes a rise in the groundwater table. As the water table rises, the subsurface inflow reduces until it equals the evapotranspiration rate and the groundwater table becomes constant.

The subsurface inflows are undesirable as the resulting high groundwater tables promote capillary salinisation. With estimates of the inflows made and the groundwater flow directions and slopes known (see Chap. 5, Sec. 5.2), it is possible to design cut-off drains and properly locate them. For example, in the case of subsurface inflow from Kamleza scheme to Kimorigo scheme, a cut-off drain can be located along the road between the two schemes. This cut-off drain may also serve the purposes of discharging excess surface flows or as a main drain for Kamleza scheme.

Although some acceptable estimates of the irrigation efficiencies were made (around 40 %), the very low irrigation efficiency of 23 % in Kamleza Central indicates that there is no strict irrigation water management in the scheme. In Chap. 4, flooding of farms in Kamleza North was reported (see photo in Fig.4.8) which too is a pointer to poor irrigation water management. During the investigations it was not uncommon to come across irrigation water flowing even in uncultivated plots, an example being the area around Well B5 in Kamleza South.

A low irrigation efficiency means high amounts of water lost to the groundwater table, the consequence of which is a groundwater table rise in the irrigated and adjacent areas and an enhanced capillary salinisation. The water management in the scheme therefore needs to be improved and this will not only result in reduced recharge to the groundwater table but the irrigation water thus saved can be used in other non-irrigated areas. Where additional irrigation water is required for leaching, low irrigation efficiency is inevitable. However, in such cases, there should be provision of adequate drainage to ensure the evacuation of the extra leaching water. As already noted in the previous chapters, drainage is inadequate in the project area and the low efficiencies, at the moment, though desirable for leaching of salts, only exacerbate the drainage situation.

Percolation from excess precipitation and floodwater is high due to low run-off. When there is intense rainfall over a short period as occurred in April, 1989, percolation is high causing groundwater tables to rise to the surface. The percolation to the groundwater table can be reduced through construction of surface drains to channel away ponded water. The influence of floodwater on the groundwater table can be reduced through flood control measures (see Chap. 4).

In Chap. 2, Sec. 2.2.1, it was mentioned that Berger and Kalders (1983) never considered subsurface inflow in their field drainage design as they assumed that it was negligible. The results obtained in this chapter prove that subsurface inflow is substantial and cannot be neglected in the design of field drainage, except when it is prevented from entering the field through installation of cut-off drains as mentioned above. Although no groundwater balance has been made for the areas close to the river , it is evident from the groundwater table contour map in Fig.5.2 that there is subsurface inflow from the river to the adjacent low-lying areas. The high groundwater tables in areas close to the river, as shown by the hydrograph in Fig.A-1, App. A, is due to this subsurface inflow (also refer to Chap. 5).

The values of the drainable pore space calculated (9 - 10 %) lie within the expected range for silt loam soils as indicated in Table 2.15, Chap. 2.

Values have been calculated of the capillary rise ranging from 1.7 mm/day to 3.7 mm/day. The rate of capillary rise as mentioned in Chap. 2, decreases with increase in depth of the groundwater table below the surface. The soil texture also influences the rate of rise. The values calculated appear to be within acceptable limits.

8. SALT BALANCE ASSESSMENTS

8.1. Salt balance calculations

In Chap. 6, it has been shown that capillary salinisation exists in various parts of the project area. This a net upward salt movement could be counteracted by leaching water, washing salts down again. In Chap. 7, it has been shown that capillary rise may be as high as the evapotranspiration rate in areas with shallow groundwaters and a net positive subsurface inflow (seepage). It could thus be useful to have an idea of the magnitude of the leaching requirement, so that one can assess if leaching as a management practice can solve the problem. If so, quantification would provide a basis for drainage design at the same time.

Considering steady state conditions, a salt balance can be made to determine the extra irrigation requirement in various locations needed to maintain favourable salt conditions in the rootzone by using equation 24 (Chap. 2). The parameters which are required for the water balance are Et-rate (E); the rainfall amount (R); the rate of capillary rise (G); the groundwater quality (ECg); the irrigation water quality (ECi); the allowable soil salinity level in the rootzone (ECe); and the leaching efficiency factor (f).

The values of the evapotranspiration used (E) and rainfall (R) have been obtained from Tables C-1 and C-2 in App.C. The rate of capillary rise (G), has been determined by reference to Fig. 2.3 and Table C-3, App. C, which show the rate of capillary rise for different soil textures at different depths. Information on the soil textures is in Table B, App. B. For our case, the maximum rate of capillary rise, on average, is taken as the maximum average evapotranspiration, which is 4.23 mm/day (annual average). Average water table depths have been obtained by reference to Tables A-1 and A-2, App. A. The groundwater salinity averages have been obtained by reference to Table A-4, while the leaching efficiency factors have been obtained from Table 2.15 (Chap.2). The rootzone depth considered is 50 cm (see Chap.6).

Eight sites have been considered for the assessment and the details of the average groundwater quality, ECg, average water table depth (W), soil texture (st.) above the water table, the estimated capillary rise,G, based on the water table depth and the soil texture, and finally the leaching efficiency factor,f, are presented in Table 8.1. The height of the rootzone above the water table (H) is also indicated.

Three sample calculations of salt balance , considering steady state conditions are presented below for sites E3, D3 and C5.

<u>Sample calculation (1) - site E3</u>

Data

Average annual ET	=	1544 mm (from Table 1.1)
Average rainfall, R	=	595 mm (from Table 1.1)
Capillary rise, G	=	3.5 mm/day = 1277.5 mm/yr (from Table 8.1)
Average groundwater quality,ECg	=	13 mS/cm (from Table 8.1)
Allowable ECe (crop rootzone)	=	4 mS/cm *

NB: * - the allowable ECe for 75 % yield potential for maize and some vegetables as shown in Table 2.3, Chap. 2). Substituting the above figures and f = 0.4 (from Table 8.1), into eqn. (24), as below,

Table 8.1: Sites for water and salt balances and their characteristics.

Site	ECg mS/cm	Texture	W (m)	H (m)	G (mm/day)	f
5 (pit no.17)	3.8	siL/C	0.9	0.4	4.2	0.4
3 (pit no.9)	2.7	L	0.9	0.4	4.2	0.45
5 (pit no.16)	7.6	L	1.0	0.5	4.2	0.4
3 (pit no.10)	1.3	L	1.1	0.6	4.2	0.45
2 (pit no.4)	11.5	C	0.85	0.35	0.3	0.25
3 (pit no.11)	13	CL	1.3	0.8	3.5	0.4
4 (pit no.12)	43	C	1.2	0.7	4.0	0.4
3 (pit no.13)	7.9	C	0.8	0.3	4.0	0.25

$$f.I = \frac{(E-R).1.5ECe}{(1.5ECe - ECi)} + \frac{G.(ECg - 1.5ECe)}{(1.5ECe - ECi)}$$

one obtains; I = 6363 mm and P = 5086 mm (from eqn.22).

Sample calculation (2) - site D3

The data is the same as above except that ECg = 1.3 mS/cm, f = 0.45 and G = 4.23 mm/day = 1544 mm/yr. Using eqn.(24), we get; I = -604 mm and P = 323 mm.

This shows that irrigation water is not needed as there is already enough water brought from the groundwater table by capillary rise. There is also no need for leaching as (P-G) is negative. The results for other sites are given in Table 8.2 below.

Sample calculation (3) - site C5

Data is same as for the two cases above except that ECg = 7.6 mS/cm, G = 4.2 mm/day, and f= 0.4. By substituting these figures into eqn. 24, one obtains; I = 3549 mm, and by using eqn.22, P = 4144 mm.

The results of the salt balance calculations for the above and 5 other sites are given in Table 8.2 below. Also shown in the Table are the leaching ratio (100 x P/I) and the leaching requirement (100 x (P-G)/I).

Table 8.2: Results of salt balance calculations (steady state)

site	I	P	P-G	P/Ix100	(P-G)/Ix100
B5	998	1593	49	160	4.9
C3	231	826	-718	-	-
C5	3549	4144	2600	117	73
D3	-604	-9	-1535	-	-
E2	9546	10141	8597	106	90
E3	6363	5085	3808	80	60
E4	25962	26473	25013	102	96
F3	5890	6401	4961	109	84

NB: I = infiltrating irrigation water (mm/year)
P = total deep percolation (mm/ycar)
G = capillary rise from groundwatert (mm/year)

8.2 : Discussion

From the salt balance calculations, it can be seen that the amount of (extra)-irrigation water depends on the salinity level of the groundwater, the rate of capillary rise, and the leaching efficiency (other factors being equal). In the area between Block C and the lower parts of Kimorigo scheme around well E4, where the groundwater salinity is very high, the amount of irrigation water required for maintenance of favourable salt conditions in the rootzone is enormous; 25,962 mm/year. Without this amount of water applied, then capillary salinisation is bound to occur. However, such annual amounts of water are out of the question; proper measures would include lowering of the groundwater table, improving the drainage and a rigorous reclamation programme, after which more normal annual leaching requirements would be needed.

In the upper areas of Kimorigo scheme where both the groundwater salinity and the leaching efficiency are high, irrigation water requirements are high , although less than at well E4 due to the lower groundwater salinity level. In areas where the groundwater salinity is less than 1.5ECe, irrigation water requirements are relatively lower and as at well D3 in the central part of Kimorigo scheme, where the groundwater salinity is 1.3 mS/cm, no irrigation water is required; the capillary rise from below can be considered as "rainfall from below" providing the net irrigation water requirement. It was noted maize and banana crops did well in this area despite there being no irrigation. At wells C3 and B5 in the central and southern parts of Kamleza scheme, irrigation water requirements are also low as the groundwater salinity is less than 1.5ECe.

In the central area of Kimorigo scheme, towards the old Kimorigo drain around well E3, the increase in groundwater salinity results in higher amounts of irrigation water for maintenance of favourable salt conditions in the rootzone. From the groundwater salinity map in Fig.5.4 show that most parts of the central and upper areas of Kimorigo scheme have ECg- values greater than 8 mS/cm. The watertable depths are also often less than 1.5 m from the surface (see Table A-2, App.A). As there is no irrigation, salinisation is expected to be pronounced and the high soil salinity conditions at profile no.11 (around well E3), prove that this is so (see Chap.6).

In conclusion, it can be said that salinisation is bound to continue in most parts of the area unless there is adequate leaching and drainage. Groundwater tables need to be lowered to reduce capillarity into the rootzone and as noted in Chap. 6, the groundwater table depth should lie at not less than 1.5 m from the surface. Decision on what measures to take in various parts of the project area are given in the next chapter.

9 APPROPRIATE REMEDIAL MEASURES

9.1 Identified problems

From the information provided in Chapters 4 to 7, some remedial measures can be recommended to solve the problems afflicting irrigation development in the Kimorigo/Kamleza area. In Chap. 4, two problems were identified; flood and surface drainage problems (which lead to surface water ponding for long durations). In Chap. 5, subsurface drainage problems were noted to exist in many parts of the schemes; high groundwater tables do occur for long durations; water at times is present for upto 3 months in the rootzone. The groundwaters were also noted to be saline and/or sodic and their occurrence at shallow depths or within the rootzone leads to capillary salinisation as reported in Chap. 6. In Chap. 7, groundwater balance calculations have indicated that seepage inflow from higher to lower areas, excess precipitation and irrigation, and floodwaters are the major sources of excess groundwater in the two schemes. The salt balance assessment further points to the need of providing other measures in addition to extra irrigation water (leaching requirement), especially in areas with shallow and salty groundwater, because too high amounts of irrigation water would be needed to maintain favourable salt conditions in the rootzone. Moreover, any extra water needs to be removed to prevent the further rise of the groundwater table.

The measures recommended in order to help alleviate the drainage and salinity problems in the area are given in the following sub-sections.

9.2 Flood control

Flood flow over the area was noted to originate from the Lumi river, through broken parts or breaches in the river's flood dyke and also around the dyke. It was also noted that the flood and storm drains adjacent to the dyke are vegetated and silted. Based on these findings, the measures which need to be undertaken to prevent flood flow over the area would include:

(a) Repair of all broken parts of the dyke, especially the main broken part at the head of the dyke (see Chap. 4);

(b) Desilting and clearing of vegetation in the flood and storm drains so as to increase evacuation of floodwater and also to prevent backing up of floodwater, which finds its way around the dyke;

(c) Extending the dyke further north to reduce chances of flood flow around the dyke. This may involve the construction of a further 500 to 1000 m length of dyke.

The height of the flood dyke, which varies between 1.0 - 2.0 m along its course appears to be sufficient as no flood flow was noted to occur over the dyke. However, with the many broken parts, a firm decision on the adequacy of the dyke height can not be made at the moment.

While the above may be the immediate measures to be undertaken to solve the surface flooding problem, further investigations may need to be carried out to :

(a) find ways of increasing the Lumi river channel capacity in its lower reaches where the water level in the river is at a higher elevation the the adjacent land (see Chap. 4). This may involve desilting and clearing of swampy vegetation. This will result in a higher channel capacity and thus a possible reduction in flood flow onto adjacent land.

(b) find ways of increasing the discharge from lake Jipe through the Ruvu swamp to Tanzania. A higher discharge will lead to possible lowering of the Lake water level (and hence the drainage base of the project area). This will in turn result in improved drainage of adjacent areas. A clear channel of the Lumi river in its lower reaches will reduce flood flow.

(c) find ways of diverting some flood waters to either flow directly to the Ruvu swamp by-passing Lake Jipe or divert the flood water to the Lake Jipe through a channel before the Njoro Kubwa springs. However, this may in turn result in flood problems in other areas.

9.3 Surface drainage

Surface water ponding is common in the project area after occurrences of flood flows, high precipitation, excessive irrigation or canal overflows. Measures which need to be undertaken to avoid these surface ponding problems, apart from those mentioned in Sec. 9.2 are :

(a) Completing the New Kimorigo drain; the remaining length is 3.4 km. The drain is designed to carry a peak discharge of 2 m^3/s at a slope of 0.05 % and is 2.5 m deep (Berger and Kalders, 1983). This drain was intended to serve an area of 2000 ha stretching from the Njoro Kubwa canal area to Ngutini in the south (also to collect water from field drains).

(b) If the above drain may not be possible in the next one or two years, due to lack of funds, then the old Kimorigo drain can be desilted and cleared of vegetation to help in discharge of excess surface water.

(c) Installation of a main drain between Kimorigo and Kamleza schemes (along the road, see Fig.8.1) for dispossal of excess surface and subsurface water from Kamleza scheme. This drain should start from around well D2 upto well D5, a length of 3 km, before joining the old Kimorigo drain (see Fig.8.1). As noted in Chap. 5, there is sufficient head between point D2 and the outlet at Ruvu swamp and this main drain can be as deep as the New Kimorigo drain (2.5 m).

(d) Installation of collector drains in the schemes for disposal of excess surface and subsurface water from the schemes and discharging into the main drain. The collectors will also receive water from field drains (see next section).

9.4: Field drainage

Capillary salinisation as already mentioned in chapter is pronounced in many parts of the project area. In order to prevent capillary salinisation, a net downward movement of excess water and salts should be ensured. This can be achieved through provision of adequate water for leaching (see Chap. 8). The excess water and salts must then be evacuated out of the soil by providing adequate field drainage. The amounts of extra irrigation water required as already estimated through salt balance assessment calculations (Table 8.2, Chap.8) are extremely high for some locations. In order to reduce the amount of salts transported to the surface by upward capillary flow, the groundwater table should be maintained at depths greater than 1.5 m from the surface as shown in Chap.6. However the occurrence of the calcareous layer at shallow depths, less than 1.5 m in many places may be hindrance to maintaining the water table at 1.5 m below the surface.

From the investigations and the groundwater and salt balance assessments, the following information needed for design of field drainage system is availabe:

i) depth of the calcareous layer within the schemes,
ii) K-values at several locations,
iii) drainable pore space ,
iv) leaching requirements (for current situation),
v) estimate of irrigation efficiencies and thus an estimate of expected irrigation losses, and
vi) net subsurface inflows.

However, before carrying out a field drainage design, more investigations are necessary to establish:

i) the depth to the impermeable layer, especially where the underlying calcareous layer is perviuos as in the central parts of Kimorigo scheme.

ii) the K-value of the semi-pervious calcareous layer (any design at the moment in places where the semi-pervious layer exists will assume that the layer is impervious or has a K-value less than 1/10th of that of the overlying soil).

ii) K-values in many other places in the scheme as the determined K-values only give an indication at a few locations. Differences may exist within short distances as was witnessed around well B5 (see Sec. 6.3). A K-map would be advisable.

10. CONCLUSION AND RECOMMENDATIONS

The results obtained of the drainage and soil investigations in the project area lead to the following conclusions;

i) Due to the low ground slopes, both surface and subsurface drainage of excess water is slow. This often leads to surface water ponding and high groundwater tables for long periods.

ii) The main sources of excess surface water are floods, precipitation and overflowing water from irrigation canals.

iii) The main sources of excess groundwater supply (and thus the causes of the drainage problems) are floodwater, precipitation, irrigation and seepage or subsurface groundwater flow.

iv) Both surface and subsurface drainage are poor as witnessesd by surface water ponding and high groundwater tables for long duration, calling for the need to install more surface and sub-surface drainage channels.

v) The high salt content of the soils originates from the groundwater i.e there is salinisation from groundwater (capillary salinisation).

vi) A low irrigation efficiency of 21 % as estimated from groundwater balance assessment is an indication of poor water management, especially in areas where salinity is not ct a serious problem, where extra irrigation water is equired for leaching.

ii) Where the calcareous layer is impervious, vertical enetration is restricted, leading to perched water ables. The groundwaters in such areas are saline and apillary salinisation is pronounced.

iii) There is enough head between the end of the scheme and the outlet at Ruvu swamp to enable evacuation of excess urface and subsurface waters.

In order to alleviate the drainage and salinity roblems in the area, the following recommendations are iven :

) Repair of the flood control dyke and the adjacent drains s necessary to prevent flood flow into the area. ithout the control of floodflow over the area, the rainage problems will persist.

) The surface drainage problems, particularly in the the imorigo and Kamleza schemes, can be solved through nstallation of additional surface drains and proper aintenance of the existing ones.

A cut-off cum storm drain is required between Kamleza and Kimorigo scheme close to the Kimorigo canal. This drain ill cutoff seepage flow from Kamleza scheme towards imorigo. In the two schemes, collector drains will be required.

c) The northern swampy area between Kivalwa and Kimorigo should be drained to reduce seepage inflow into the upper areas of Kimorigo scheme. The New Kimorigo drain on completion will be able to drain this swamp.

d) Subsurface drains /open drains are needed in the schemes for groundwater table control and evacuation of excess water and salts from the area. At the moment, there are no such drains in the schemes.

e) Water management in the schemes needs to be improved. The right amount of water at the right time should be applied to avoid excessive losses to the groundwater. Some extra leaching water may be needed, but this should be done in a planned way. This will require an irrigation schedule.

f) A strong scheme committee is required to ensure that canals and drains are maintained properly. In the case of the dyke and the main drains, either the government should provide funds for maintenance or farmers also pay some fee to offset part of the maintenance expenses.

g) Reclamation of the upper areas of Kimorigo scheme and the Block C areas are not advisable due to i) the high EC- and ESP-value of the soils,ii)low hydraulic conductivity and shallow depth of the calcareous layer which both would result in very closely spaced drains and very high leaching requirementsas shown in Chap. 8.

h) Due to fairly good drainage conditions in the central part of Kimorigo scheme, the soils can be reclaimed through leaching and ensuring that field drains are provided to evacuate the excess salts out of the area.

i) In Kamleza scheme, the affected areas in the northern area adjacent to Kimorigo scheme are not recommended for reclamation due to the high ESP-values and the shallow depth of the calcareous layer which would require closely spaced drains. Similarly in the lower areas around wells C5 and B5, both soil salinity and sodicity conditions are very high in the rootzone and thus reclamation would be difficult and expensive.

j) In the central areas of Kamleza scheme, where salty patches are found as a result of the impervious calcareous layer, further salinity problems can be prevented through regular leaching of salts and provision of field drains to evacuate the excess salts from the area.

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A, TABLE A-1

WATER LEVEL MEASUREMENTS

H	A2	A5	A6	B2	B4	B5	B6	B7	B7-750	C0	C0-1000	C1	C2
H	3.10	4.25	1.77	1.47		2.45	2.10	2.70	3.70		2.90	2.76	1.90
				0.61	0.65	1.11	1.57					1.39	0.90
8													
8													
8													
8					1.50	1.10	1.30					1.8	0.99
8				0.55	1.40	1.27	1.47					1.73	0.86
8				0.72	3.18	1.13	1.59					1.64	0.94
8				0.59		1.42	1.67					1.65	0.98
8				0.42	3.87	1.35	1.70					1.61	0.49
8		3.65	1.45	0.31	1.87		1.71					1.57	0.21
8		3.41	1.45	0.00		1.25	1.73	2.10				1.50	0.64
8		3.39	1.44	0.00		1.25	1.71	2.08				1.50	0.63
88		3.33	1.44	0.00		1.24	1.72	2.10				1.50	0.65
88		3.38	1.44	0.00		1.26	1.70	2.13				1.62	0.67
88		3.36	1.22	0.00		1.15	1.51	2.05				1.69	0.72

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D. PTH	C2-500	C3	C3-500	C4	C5	C6	C7	C7-1000	C7-1150	D0	D0-1000	D1-D	D1-P
PTH	1.10	2.72	1.92	3.67	2.40	2.30	2.76	2.30		1.05		2.92	1.65
88		0.84		2.37	1.47								
88												1.47	
88													
88		1.21		2.57	1.48	1.96	2.18					1.13	
-88		1.01		2.60	1.69	2.04	2.53			0.22		1.21	
-88		0.76		2.47	1.58	1.97	2.43			0.10		1.05	
-88		0.87		2.43	1.62	2.17	2.54			0.30		1.07	
-88		1.13		2.40	1.66	2.10	2.54			0.25		1.00	
-88		0.63		2.20	1.62	2.12	2.57			0.29		1.03	
-88		0.19		2.09	1.61	2.14	2.57			0.14		0.98	
-88		0.16		2.02	1.59	2.15	2.57			0.10		0.88	
-88		0.43		2.12	1.58	2.14	2.55			0.16		0.94	
-88		0.4		2.14	1.64	2.06	2.47			0.75		1.04	
-88		0.49		2.08	1.57	2.15				0.11		0.57	

TABLE A - 1 CONT'D

1988

WELL NO.	D2	D2-500	D3	D3-500	D4	D4-500	D5	D6	D7	D8	D9	E0	E1
WELL DEPTH	2.54	1.27	2.00	2.30	2.40	1.15	2.82	3.20	2.67	(D7-1000)	(D7-1700)	1.58	2.05
21-Oct-88	1.55		1.30		2.05								
22-Oct-88												1.33	
28-Oct-88												1.37	
19-Nov-88	1.17		1.51		2.12		2.07	2.45	1.97			0.52	
19-Nov-88	1.15		1.27		2.05		2.27	2.62			0.12	0.78	
25-Nov-88	1.03		1.23		2.05		2.26	2.35	2.22		0.12	0.60	
28-Nov-88	1.06		1.27		2.08		2.40	2.72	2.30		0.18	0.72	
02-Dec-88	1.00		1.20		2.09		2.55		2.36		0.23	0.82	
05-Dec-88	1.10		1.17		2.01		2.50		2.36		0.30	0.85	
09-Dec-88	1.05		1.10		1.95		2.53				0.00	0.82	
12-Dec-88	1.00		1.09		1.91		2.51	2.87	2.44		0.02	0.75	
16-Dec-88	1.04		1.12		1.91		2.46	2.89	2.42		0.15	0.76	
23-Dec-88	1.06		1.05		1.92		2.38				0.27		
30-Dec-88	1.01		1.05		1.86		2.47				0.10		

1988

WELL NO.	E2	E3	E3-500	E4	E4-500	E5	E6	E7	E7-1000	F0	F1	F2	F3
WELL DEPTH	1.70	1.75	1.83	1.90	1.58	3.27	3.25	3.08		2.20	1.33	2.90	1.90
21-Oct-88													
22-Oct-88	1.32	1.79		1.63			2.77				1.12	2.38	1.00
28-Oct-88	1.14												
19-Nov-88		1.29		1.38		2.50	2.49	2.33					
19-Nov-88	0.94	1.45		1.39		2.88	2.61	2.50			0.65	1.74	0.96
25-Nov-88	0.77	1.52		1.49		2.89	2.70	2.57			0.49	1.74	0.97
28-Nov-88	0.81	1.52		1.42		2.89		2.50			0.60	1.74	0.93
02-Dec-88	0.90	1.52		1.48		2.92					0.70	1.70	0.95
05-Dec-88	0.92	1.55		1.57		2.95					0.79	1.74	1.01
09-Dec-88	0.91	1.53		1.50		2.91					0.75	1.74	1.00
12-Dec-88	0.86	1.48		1.49		2.92	2.84	2.67			0.63	1.74	1.02
16-Dec-88	0.87	1.49		1.51		2.94	2.85	2.69			0.67	1.71	1.03
23-Dec-88		1.53		1.50		2.98					0.81	1.71	
30-Dec-88		1.49		1.47		2.91					0.70		

TABLE A - 1 CONT'D

1988

WELL NO.	D2	D2-500	D3	D3-500	D4	D4-500	D5	D6	D7	D8	D9	E0	E1
WELL DEPTH	2.54	1.27	2.00	2.30	2.40	1.15	2.82	3.20	2.67	(D7-1000)	(D7-1700)	1.58	2.05
21-Oct-88	1.55		1.30		2.05								
22-Oct-88												1.33	
28-Oct-88												1.37	
19-Nov-88	1.17		1.51		2.12		2.07	2.45	1.97			0.52	
19-Nov-88	1.15		1.27		2.05		2.27	2.62			0.12	0.78	
25-Nov-88	1.03		1.23		2.05		2.26	2.35	2.22		0.12	0.60	
28-Nov-88	1.06		1.27		2.08		2.40	2.72	2.30		0.18	0.72	
02-Dec-88	1.00		1.20		2.09		2.55		2.36		0.23	0.82	
05-Dec-88	1.10		1.17		2.01		2.50		2.36		0.30	0.85	
09-Dec-88	1.05		1.10		1.95		2.53				0.00	0.82	
12-Dec-88	1.00		1.09		1.91		2.51	2.87	2.44		0.02	0.75	
16-Dec-88	1.04		1.12		1.91		2.46	2.89	2.42		0.15	0.76	
23-Dec-88	1.06		1.05		1.92		2.38				0.27		
30-Dec-88	1.01		1.05		1.86		2.47				0.10		

1988

WELL NO.	E2	E3	E3-500	E4	E4-500	E5	E6	E7	E7-1000	F0	F1	F2	F3
WELL DEPTH	1.70	1.75	1.83	1.50	1.58	3.27	3.25	3.08		2.20	1.33	2.90	1.90
21-Oct-88													
22-Oct-88	1.32	1.79		1.63			2.77				1.12	2.38	1.00
28-Oct-88	1.14												
19-Nov-88		1.29		1.38		2.50	2.49	2.33					
19-Nov-88	0.94	1.45		1.39		2.88	2.61	2.50			0.65	1.74	0.96
25-Nov-88	0.77	1.52		1.49		2.89	2.70	2.57			0.49	1.74	0.97
28-Nov-88	0.81	1.52		1.42		2.89		2.50			0.60	1.74	0.93
02-Dec-88	0.90	1.52		1.48		2.92					0.70	1.70	0.95
05-Dec-88	0.92	1.55		1.57		2.95					0.79	1.74	1.01
09-Dec-88	0.91	1.53		1.50		2.91					0.75	1.74	1.00
12-Dec-88	0.86	1.48		1.49		2.92	2.84	2.67			0.63	1.74	1.02
16-Dec-88	0.87	1.49		1.51		2.94	2.85	2.69			0.67	1.71	1.03
23-Dec-88		1.53		1.50		2.98					0.81	1.71	
30-Dec-88		1.49		1.47		2.91					0.70		

TABLE - 1 CONT'D

1989

WELL NO.	A2	A5	A6	B2	B4	B5	B6	B7	B7-750	C0	C0-100	C1	C2
WELL DEPTH	3.10	4.25	1.77	1.47		2.45	2.10	2.70	3.70		2.90	2.76	1.90
06-Jan-89		3.26	1.20	0.00		1.15	1.51	1.99				1.70	0.73
13-Jan-89		3.17	1.25	0.14		1.02	1.53	2.00				1.78	0.80
20-Jan-89	2.36	2.89	1.16	0.64		0.58	1.48	1.97				1.77	0.80
27-Jan-89	2.46	2.44	1.06	0.76		0.00	1.46	1.91				1.76	0.90
03-Feb-89	2.50	2.49	1.03	1.05		0.31	1.40	1.92				1.80	1.12
10-Feb-89	2.55		0.91	1.18		0.42	1.33	1.92				1.86	
17-Feb-89			1.06	1.20		1.33	1.37	1.93				1.90	
24-Feb-89			1.14	1.05		1.51	1.45	1.97				1.98	
03-Mar-89			1.23	1.21		1.10	1.55	1.99				2.01	
10-Mar-89			1.33	1.22		1.16	1.61	2.05				2.06	
17-Mar-89			1.34			1.25	1.70	2.00				2.07	1.60
24-Mar-89			1.41	1.22		1.28	1.69	>2.00				>2.10	1.52
31-Mar-89	>3.00		1.43	1.37		1.39	1.73	>2.00		1.02		2.07	1.60
07-Apr-89	>2.68		1.01	1.30		1.10	1.42			0.17		2.37	1.43
10-Apr-89	>2.68		0.00	0.95		0.00	0.00	0.00		0.02		2.04	1.00
14-Apr-89	3.00		0.15	0.99		0.22	0.27	0.54		0.07		2.12	0.85
17-Apr-89	2.85		0.00	1.17		0.15	0.13	0.56		0.53		2.38	1.01
21-Apr-89	2.75		0.00	1.03		0.24	0.23	0.65		0.52		2.10	1.02
24-Apr-89	2.78		0.00	0.90		0.10	0.25	0.69		0.59		2.17	0.95
28-Apr-89	2.60	3.80	0.15	1.05		0.25	0.30			0.42		1.91	0.96
01-May-89	2.67	3.65	0.03	1.00		0.00	0.18	0.62		0.25		1.90	0.85
05-May-89	2.70	3.50	0.10	1.10		0.15	0.16	0.80		0.50		1.64	1.00
08-May-89	2.80	3.55	0.15	1.12		0.25	0.48	0.90		0.54		1.75	1.06
15-May-89	2.45	3.35	0.06	1.00		0.10	0.13	0.65		0.33		1.70	0.90
22-May-89	2.33	3.45	0.00	0.75		0.00	0.10	0.70		0.47		1.60	0.80
26-May-89	2.40	3.48	0.15	0.75		0.24	0.38	0.75		0.37		1.65	0.84
02-Jun-89	2.45	3.54	0.35	0.92		0.35	0.49	0.88		0.49		1.74	0.93
12-Jun-89	2.66		0.42	1.09		0.57	0.66	1.08		0.50		1.92	1.04
16-Jun-89	2.87		0.55	1.76		0.68	0.74	1.17		0.55		2.10	1.05
23-Jun-89	2.72		0.59	1.20		0.78	0.85	1.26		0.59		1.80	1.09
03-Jul-89	2.40		0.70	1.10		0.82	0.98	1.40		0.56		1.76	1.10
07-Jul-89	2.40		0.74	0.98		0.85	1.30	1.50	0.20	0.56		1.78	1.12
14-Jul-89	2.19		0.80	0.79		0.10	1.10	1.60	0.20	0.52		1.60	1.07
21-Jul-89	1.50		0.83	0.52		1.00	1.10	1.60	0.22	0.56		1.58	0.95
28-Jul-89	1.55		0.88	0.40		0.83	1.20	1.78	0.22	0.51	2.40	1.50	0.78

LE A - 1 CONT'D

1989

LL NO. / LL DEPTH	D2 2.54	D2-500 1.27	D3 2.00	D3-500 2.30	D4 2.40	D4-500 1.15	D5 2.82	D6 3.20	D7 2.67	D8 (D7-1000)	D9 (D7-1700)	E0 1.58	E1 2.05
-Jan-89	1.01		1.06	1.87	1.87		2.32					0.18	
-Jan-89	1.09		1.20	1.88	1.88		2.30	2.80	2.45			0.04	
-Jan-89	1.02		1.13	1.82	1.82		2.39	2.82	2.40			0.14	
-Jan-89	0.94		1.06	1.68	1.68		2.23	2.84	2.39			0.15	
-Feb-89	1.10		1.17	1.65	1.65		2.32	2.82	2.43			0.25	0.87
-Feb-89	1.13		1.37	1.72	1.72		2.20		2.32			0.13	0.86
-Feb-89	0.97		1.03	1.83	1.83		2.20	2.84	2.38			0.34	0.80
-Feb-89	1.24		1.45	1.92	1.92		2.32	2.86				0.41	0.90
3-Mar-89	1.35		1.55	2.04	2.04		2.35	2.80				0.50	1.02
0-Mar-89	1.40		1.64	1.98	1.98		2.37					0.35	0.88
7-Mar-89	1.52			2.04	2.04							0.56	0.95
4-Mar-89	1.47		1.64	2.08	2.08		2.40	>2.85	2.45			0.15	0.88
1-Mar-89	1.54		1.75	2.17	2.17		2.61	2.98	2.52			0.28	
7-Apr-89	0.07		1.18	1.30	1.30		1.84	>2.82	1.86			0.00	0.00
0-Apr-89	0.00		0.25	0.00	0.00		0.00	2.10	1.37			0.00	0.00
4-Apr-89	0.35		0.44	0.45	0.43		0.58	2.15				0.08	0.06
7-Apr-89	0.50		0.48	0.39	0.56		0.98	2.11				0.00	0.08
1-Apr-89	0.53	0.63	0.65	0.62	0.70		1.00	>1.83				0.10	0.08
4-Apr-89	0.50	0.53	0.53	0.45	0.60		1.09	1.93				0.60	0.07
8-Apr-89	0.60	0.65	0.61	0.39	0.79		1.08	1.35	1.35			0.03	0.55
01-May-89	0.60	0.46	0.48	0.47	0.56		0.95	1.66	1.30			0.00	0.3
05-May-89	0.48	0.56	0.60	0.55	0.75		1.09	1.66	1.24			0.10	0.3
08-May-89	0.54	0.65	0.70	0.75	0.80		1.20	1.70	1.20			0.13	0.4
15-May-89	0.40	0.55	0.63	0.75	0.90		1.10	1.55	1.15			0.13	0.3
22-May-89	0.35	0.45	0.55	0.75	0.80	0.73	1.10	1.40	1.10			0.10	0.2
26-May-89	0.57	0.67	0.72	0.90	1.00	0.89	1.19	1.55	1.16			0.13	0.4
02-Jun-89	0.74	0.83	0.91	1.10	1.19	1.08	1.38	1.57	1.26			0.20	0.6
12-Jun-89	0.90	0.96	1.06	1.22	1.32		1.46	1.65	1.28	1.41	0.20	0.24	
16-Jun-89	0.92	1.14	1.15	1.35	1.50		1.54	1.80	1.36	1.43	0.24	0.12	
23-Jun-89	1.05	1.20	1.40	1.38	1.66		1.70	1.85	1.42	1.54	0.26	0.15	
03-Jul-89	1.08	1.16	1.22	1.40	1.64		1.90	2.00	1.50	1.60	0.32	0.16	
07-Jul-89	1.09	1.18	1.05	1.44	1.60	1.45	1.90	2.00	1.60	1.70	0.35	0.11	1.0
14-Jul-89	1.20	1.18	1.10	1.30	1.60	1.60	2.00	2.04	1.73		0.35	0.00	0.6
21-Jul-89	1.10	1.20	1.13	1.40	1.60	1.63	2.10	2.00	1.90		0.43	0.07	0.6
28-Jul-89	1.10	1.20	1.00	1.42	1.69	1.66	2.14	2.20	2.00	1.80	0.50	0.10	0.6

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89

D. PTH	E2 1.70	E3 1.75	E3-500 1.83	E4 1.90	E4-500 1.58	E5 3.27	E6 3.25	E7 3.08	E7-1000	F0 2.20	F1 1.33	F2 2.90	F3 1.90
89		1.49		1.50		2.94					0.74		
-89		1.51		1.52		3.00	2.77	2.73			0.73		
-89		1.46		1.51		2.93	2.75	2.62			0.70		
-89	0.77	1.36		1.46		2.89	2.84	2.57			0.65		0.98
-89	0.89	1.45		1.34		2.88	2.88				0.76		0.90
-89	0.87	1.46		1.06		2.84	2.70				0.66		0.93
-89	0.85	1.52		1.26							0.75	1.87	0.97
-89	0.89	1.60				3.38	2.85	2.70			0.88	1.89	1.05
r-89	1.15	1.62						2.70			0.89	1.85	1.12
r-89	1.21												
r-89				1.45							0.74		1.20
r-89	1.14	1.72		1.46		2.98	>2.85	>2.47			0.73	>1.80	1.18
r-89	1.12	1.70		1.50		3.02	>2.85	2.88		0.18	0.82	>1.80	1.22
r-89	0.00	1.57		1.38		2.90	3.03	1.95		0.00	0.00	0.00	0.00
r-89	0.00	0.52		0.00		2.55	2.40	1.65		0.00	0.00	0.00	0.00
r-89	0.00	0.55		0.21		2.10	2.50	1.90		0.00	0.35	0.00	0.00
r-89	0.07	0.58		0.26		2.06	2.45	1.92		0.00	0.36	0.05	0.05
r-89	0.54	0.63		0.97		1.90	2.10	1.68		0.00	0.45	0.03	0.03
r-89	0.50	0.64		0.82		1.85	2.05	1.70		0.00	0.50	0.06	0.06
r-89	0.60	0.63		0.70		1.65	1.90			0.00	0.50	0.40	0.40
ay-89	0.36	0.45		0.48		1.60	1.78			0.00	0.29	0.00	0.00
ay-89	0.48	0.60		0.53		1.59	1.68	1.50		0.00	0.42	0.00	0.00
ay-89	0.58	0.67		0.58		1.57	1.66	1.47		0.00	0.46	0.00	0.12
ay-89	0.50	0.66		0.60		1.55	1.62	1.42		0.00	0.33	0.00	0.17
ay-89	0.40	0.60		0.50		1.56	1.59	1.42		0.00	0.29	0.00	0.13
ay-89	0.52	0.76	0.99	0.63	1.26	1.59	1.58	1.41		0.10	0.40	0.02	0.13
Jun-89	0.80	0.96	1.88	0.87	1.40	1.72	1.66	1.45		0.10	0.50	0.44	0.40
Jun-89	0.90	1.14	1.33	1.00		1.80	1.75	1.70		0.09	0.58		0.73
Jun-89	0.94	1.15	1.40	1.10		1.89	1.90	1.75		0.04	0.67	1.14	0.70
Jun-89	1.06		1.48	1.20		1.98	1.98	1.80		0.06	0.67	1.22	0.80
Jul-89		1.67	1.58	1.30		2.20	2.10		2.73	0.03	0.68	1.33	0.87
Jul-89	1.18	1.20	1.56	1.20		2.20	2.15		2.70	0.02	0.70	1.30	0.91
Jul-89	1.10	1.30	1.60	1.25	1.98	2.30	2.27		2.72	0.00	0.52	1.30	0.95
Jul-89	1.10	1.28	1.51	1.10	1.57	2.43	2.40			0.00	0.58	1.37	0.99
Jul-89	1.05	1.30	1.53	1.47	2.04	2.38	2.49		2.92	0.03	0.54	1.38	1.20

TABLE A - 1 CONT'D

1989

WELL NO.	F4	F5	F6	F7	G2	G3	G4	G5	G6
WELL DEPTH	1.95	2.03	2.10	3.05		2.70		3.20	3.30
06-Jan-89	1.52	1.30							
13-Jan-89	1.53	1.28		2.41					
20-Jan-89	1.45	1.30		2.36					
27-Jan-89	1.40	1.40	1.65	2.40					
03-Feb-89	1.40	1.41	1.81						
10-Feb-89	0.97	0.67	1.81						
17-Feb-89	1.34								
24-Feb-89									
03-Mar-89	1.56	1.53	1.90						
10-Mar-89	1.65	1.57	1.92						
17-Mar-89									
24-Mar-89	1.63	1.55	1.98	2.38					
31-Mar-89	1.61	1.50	1.92	2.30					
07-Apr-89	0.99	0.00	1.50	2.27					
10-Apr-89	0.10	0.00	0.00	0.46					
14-Apr-89	0.00	0.00	0.00	1.11					
17-Apr-89	0.10	0.00	0.00	1.24					
21-Apr-89	0.00	0.54	0.00	1.08					
24-Apr-89	0.00	0.45	0.00	1.18					
28-Apr-89	0.00	0.30	0.00	1.15					
01-May-89	0.00	0.21	0.00	1.16					
05-May-89	0.00	0.25	0.00	1.17					
08-May-89	0.00	0.26	0.00	1.17					
15-May-89	0.00	0.30	0.00	1.15					
22-May-89	0.00	0.32	0.18	1.20					
26-May-89	0.10	0.38	0.38	1.28					
02-Jun-89	0.19	0.45	0.62	1.30					
12-Jun-89	0.24	0.57	0.70	1.40	0.57	1.24	0.77	0.80	
16-Jun-89	0.76	0.64	0.79	1.48	0.61	1.32	0.83	0.89	
23-Jun-89	0.29	0.66	0.62	1.58	0.62	1.38	0.88	0.96	
03-Jul-89	0.86	0.72	0.67	1.67	0.71	1.48	0.90	1.04	2.82
07-Jul-89	1.02	0.76	0.72	1.70	0.66	1.43	0.92	1.20	1.80
14-Jul-89	1.01	0.80		1.80	0.67	1.35	0.92	1.24	1.87
21-Jul-89	1.36	0.83		1.90		1.38	0.95	1.18	1.96
28-Jul-89	1.13	0.87		1.90	0.89	1.41	0.93	1.20	2.92

, TABLE A-?

ERAGE DEPTH TO WATER LEVEL MEASUREMENTS

	A2	A5	A6	B2	B4	B5	B6	B7	B7-750	C0	C0-1000	C1	C2	C2-500	C3	C3-500
	3.10	4.25	1.77	1.47		2.45	2.10	2.70	3.70		2.90	2.76	1.90	1.10	2.72	1.92
				0.61	0.65	1.14	1.57					0.90	0.90		0.84	
				0.62	2.03	1.38	1.51					0.94	0.94		0.96	
		3.42	1.41	0.10	2.87	1.25	1.68	2.09				1.57	0.57		0.49	
	2.41	2.94	1.17	0.51		0.92	1.50	1.97				1.75	0.81		0.81	
	2.53	2.49	1.04	1.12		0.89	1.39	1.94				1.89	1.12		1.15	
	3.00		1.35	1.26		1.24	1.66	2.01		1.02		2.05	1.57		1.50	
	2.80	3.80	0.19	1.06		1.10 0.16	1.42 0.20	0.49		0.33		2.16	1.03	0.52	0.82	1.37
	2.56	3.50	0.08	0.95		0.12	0.24	0.74		0.41		1.71	0.91	0.63	0.78	1.63
	2.68	3.54	0.48	1.12		0.60	0.69	1.10		0.53		1.89	1.03	0.80	1.19	1.85
	2.01		0.79	0.76		0.72	1.14	1.58	0.21	0.54	2.40	1.64	1.00	0.36	0.93	1.30

	C4	C5	C6	C7	C7-1000	C7-1150	D0	D0-1000	D1-D	D1-P	D2	D2-500	D3	D3-500	D4	D4-500
	3.67	2.40	2.35	2.76	2.30		1.05		2.92	1.65	2.54	1.27	2.00	2.30	2.40	1.15
	2.37	1.47							1.47		1.55		1.30		2.05	
	2.52	1.59	2.04	2.42			0.21		1.12		1.10		1.32		2.08	
	2.15	1.61	2.12	2.55			0.26		0.92		1.04		1.11		1.95	
	2.00	1.37	2.02				0.22		1.08		1.02		1.11		1.81	
	2.15	1.14	1.97	2.43			0.35		1.15		1.11		1.26		1.78	
	2.59	1.58	2.09	2.62			0.43		1.42		1.47		1.65	2.04	2.06	
	2.40 1.13	1.53 0.23	2.12 0:66	1.24			0.16		0.51		0.36	0.60	0.59	0.62	0.63	
	1.48	0.35	0.72	1.24			0.20	1.71	0.54	0.51	0.49	0.56	0.61	0.70	0.80	0.81
	1.99	0.76	1.04	1.51			0.19	1.85	0.82	0.90	0.90	1.03	1.13	1.26	1.42	1.08
	2.03	1.12	1.30	1.81	0.52	0.45	0.14	1.88	0.84	0.88	1.11	1.18	1.10	1.39	1.63	1.59

1989

WELL NO.	F4	F5	F6	F7	G2	G3	G4	G5	G6
WELL DEPTH	1.95	2.03	2.10	3.05		2.70		3.20	3.30
06-Jan-89	1.52	1.30							
13-Jan-89	1.53	1.28		2.41					
20-Jan-89	1.45	1.30		2.36					
27-Jan-89	1.40	1.40	1.65	2.40					
03-Feb-89	1.40	1.41	1.81						
10-Feb-89	0.97	0.67	1.81						
17-Feb-89	1.34								
24-Feb-89									
03-Mar-89	1.56	1.53	1.90						
10-Mar-89	1.65	1.57	1.92						
17-Mar-89									
24-Mar-89	1.63	1.55	1.98	>2.38					
31-Mar-89	1.61	1.50	1.92	>2.30					
07-Apr-89	0.99	0.00	1.50	2.27					
10-Apr-89	0.10	0.00	0.00	0.46					
14-Apr-89	0.00	0.00	0.00	1.11					
17-Apr-89	0.10	0.00	0.00	1.24					
21-Apr-89	0.00	0.54	0.00	1.08					
24-Apr-89	0.00	0.45	0.00	1.18					
28-Apr-89	0.00	0.30	0.00	1.13					
01-May-89	0.00	0.21	0.00	1.16					
05-May-89	0.00	0.25	0.00	1.17					
08-May-89	0.00	0.26	0.00	1.17					
15-May-89	0.00	0.30	0.00	1.15					
22-May-89	0.00	0.32	0.18	1.20					
26-May-89	0.10	0.38	0.38	1.28					
02-Jun-89	0.19	0.45	0.62	1.30					
12-Jun-89	0.24	0.57	0.70	1.40	0.57	1.24	0.77	0.80	
16-Jun-89	0.76	0.64	0.79	1.48	0.61	1.32	0.83	0.89	
23-Jun-89	0.29	0.66	0.62	1.58	0.62	1.38	0.88	0.96	
03-Jul-89	0.86	0.72	0.67	1.67	0.71	1.48	0.90	1.04	2.82
07-Jul-89	1.02	0.76	0.72	1.70	0.66	1.43	0.92	1.20	1.80
14-Jul-89	1.01	0.80		1.80	0.67	1.35	0.92	1.24	1.87
21-Jul-89	1.36	0.83		1.90		1.38	0.95	1.18	1.96
28-Jul-89	1.13	0.87		1.90	0.89	1.41	0.93	1.20	2.92

TABLE A-3: GROUND ELEVATION OF WELLS

WELL NO.	ELEVATION (m - a.m.s.l)
A2	716.66
A5	713.67
A6	710.55
B2	716.30
B3	719.01
B4	716.39
B5	711.55
B6	710.34
B7	710.13
C0	717.52
C1	717.32
C2	716.28
C3	715.45
C4	714.81
C5	712.01
C6	711.05
C7	710.87
D0	716.86
D1	715.77
D3	714.85
D3-5	714.49
D4	714.08
D5	712.94
D6	711.88
D7	711.06
D8	710.20
D9	708.85
E0	716.74
E1	716.23
E2	715.26
E3	714.33
E4	713.09
E5	713.03
E6	711.93
E7	711.37
F0	716.85
F1	716.09
F2	715.33
F3	713.65
F4	713.16
F5	711.62
F6	710.83
F7	711.08
G2	715.17
G3	715.04
G4	714.15

TABLE A - 3 CONT'D

G5	711.60
H2*	711.62
H3*	713.83
H4*	714.48
H5*	712.16

N.B. * - Bank level at the river

- 4 : GROUNDWATER EC AND pH

...O.	DATE	EC	PH
	22-JAN-89	0.59	8.45
	22-APR-89	0.69	8.50
	11-MAY-89	0.67	-
	28-JUN-89	0.88	8.32
	08-DEC-88	32.60	8.42
	10-MAY-89	37.20	8.77
	18-MAY-89	49.20	8.13
	22-MAY-89	27.40	8.43
	04-JUN-89	51.00	8.45
	08-DEC-89	22.40	8.37
	06-FEB-89	12.27	8.65
	29-MAR-89	18.50	8.51
	22-APR-89	8.63	8.80
	25-APR-89	6.24	8.97
	04-MAY-89	9.38	8.92
	22-MAY-89	11.61	9.02
	04-JUN-89	23.60	8.78
	27-JUN-89	24.10	8.80
	28-JUN-89	0.88	8.32
	14-JUL-89	23.80	8.86
	22-NOV-89	1.15	8.06
	25-NOV-88	1.17	8.58
	24-JAN-89	0.36	8.68
	22-APR-89	0.76	9.22
	24-APR-89	0.78	8.88
	11-MAY-89	0.78	8.68
	22-MAY-89	0.76	9.13
	28-JUN-89	0.82	8.76
	17-JUL-89	0.81	8.89
	09-NOV-88	6.15	8.44
	25-NOV-88	5.94	8.30
	07-DEC-88	5.97	8.10
	06-FEB-89	3.33	9.18
	09-MAR-89	3.44	9.04
	29-MAR-89	5.12	9.16
	14-APR-89	1.20	9.64
	24-APR-89	2.58	9.56
	06-MAY-89	2.45	9.61
	06-MAY-89	2.45	9.61
	13-MAY-89	2.82	9.45
	18-MAY-89	3.14	9.38
	22-MAY-89	24.10	8.87
	04-JUN-89	4.00	9.40
	28-JUN-89	4.47	9.21

WELL NO.	DATE	EC	PH
	09-NOV-88	36.70	7.40
B6	26-NOV-88	36.70	8.31
	07-DEC-88	36.10	8.18
	06-FEB-89	27.30	8.22
	29-MAR-89	37.70	8.51
	04-MAY-89	36.20	8.40
	25-MAY-89	37.10	8.62
	14-JUN-89	39.10	8.44
	26-JUN-89	39.10	8.18
B7	13-DEC-88	29.90	8.06
	06-FEB-89	16.70	8.32
	22-APR-89	1.00	8.18
	25-APR-89	0.40	9.26
	04-MAY-88	9.00	8.62
	22-MAY-89	14.93	8.08
	27-JUN-89	14.37	8.70
	14-JUL-89	15.20	8.56
B7-750	12-JUL-89	8.08	7.34
C1	09-NOV-88	6.01	8.90
	07-DEC-88	6.80	9.25
	06-APR-89	4.58	26.1
	11-APR-89	1.34	9.07
	15-APR-89	1.38	9.08
	17-APR-89	1.69	7.34
	18-APR-89	1.70	7.83
	20-APR-89	1.72	8.14
	21-APR-89	1.74	8.04
	22-APR-89	1.78	9.31
	23-APR-89	1.63	8.21
	25-APR-89	1.91	8.34
	27-APR-89	1.98	8.34
	28-APR-89	2.04	8.53
	29-APR-89	2.10	8.50
	01-MAY-89	1.94	8.47
	02-MAY-89	1.69	8.71
	02-MAY-89	1.69	8.71
	03-MAY-89	1.67	9.00
	04-MAY-89	1.73	8.83
	05-MAY-89	1.71	9.09
	09-MAY-89	2.06	9.01
	22-MAY-89	1.35	9.05
	25-MAY-89	1.32	9.08
	27-JUL-89	3.69	8.93

- 4 CONT'D

WELL NO.	DATE	EC	PH
	09-NOV-88	1.52	7.59
	23-NOV-88	1.51	8.23
	07-DEC-88	1.60	8.23
	24-JAN-89	1.24	8.38
	17-MAR-89	0.75	8.10
	30-MAR-89	1.42	8.30
	08-APR-89	1.00	8.13
	21-APR-89	0.90	8.83
	25-APR-89	0.88	8.56
	11-MAY-89	0.68	8.34
	11-MAY-89	1.00	8.76
	22-APR-89	0.88	8.52
	30-APR-89	0.87	8.67
3			
	09-NOV-88	3.50	8.92
	22-NOV-88	2.92	9.13
	07-DEC-88	2.93	9.17
	24-JAN-89	2.94	9.35
	09-MAR-89	2.79	9.29
	30-MAR-89	2.46	9.30
	17-APR-89	2.31	9.39
	22-APR-89	2.33	9.54
	25-APR-89	2.38	9.43
	17-JUL-89	2.26	9.55
	21-APR-89	0.44	8.59
	30-APR-89	0.42	8.46
	17-JUL-89	0.49	?
	18-NOV-88	2.52	8.85
	23-NOV-88	2.52	8.68
	07-DEC-88	2.57	8.90
	23-JAN-89	2.64	8.74
	09-MAR-89	2.71	8.62
	29-MAR-89	2.81	8.67
	14-APR-89	2.06	8.58
	25-APR-89	2.25	8.49
	17-JULY-8	2.59	8.59

WELL NO.	DATE	EC	PH
C5			
	09-NOV-88	6.38	8.80
	22-NOV-88	5.13	8.66
	25-NOV-88	5.14	8.54
	07-DEC-88	5.70	8.69
	23-JAN-89	5.81	8.22
	09-MAR-89	6.11	8.43
	29-MAR-89	5.65	8.96
	14-APR-89	11.05	8.63
	25-APR-89	7.65	8.64
	06-MAY-89	11.19	8.62
	13-MAY-89	4.46	8.84
	22-MAY-89	10.39	8.79
	04-JUN-89	10.35	8.76
	28-JUN-89	9.01	8.47
	27-JUL-89	10.85	8.69
C6	18-NOV-88	14.60	7.77
	26-NOV-88	13.64	8.47
	07-DEC-88	13.40	8.22
	08-JAN-89	11.60	8.42
	29-MAR-89	15.10	8.23
	21-APR-89	9.78	8.87
	25-APR-89	3.60	8.67
	25-MAY-89	11.65	8.69
	04-JUN-89	18.18	8.42
	27-JUN-89	21.20	8.52
	26-JUL-89	22.50	8.31
C7			
	22-NOV-88	16.21	8.91
	07-DEC-88	19.40	8.70
	08-FEB-89	14.85	8.82
	01-APR-89	7.67	9.13
	21-APR-89	3.91	8.71
	25-APR-89	14.29	9.05
	04-MAY-89	13.20	9.19
	27-JUN-89	21.60	8.52
	26-JUL-89	26.00	8.71
C7-1000			
	06-JUL-89	18.50	7.60
	26-JUL-89	18.30	7.92

A -4 CONT'D

NO.	DATE	EC	PH	WELL NO.	DATE	EC	PH
000	08-APR-89	1.82	8.62	D1	20-APR-89	14.05	8.36
	05-MAY-89	1.52	9.08		21-APR-89	14.11	8.26
	22-MAY-89	1.31	9.20		22-APR-89	13.92	8.30
	06-JUN-89	1.35	9.18		23-APR-89	13.26	8.13
	17-JUL-89	1.80	8.75		24-APR-89	12.80	8.57
					26-APR-89	12.05	8.33
	18-NOV-88	4.54	7.96		27-APR-89	11.41	8.21
	25-NOV-88	4.58	8.40		28-APR-89	10.92	8.44
	07-DEC-88	4.65	8.64		29-APR-89	9.89	8.51
	20-MAR-89	5.80	9.40		01-MAY-89	10.54	8.60
	30-MAR-89	4.59	9.71		02-MAY-89	10.54	8.55
	08-APR-89	3.11	8.75		03-MAY-89	10.48	8.61
	11-APR-89	2.97	9.16		04-MAY-89	10.45	8.48
	12-APR-89	2.95	9.21		05-MAY-89	10.31	8.57
	15-APR-89	3.00	9.19		06-MAY-89	10.23	8.58
	17-APR-89	3.02	9.06		09-MAY-89	9.50	8.43
	18-APR-89	3.17	9.34		12-MAY-89	9.56	8.40
	20-APR-89	2.71	8.98		18-MAY-89	9.25	8.42
	21-APR-89	2.68	9.11		26-MAY-89	9.47	8.54
	22-APR-89	3.32	9.26		04-JUN-89	7.45	8.55
	23-APR-89	3.23	9.11		06-JUN-89	6.81	8.41
	24-APR-89	3.29	9.35		14-JUN-89	5.05	8.61
	25-APR-89	3.38	9.32		20-JUN-89	4.01	8.47
	26-APR-89	3.32	9.41		28-JUN-89	3.43	8.84
	27-APR-89	3.34	9.32		07-JUL-89	3.09	25.5
	28-APR-89	3.36	9.24		17-JUL-89	2.96	8.43
	29-APR-89	3.35	9.27		27-JUL-89	2.92	8.49
	01-MAY-89	3.41	9.43		25-NOV-88	1.04	8.30
	02-MAY-89	3.32	9.48		07-DEC-88	1.09	8.08
	03-MAY-89	3.76	9.52		29-MAR-89	1.02	8.61
	04-MAY-89	3.35	9.42		06-APR-89	11.22	8.10
	05-MAY-89	3.36	9.51		12-APR-89	2.20	9.07
	09-MAY-89	3.40	9.36		14-APR-89	2.34	9.03
	22-MAY-89	2.87	9.52		15-APR-89	2.38	8.96
	27-MAY-89	1.29	9.01		17-APR-89	2.52	8.86
	06-JUN-89	3.02	9.18		19-APR-89	2.79	8.83
	14-JUN-89	3.11	9.27		20-APR-89	2.95	8.72
	20-JUN-89	3.22	9.21		21-APR-89	3.03	8.76
	17-JUL-89	3.57	9.02		22-APR-89	3.04	8.79
	27-JUL-89	3.93	9.34		23-APR-89	3.02	8.44
					24-APR-89	3.04	8.90
					26-APR-89	3.23	8.73
	09-NOV-88	2.16	7.05		27-APR-89	3.28	8.92
	09-NOV-88	2.50	8.30		28-APR-89	3.31	8.92
	09-NOV-88	2.75	8.35		29-APR-89	3.00	8.86
	07-DEC-88	2.79	8.17		01-MAY-89	4.02	8.78
	26-JAN-89	3.78	8.27		02-MAY-89	4.49	8.83
	06-FEB-89	2.58	8.12		03-MAY-89	4.74	8.84
	29-MAR-89	1.69	8.13		05-MAY-89	4.49	8.58
	11-APR-89	11.62	9.16		09-MAY-89	3.79	8.55
	12-APR-89	12.85	9.14		12-MAY-89	4.51	8.44
	14-APR-89	12.52	8.43		18-MAY-89	3.75	8.56
	15-APR-89	14.26	8.37		26-MAY-89	3.68	8.68
	17-APR-89	14.63	8.22		04-JUN-89	2.02	8.48

WELL NO.	DATE	EC	PH
	06-JUN-89	1.90	8.50
	14-JUN-89	1.69	8.72
	26-JUN-89	1.45	8.16
	28-JUN-89	1.30	8.42
	07-JUL-89	1.23	8.03
	17-JUL-89	0.81	8.99
	27-JUL-89	1.23	7.99
	09-NOV-88	14.40	9.40
	23-NOV-88	12.19	8.52
	24-NOV-88	12.39	8.73
	07-DEC-88	11.46	8.69
	24-JAN-89	7.86	8.75
	09-MAR-89	10.40	8.41
	30-MAR-89	12.04	8.52
	08-APR-89	0.90	8.04
	12-APR-89	1.08	8.87
	20-APR-89	1.78	8.93
	21-APR-89	1.74	8.97
	26-APR-89	2.12	9.02
	04-MAY-89	2.89	8.91
	11-MAY-89	3.26	8.96
	18-MAY-89	4.72	8.92
	06-JUN-89	12.83	8.49
	07-JUL-89	16.56	8.23
	17-JUL-89	13.45	8.91
	27-JUL-89	12.68	8.89
	09-NOV-88	0.71	7.63
	22-NOV-88	0.63	8.08
	07-DEC-88	0.88	8.49
	23-JAN-89	0.92	8.24
	09-MAR-89	1.55	7.92
	01-APR-89	0.83	8.40
	12-APR-89	1.30	8.35
	20-APR-89	1.81	8.51
	26-APR-89	1.89	8.57
	12-MAY-89	1.81	8.69
	18-MAY-89	1.72	8.53
	17-JUL-89	1.01	8.17
00			
	03-APR-89	1.75	8.61
	12-APR-89	1.42	8.64
	20-APR-89	1.53	8.83
	26-APR-89	1.39	8.66
	18-APR-89	2.01	8.79
	17-JUL-89	2.29	8.49

WELL NO.	DATE	EC	PH
D4	09-NOV-88	1.32	8.20
	24-NOV-88	1.49	8.65
	07-DEC-88	1.69	8.30
	23-JAN-89	1.66	8.35
	09-MAR-89	1.29	8.39
	29-MAR-89	3.71	7.98
	01-APR-89	1.64	8.46
	25-APR-89	3.13	8.45
	17-JUL-89	1.34	8.46
D4-500	13-MAY-89	0.92	7.90
	12-JUL-89	0.77	8.46
D5	09-NOV-88	3.59	7.74
	18-NOV-88	3.28	8.30
	25-NOV-88	3.20	8.37
	07-DEC-88	3.15	8.45
	23-JAN-89	3.31	8.31
	09-MAR-89	4.02	7.93
	30-MAR-89	3-27	8.21
	26-APR-89	1.81	8.54
	13-MAY-89	2.70	8.35
	22-MAY-89	3.04	8.82
	04-JUN-89	3.31	8.72
	28-JUN-89	3.61	8.55
	26-JUL-89	3.62	8.29
D6	09-NOV-88	8.96	7.99
	26-NOV-88	8.86	8.70
	13-DEC-88	9.96	8.61
	03-APR-89	8.91	8.35
	26-APR-89	4.91	8.60
	26-MAY-89	9.20	8.69
	04-JUN-89	9.32	8.81
	26-JUN-89	10.19	9.72
	27-JUL-89	11.93	8.48
D7	26-NOV-88	11.15	9.00
	13-DEC-88	11.46	8.89
	03-APR-89	8.91	9.45
	04-MAY-89	7.13	9.41
	27-JUN-89	11.05	8.65
D7-1000			
	06-JUL-89	18.56	7.92
	27-JUL-89	16.83	8.09
D7-1700			
	06-JUL-89	24.50	8.05
	20-JUL-89	14.86	9.21

-4 CONT'D

	DATE	EC	PH
	18-NOV-88	2.58	8.26
	25-NOV-88	2.83	9.21
	07-DEC-88	3.02	8.92
	20-MAR-89	6.12	9.44
	29-MAR-89	4.30	9.74
	26-APR-89	2.83	9.22
	26-APR-89	2.84	9.18
	26-APR-89	2.82	9.06
	26-APR-89	2.87	9.12
	01-MAY-89	2.58	9.22
	02-MAY-89	2.70	9.36
	03-MAY-89	2.84	9.42
	04-MAY-89	2.92	9.31
	05-MAY-89	2.93	9.35
	09-MAY-89	2.92	9.30
	22-MAY-89	3.13	9.62
	27-MAY-89	3.04	9.32
	06-JUN-89	3.25	9.20
	14-JUN-89	3.13	9.37
	20-JUN-89	3.18	9.09
	17-JUL-89	3.37	8.56
	27-JUL-89	3.57	8.87
	09-NOV-89	3.81	8.86
	18-NOV-88	6.31	9.40
	07-DEC-88	9.03	9.58
	20-MAR-89	11.70	9.58
	29-MAR-89	2.81	9.71
	15-APR-89	0.52	9.39
	17-APR-89	0.57	9.24
	19-APR-89	0.65	9.10
	20-APR-89	0.64	9.27
	21-APR-89	1.97	9.55
	22-APR-89	0.72	9.31
	25-APR-89	0.85	9.33
	27-APR-89	3.01	8.95
	28-APR-89	3.54	9.04
	01-MAY-89	5.78	9.29
	02-MAY-89	6.28	9.46
	03-MAY-89	7.72	9.56
	04-MAY-89	7.02	9.40
	09-MAY-89	7.50	9.52
	10-MAY-89	7.82	9.03
	22-MAY-89	8.24	9.62
	26-MAY-89	9.02	9.72
	27-MAY-89	5.53	8.82
	27-JUN-89	5.04	8.62

WELL NO.	DATE	EC	PH
E2	09-NOV-88	4.78	8.83
	23-NOV-88	5.50	8.96
	24-NOV-88	4.95	9.48
	07-DEC-88	6.72	9.50
	07-FEB-89	7.58	9.60
	09-MAR-89	15.17	9.61
	30-MAR-89	14.07	9.81
	17-APR-89	0.94	9.28
	27-APR-89	1.21	9.10
	12-MAY-89	13.67	9.27
	16-MAY-89	14.24	9.25
	22-MAY-89	13.85	9.28
	27-MAY-89	14.21	9.43
	06-JUN-89	14.88	9.32
	14-JUN-89	15-98	9.50
	29-JUN-89	22.60	9.30
	12-JUL-89	22.60	9.30
	14-JUL-89	13.63	9.21
	17-JUL-89	10.95	
E3	09-NOV-88	14.42	8.43
	24-NOV-88	15.58	8.97
	24-NON-88	30.50	8.78
	07-DEC-88	16.60	9.37
	24-JAN-89	12.91	9.50
	08-FEB-89	11.28	9.29
	30-MAR-89	21.70	9.51
	17-APR-89	6.72	9.42
	27-APR-89	11.08	9.17
	12-MAY-89	8.40	9.46
	16-MAY-89	8.93	9.40
	22-MAY-89	9.14	9.48
	27-MAY-89	9.54	9.45
	06-JUN-89	10.38	9.38
	14-JUN-89	10.56	9.70
	07-JUL-89	10.44	8.96
	17-JUL-89	10.95	9.21
E3-500	27-MAY-89	34.70	8.50
	07-JUL-89	36.00	8.34
	17-JUL-89	39.80	8.90
E4	09-Nov-88	8.32	8.89
	24-Nov-88	5.13	9.14
	07-Dec-88	8.66	8.94
	08-Feb-89	12.20	8.65
	29-Mar-89	19.02	8.83
	17-APr-89	>20.00	8.90

-4 CONT'D

	DATE	EC	PH
D	20-APR-89	>20.00	8.53
	27-APr-89	>20.00	8.72
	05-May-89	70.60	8.46
	16-May-89	56.80	8.70
	22-May-89	36.50	9.08
	27-May-89	72.20	8.51
	06-Jul-89	76.70	8.42
	14-Jul-89	79.80	8.70
	14-Jul-89	92.00	8.90
	27-Jul-89	88.60	9.11
	19-MAY-89	18.72	8.81
	26-MAY-89	18.32	9.13
	27-MAY-89	18.48	8.96
	17-JUL-89	12.77	8.87
	26-JUL-89	16.28	8.98
	09-Nov-88	23.00	8.26
	18-Nov-88	23.00	18.26
	25-Nov-88	21.10	8.51
	07-Dec-88	20.70	8.22
	08-Feb-89	5.50	8.47
	03-Apr-89	4.59	8.02
	14-Apr-89	2.81	9.07
	21-Apr-89	1.00	8.75
	27-Apr-89	6.55	8.78
	12-May-89	11.28	8.55
	16-May-89	12.05	8.78
	27-May-89	13.82	8.52
	04-Jan-89	14.56	8.86
	14-Jan-89	17.07	8.47
	28-Jan-89	18.23	8.78
	18-Nov-88	10.26	8.03
	13-Dec-88	10.45	8.67
	26-Jan-88	8.22	8.39
	21-APr-88	4.49	8.89
	16-May-88	5.73	8.86
	26-May-88	6.46	9.27
	27-May-88	6.51	8.81
	04-Jan-88	6.97	9.02
	06-Jan-88	7.80	8.99
	26-Jan-88	9.70	9.09
	26-Jul-88	14.53	8.79

WELL NO.	DATE	EC	PH
E7	18 Nov.88	7.35	8.77
	13 Dec-88	7.31	8.85
	26-Jan-89	3.35	8.93
	03-Apr-89	4.43	9.05
	21-Apr-89	4.05	8.92
	27-Apr-89	1.97	9.38
	16-May-89	6.28	9.20
	04-Jan-89	7.03	9.23
	14-Jan-89	6.92	9.38
	20-Jan-89	8.76	9.28
F0	03-Apr-89	1.35	9.11
	17-Apr-89	0.91	8.84
	21-Apr-89	0.99	9.08
	22-Apr-89	1.00	9.04
	23-Apr-89	1.21	9.00
	25-Apr-89	1.21	9.00
	27-Apr-89	0.98	9.09
	28-Apr-89	1.00	8.98
	29-Apr-89	1.03	9.18
	01-May-89	1.39	9.36
	02-May-89	1.19	9.35
	03-May-89	1.08	9.34
	04-May-89	1.03	8.98
	22-May-89	1.16	9.07
	27-May-89	1.02	8.64
	20-Jan-89	1.29	9.38
F1	18-Nov-88	10.05	9.39
	25-Nov-88	9.67	9.32
	07-Dec-88	10.74	9.43
	07-Feb-88	10.11	9.69
	20-Mar-88	12.14	9.72
	30-Mar-88	8.56	9.92
	12-Apr-88	1.31	8.65
	14-Apr-88	0.91	8.87
	15-Apr-88	1.42	9.29
	17-Apr-88	1.48	9.26
	21-Apr-88	0.68	9.49
	22-Apr-88	2.06	9.53
	23-Apr-88	2.10	9.00
	25-Apr-88	2.37	9.55
	27-Apr-88	2.39	9.48
	01-May-88	1.21	9.43
	02-May-88	1.49	9.49
	04-May-88	1.44	9.46
	12-May-88	2.04	9.44
	22-May-88	1.39	9.26
	26-May-88	1.49	9.11
	27-May-88	1.92	9.56

ABLE A -4 CONT'D

ELL NO.	DATE	EC	PH
3	09-NOV-88	5.33	9.12
	25-NOV-88	10	9.75
	07-NOV-88	14.2	9.79
	07-FEB-89	4.05	9.59
	30-MAR-89	15.88	9.66
	12-APR-89	0.67	8.2
	30-APR-89	3.88	9.45
	12-MAY-89	9.34	9.54
2			
	09-Nov-88	31.40	8.25
	23-Nov-89	30.70	8.77
	07-Dec-88	32.40	8.79
	12-Apr-89	1.89	8.40
	28-Apr-89	4.47	9.07
	12-May-89	6.13	9.15
	30-Sep-89	34.4	8.71
4	18-Nov-88	9.60	9.05
	25-Nov-88	10.75	9.38
	07-Dec-88	13.50	9.38
	07-Feb-89	22.80	9.43
	30-Mar-89	13.11	9.01
	17-Apr-89	1.18	9.41
	30-Apr-89	1.22	9.61
5			
	09-Nov-88	9.47	7.47
	24-Nov-88	8.26	9.56
	26-Jan-89	3.79	9.46
	30-Mar-89	9.13	9.60
	13-May-89	17.22	9.99
	28-Jan-89	18.20	9.52
6			
	09-Apr-88	1.59	7.91
	24-Apr-88	1.31	8.85
	26-Jan-89	1.55	8.05
	26-Jan-89	1.55	8.05
	30-Apr-89	0.54	8.58
	26-May-89	0.8	8.88
	28-Jan-89	1.01	8.82
6-500	14-Jan-89	87.40	8.75
7	22-Nov-88	7.55	8.92
	26-Jan-89	8.27	8.80
	20-Apr-89	2.61	9.13
	30-Apr-89	17.30	8.92
	28-Jan-89	18.03	9.02

Table A-5

R ANALYSIS REPORT

04-Jan-89

		SITE							
RAMETERS	UNITS	B4	B5	B6	C1	C2	C3	C5	Di(PIU)
	pH Scale	7.9	8.5	7.9	9.1	7.8	9.0	8.0	8.0
uctivity (250C)	uS/Ca	1,056	6,480	36,000	6,240	2,040	3,720	6,720	984
ium	mgCa/1	43	3.4	1375	59	157	0.8	12.2	5
esium	mgHg/1	13	9.3	1660	5.8	55	-	31	19
um	mg/Na/1	126	1,155	8,400	1,470	630	882	1,050	137
ssium	mgK/1	14.7	12.6	80	53	23	105	42	8.4
l Hardness	mgCaCO3/1	156	70	14,120	17	452	10	188	148
l Alkalinity	mgCaCO3/1	364	1,088	722	2,382	278	1,824	676	406
ride mg Cl/1	mgCl/1	77	530	9,900	620	300	600	570	55
hate	mgSO4/1	94	532	866	193	90	61	1567	25
	mg/1	633	3,890	21,600	3,744	1,224	2,232	4,032	590
	mg/1	3.1	73	25.4	-	7.8	117	25.6	4.4

R ANALYSIS REPORT Con't

		SITE							
METERS	UNITS	D1	D2	D3	D4	D5	D6	E1	E2
	pH Scale	8.2	8.4	7.6	7.9	8.0	8.0	8.8	8.8
uctivity (250C)	uS/ca	2,880	14,400	768	2,040	5,400	11,760	5,400	6,480
ium	mgCa/1	2.5	33	70	290	49	41	1.5	14
esium	mgHg/1	10.2	75	28	102	46	56	2.8	6
um	mgNa1/	494	2,730	42	42	672	1,890	966	1,050
ssium	mgK/1	8.4	16.8	19	27	25	19	0.5	1.7
l Hardness	mgCaCO3/1	90	486	280	1,140	334	450	24	60
ride mg Cl/1	mgCaCO3/1	255	3,250	64	70	530	1,120	350	370
hate	mgSO4/1	95	333	16	220	797	3660	155	83
	mg/1	1,720	8,640	460	1,224	3,240	7,056	3,240	3,890
	mg/1	21.8	42.2	0.76	0.54	11.7	32.7	75.6	5.9

Table A-5

ER ANALYSIS REPORT

04-Jan-89

ARAMETERS	UNITS	SITE							
		B4	B5	B6	C1	C2	C3	C5	Di(PIU)
	pH Scale	7.9	8.5	7.9	9.1	7.8	9.0	8.0	8.0
ductivity (250C)	uS/Ca	1,056	6,480	36,000	6,240	2,040	3,720	6,720	984
cium	mgCa/1	43	3.4	1375	59	157	0.8	12.2	5
nesium	mgMg/1	13	9.3	1660	5.8	55	-	31	19
ium	mg/Na/1	126	1,155	8,400	1,470	630	882	1,050	137
assium	mgK/1	14.7	12.6	80	53	23	105	42	8.4
al Hardness	mgCaCO3/1	156	70	14,120	17	452	10	188	148
al Alkalinity	mgCaCO3/1	364	1,088	722	2,382	278	1,824	676	406
oride mg Cl/1	mgCl/1	77	530	9,900	620	300	600	570	55
phate	mgSO4/1	94	532	866	193	90	61	1567	25
	mg/1	633	3,890	21,600	3,744	1,224	2,232	4,032	590
	mg/1	3.1	73	25.4	-	7.8	117	25.6	4.4

ER ANALYSIS REPORT Con't

AMETERS	UNITS	SITE							
		D1	D2	D3	D4	D5	D6	E1	E2
	pH Scale	8.2	8.4	7.6	7.9	8.0	8.0	8.8	8.8
ductivity (250C)	uS/ca	2,880	14,400	768	2,040	5,400	11,760	5,400	6,480
cium	mgCa/1	2.5	33	70	290	49	41	1.5	14
nesium	mgMg/1	10.2	75	28	102	46	56	2.8	6
ium	mgNal/	494	2,730	42	42	672	1,890	966	1,050
assium	mgK/1	8.4	16.8	19	27	25	19	0.5	1.7
al Hardness	mgCaCO3/1	90	486	280	1,140	334	450	24	60
oride mg Cl/1	mgCaCO3/1	255	3,250	64	70	530	1,120	350	370
phate	mgSO4/1	95	333	16	220	797	3660	155	83
	mg/1	1,720	8,640	460	1,224	3,240	7,056	3,240	3,890
	mg/1	21.8	42.2	0.76	0.54	11.7	32.7	75.6	5.9

NALYSIS REPORT Table A-5 Con't
04-JAN-89

		SITE							
ERS	UNITS	E3	E4	E6	F2	F3	F4	F5	F6
	pH Scale	8.7	9.1	8.3	8.4	9.2	8.6	9.1	8.0
ivity (25oC)	uS/cm	15,600	9,120	11.000	32,400	6,000	5,520	9,360	2,040
	mgCa/1	87	1.1	64	56	0.8	1.6	1.3	46
um	mgMg/1	8.8	4.9	74	118	4.4	1.3	2.5	15
	mgNa/1	4,095	1,785	2,310	6,930	1,050	840	3,465	294
um	mgK/1	2.4	1	4.1	3.3	1.7	1	11	1.8
ardness	mgCaCO3/1	252	34	634	602	20	34	45	132
lkalinity	mgCaCo3/1	4,500	1,400	850	1,100	1,600	800	2,100	700
e mg Cl/1	mgCl/1	1,820	1,670	660	13,000	660	480	740	130
e	mgSO4/1	216	246	6000	196	112	296	100	107
	MG/1	9,360	5,472	6,600	19,440	3,600	3,312	5,620	1,224
	mg/1	1.2	114	-	84.8	71.6	84.2	288	6.8

NALYSIS REPORT
24-Jul-89

		SITE							
	UNITS	Well C0	Well C5 P	Well D1	Well D0	Well C4	Well E4	Flood Wat	Well B5 P
TERS	pH Scale	9.8	7.2	8.0	8.2	7.6	8.2	9.2	8.0
tivity (25oC)	uS/cm	3,420	20,206	15,548	2,332	2,487	69,944	2,642	43,520
	mg/Ca/1	12	260	140	4.8	124	337	12	321
ium	mg/Mg/1	7.3	328	35	1.9	14	26	4.8	371
	mgNa/1	662	2,095	1,036	199	199	13,010	375	7,277
ium	mgK/1	40	143	44	27	48	17	29	19
Hardness	mgCaCO3/1	60	2,000	496	20	370	950	50	2,330
de mg Cl/1	mgCl/1	500	3,850	1,630	138	200	1,850	295	18,100
te	mgSO4/1	18	4634	992	15	700	14,100	19	2.9
	mg/1	2,052	12,124	9,329	1,399	1,492	41,966	1,586	26,112
	mg/1	-	-	-	-	-	-	-	6.5

ANALYSIS REPORT Table A-5 Con't
09-Aug-89

ETERS	UNITS	Ruvu Swamp	Njoro Kubwa	River Lumi	Kamleza Canal
		SITE			
	pH Scale	8.6	7.5	7.4	7.5
ctivity (25oC)	uS/cm	1,696	269	254	268
um	mgCa/l	43	18	17	18
sium	mgMg/l	16	15	15	15
m	mgNa/l	284	8	11	13
sium	mgK/l	9.5	4.4	3.6	4.5
Hardness	mgCaCO3/l	170	102	104	104
Alkalinity	mgCaCO3/l	638	106	98	102
ide mg Cl/l	mgCl/l	90	4	9	3
ate	mgSO4/l	36	3.6	5.2	5.8
	mg/l	1,017	161	153	161
	mg/l	-	-	-	-

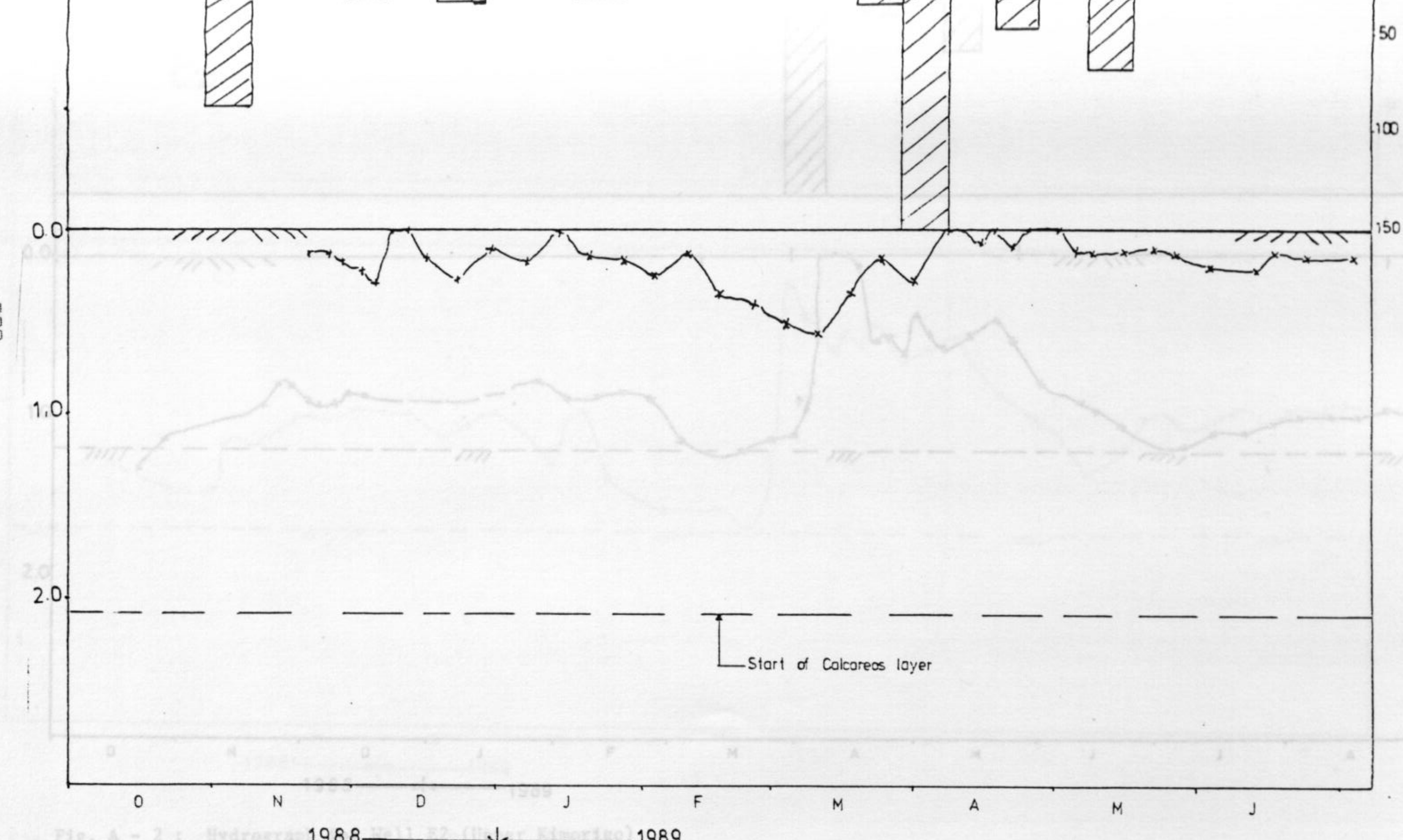


Fig. A - 1: Hydrograph for Well Eo (Northern Swampy area).

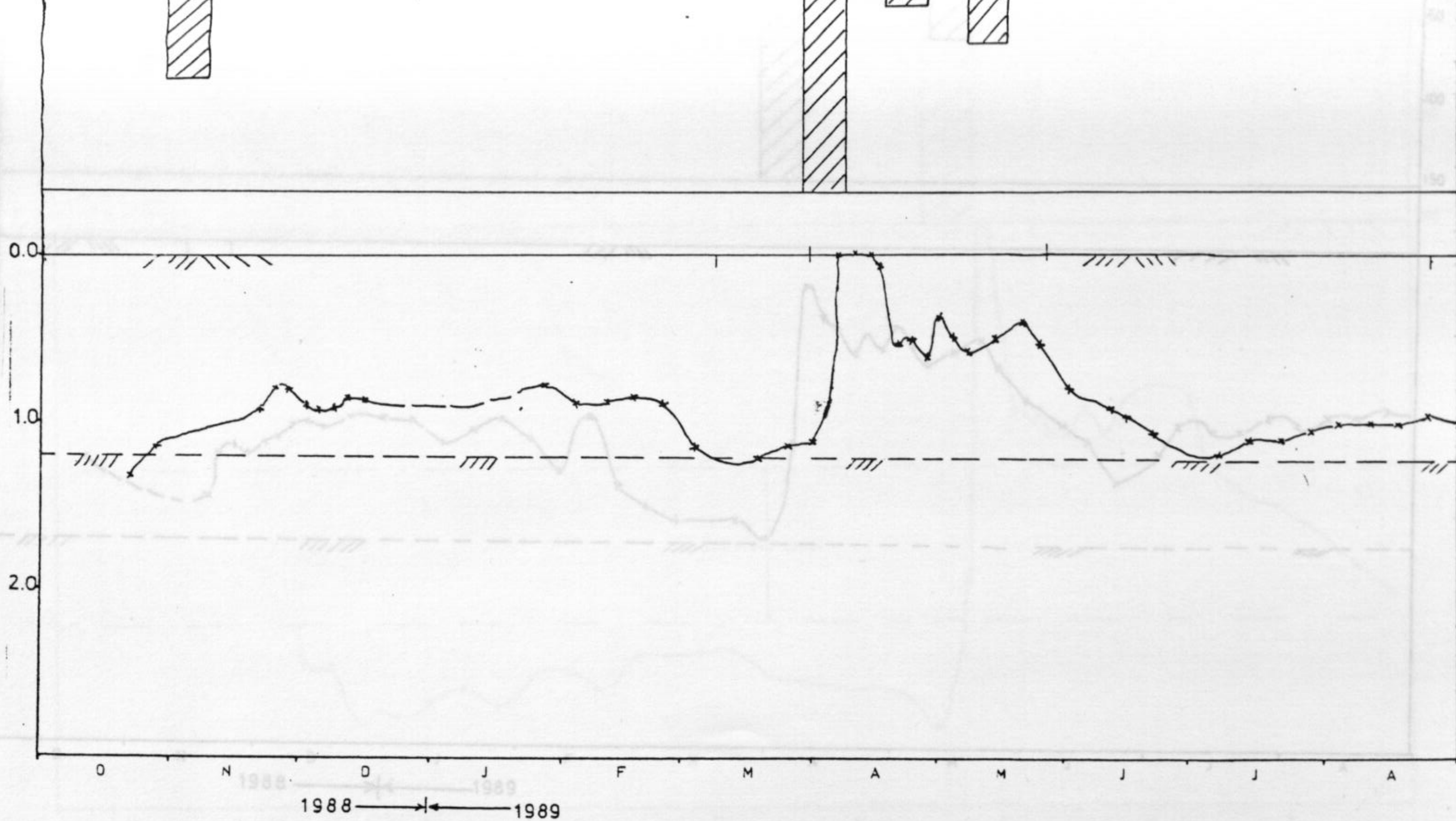


Fig. A - 2 : Hydrograph for Well E2 (Upper Kimorigo)

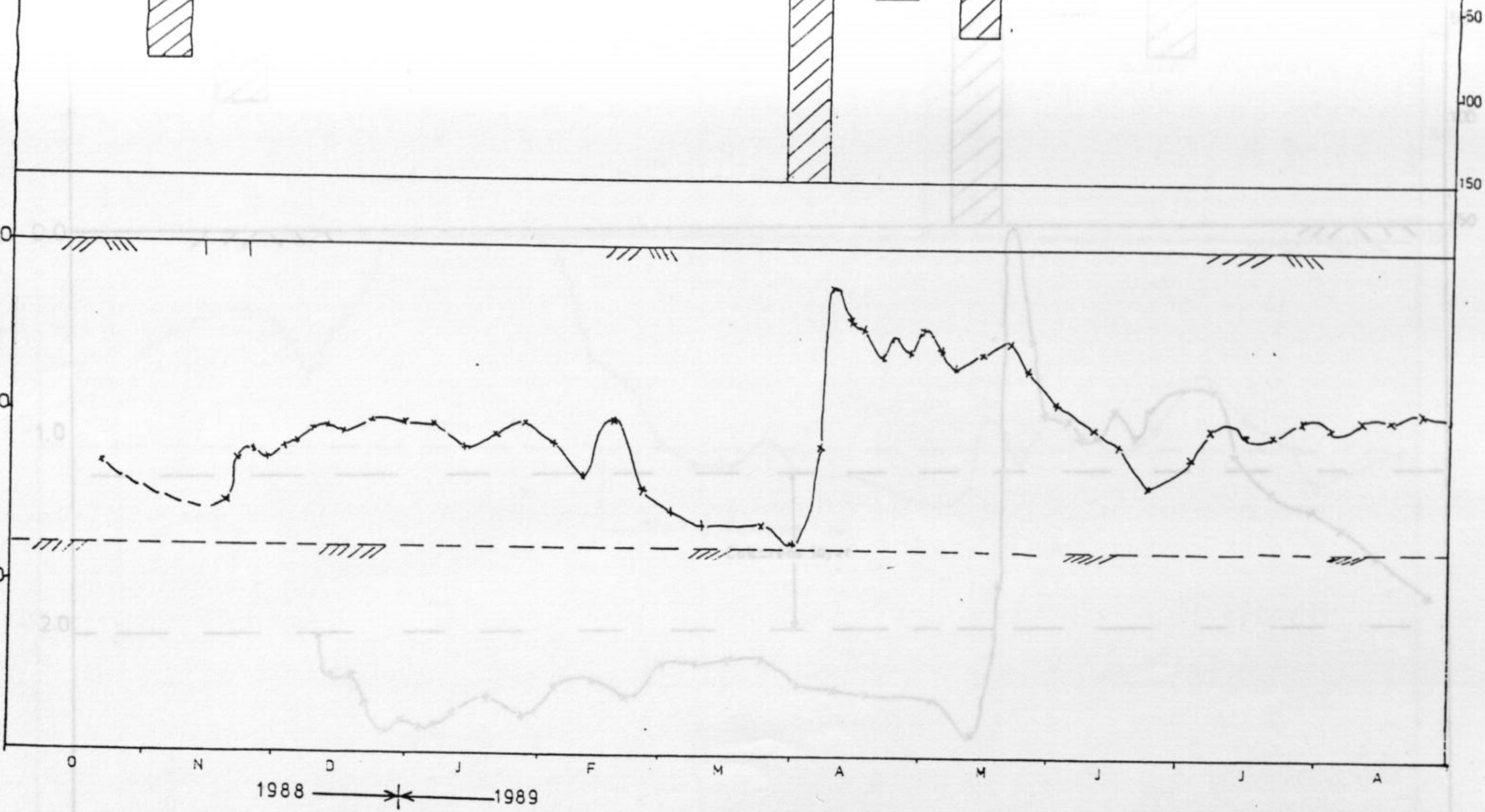


Fig. A - 3: Hydrograph for Well D3 (Kimorigo Central)

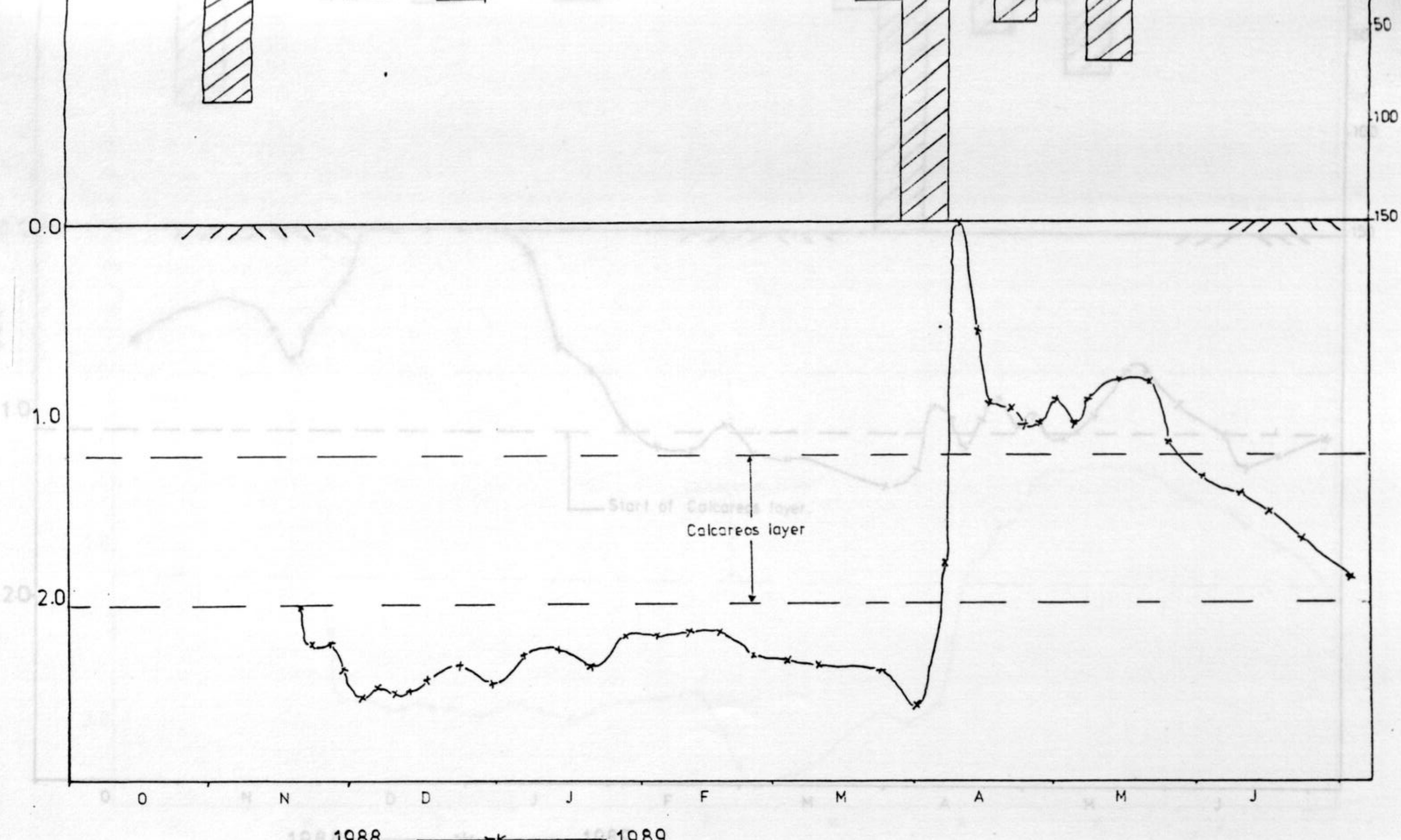


Fig. A - 4: Hydrograph for Well D5 (Lower Kimorigo)

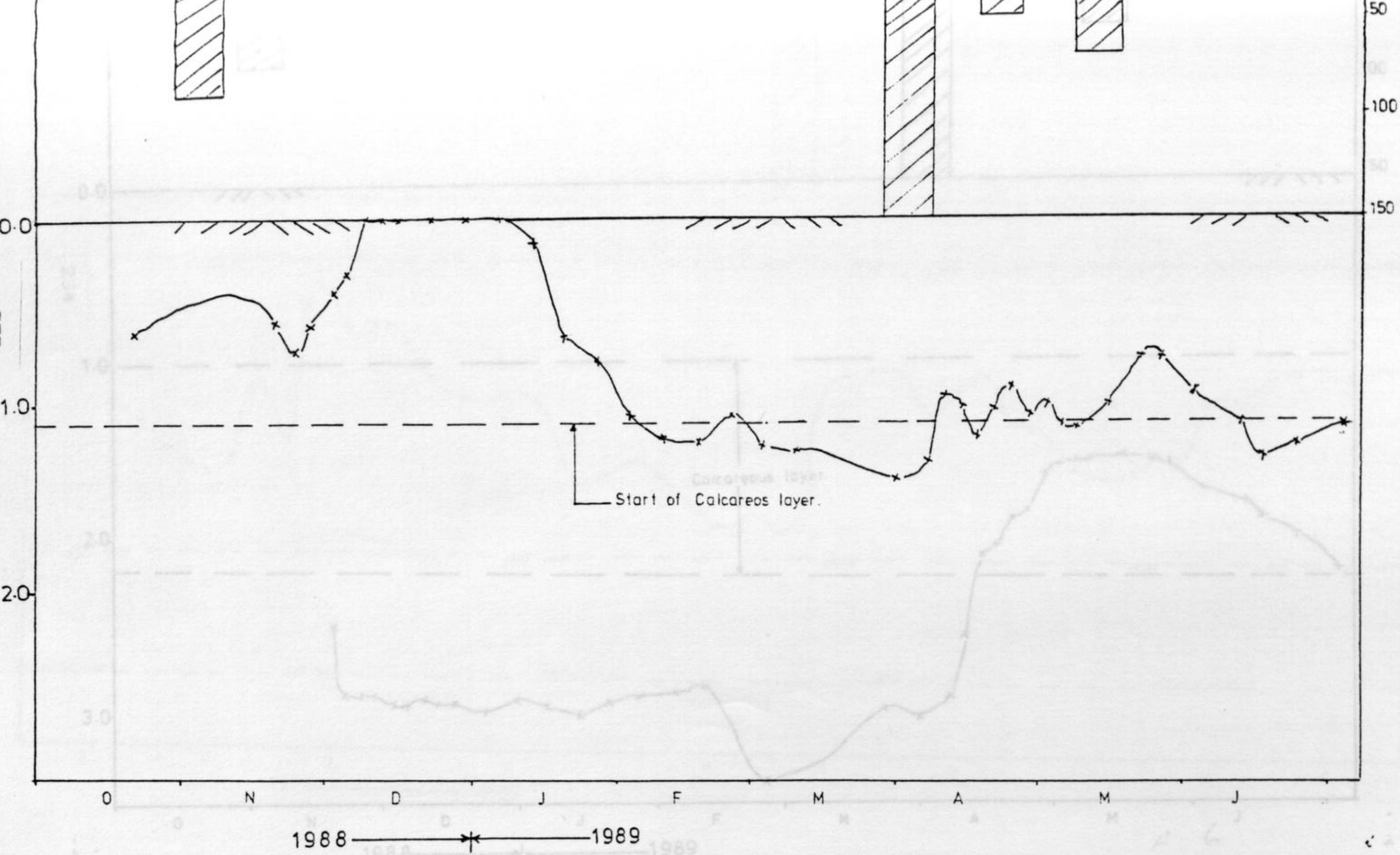
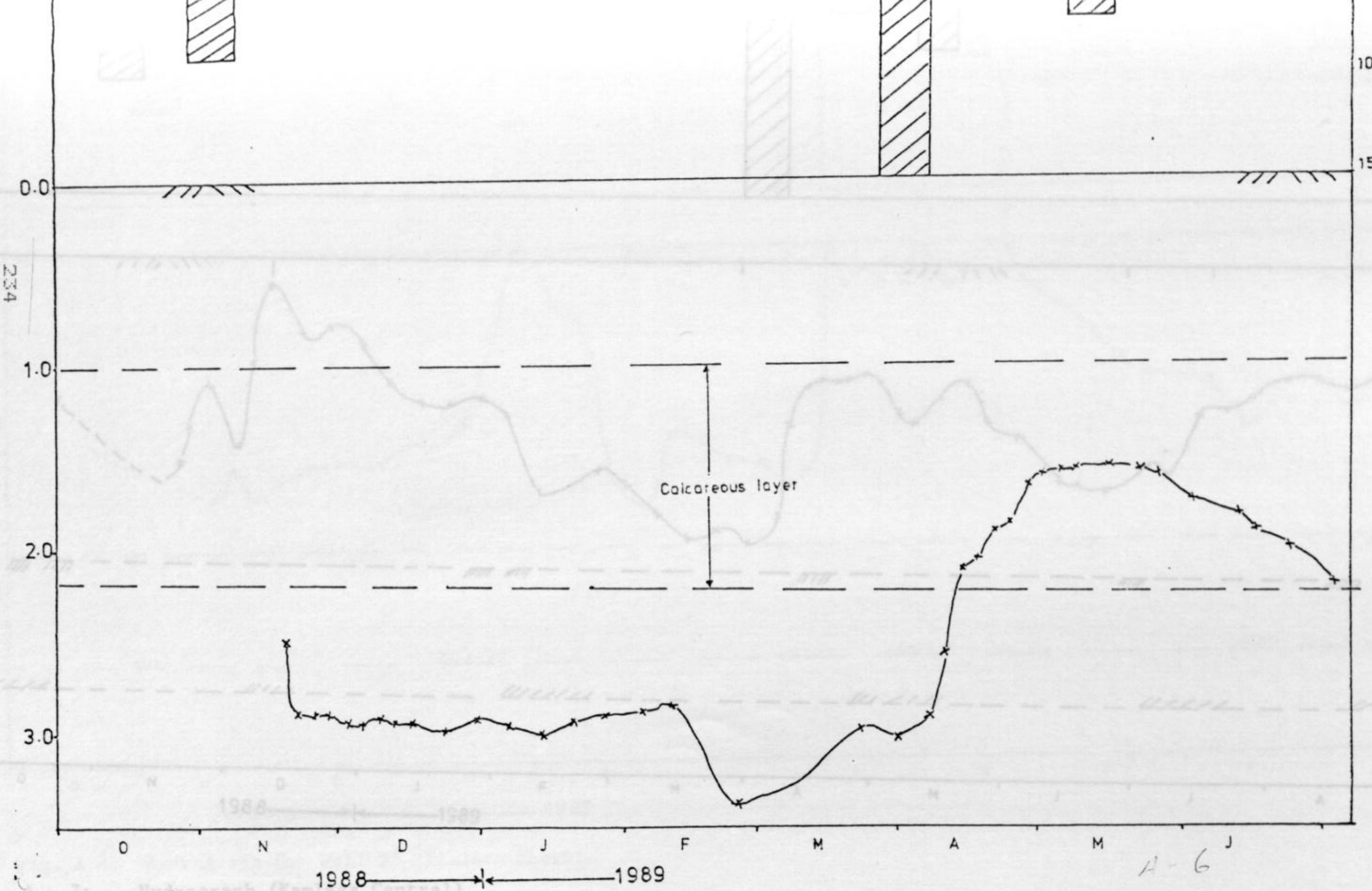


Fig. A - 5: Hydrograph for Well B2 (Kamleza North)



A-6

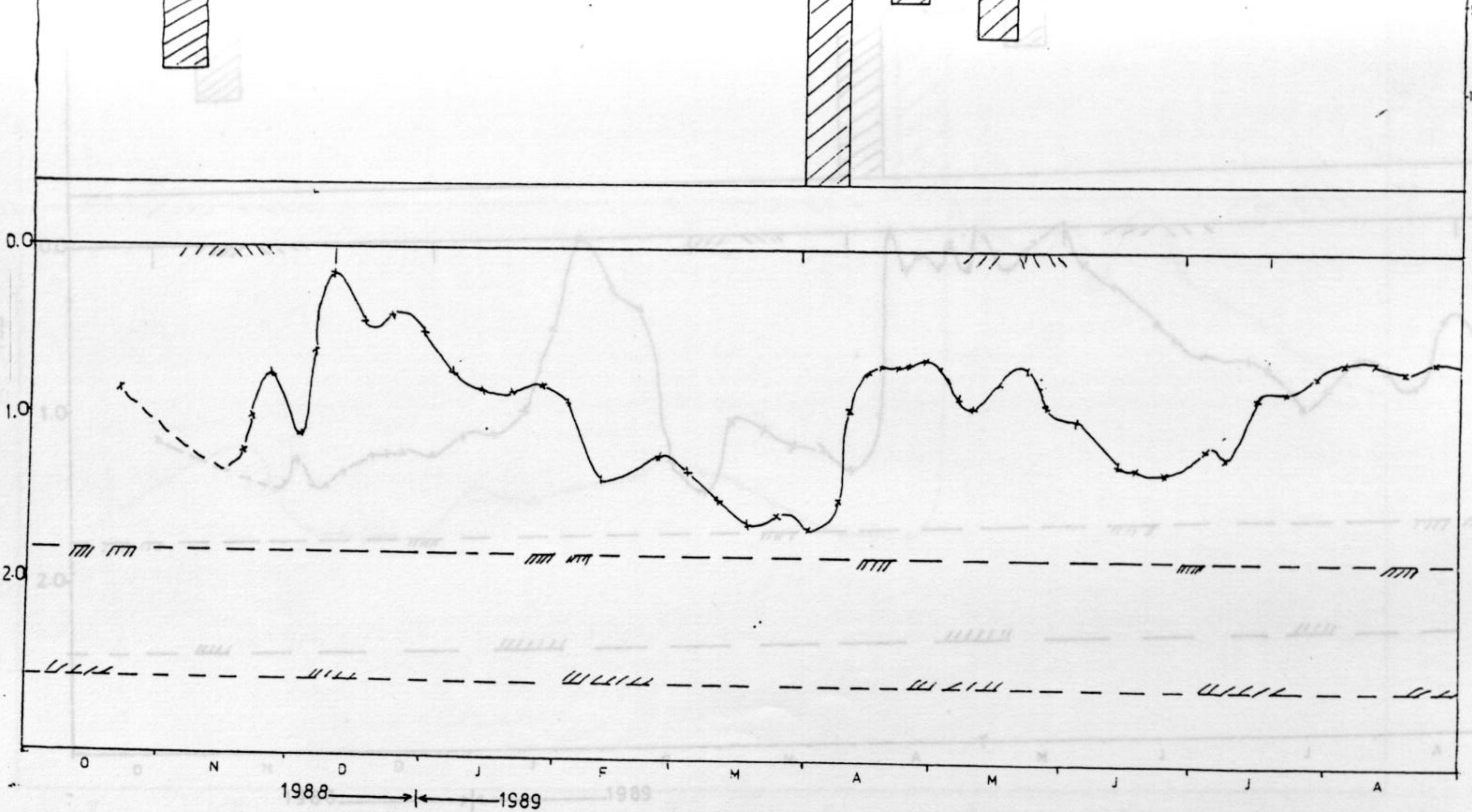


Fig. A - 7: Hydrograph (Kamleza Central)

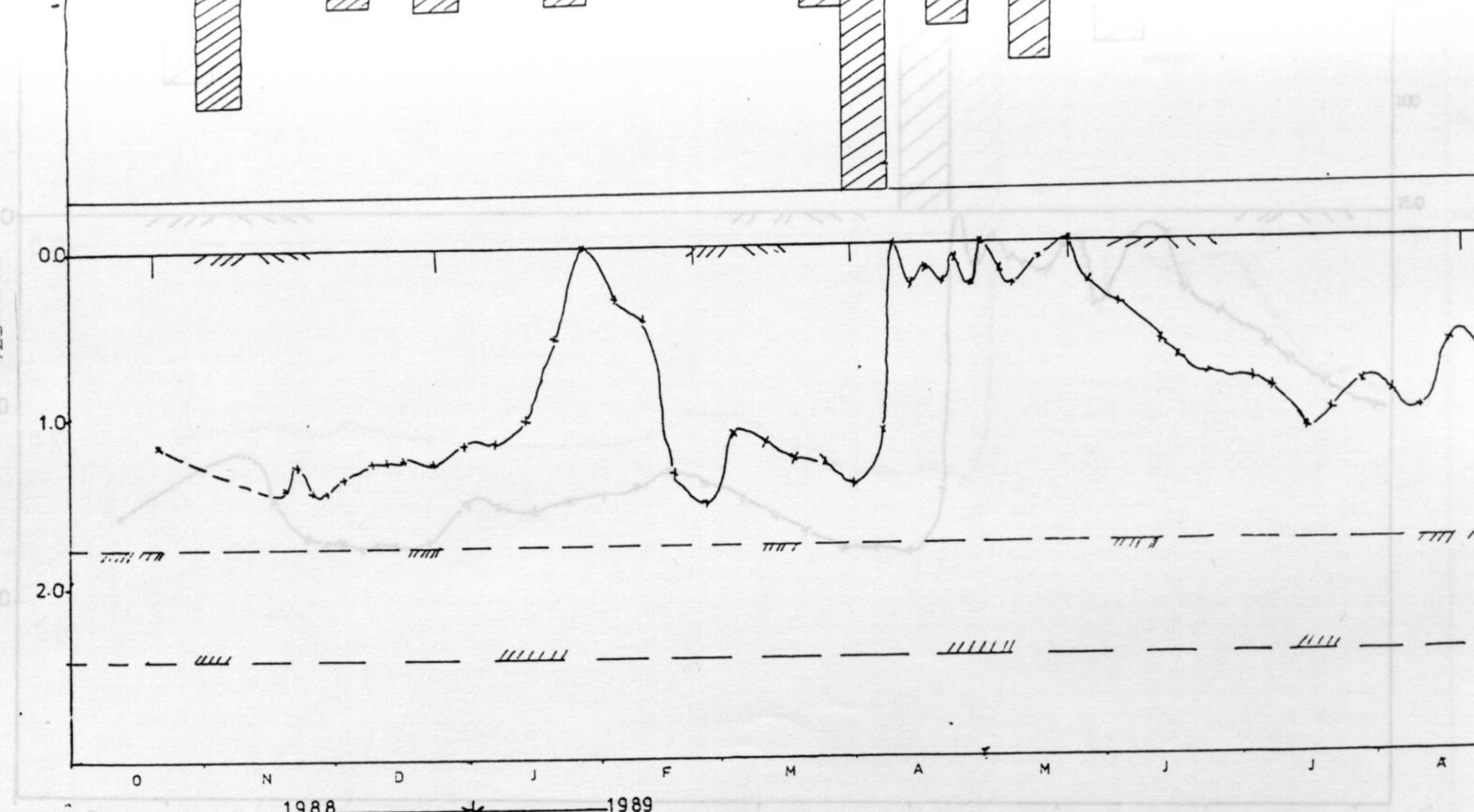


Fig. A - 8: Hydrograph for Well B5 (Kamleza South)

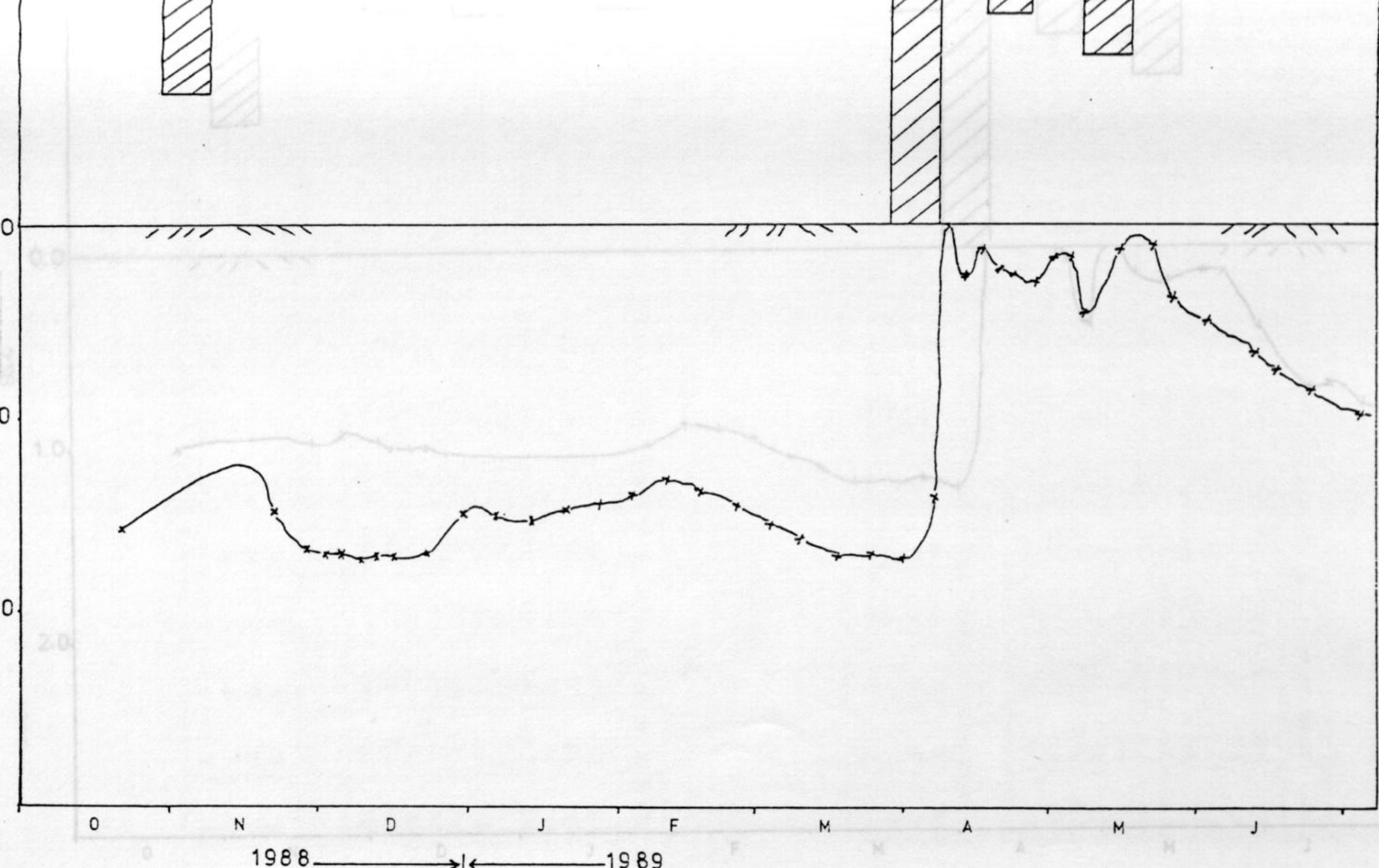


Fig. A - 9: Hydrograph for Well B6 (Ngutini - close to Southern Swamps)

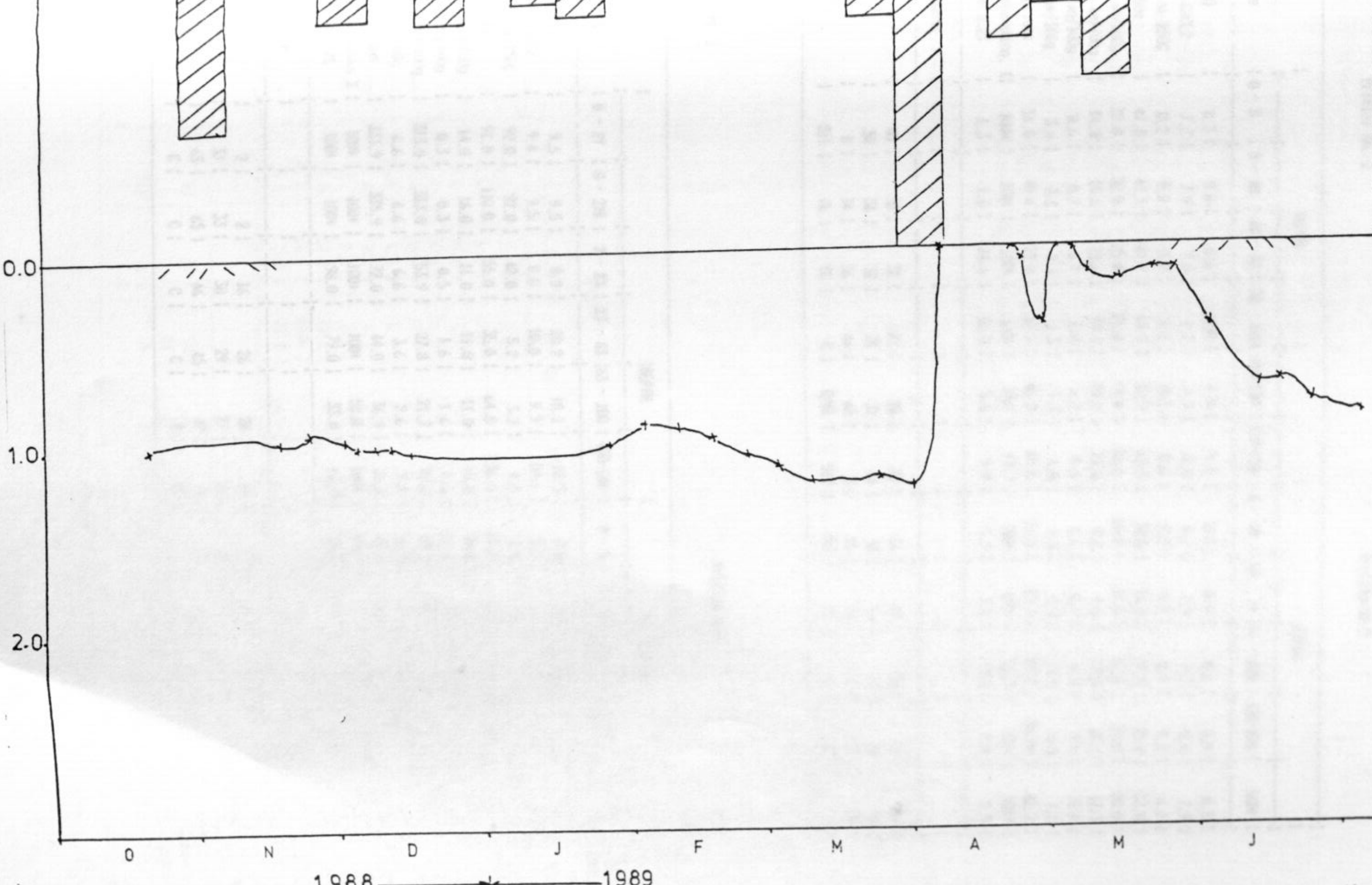


Fig. A - 10: Hydrograph for Well F3 (Block C)

Prifile No. 1 — Profile No.2

	DEPTH						DEPTH				
	0 - 5	5 - 40	40 - 70	70 - 100	100-120	120-150	0 - 50	50 - 74	74 - 120	120-160	160+
	8.3	8.8	8.6	8.8	9.0	9.1	8.3	8.4	8.6	8.9	8.3
CaCL2	7.7	7.9	7.9	7.7	7.7	8.0	8.1	7.9	7.7	8.0	7.9
t 250C	0.2	0.2	0.2	0.3	0.3	0.6	0.3	0.2	0.2	0.3	6.1
0g	47.0	43.5	41.7	43.5	31.7	43.5	30.0	24.0	37.0	35.0	33.0
e/100g	32.0	30.0	25.0	21.0	19.0	15.0	20.0	17.0	18.0	23.0	28.0
me/100g	14.8	15.6	15.6	19.7	22.2	23.0	8.2	9.1	12.3	10.7	12.3
me/100g	0.6	0.7	6.1	7.0	1.7	4.3	1.6	0.7	0.8	0.8	0.8
e/100g	3.6	3.1	2.1	1.5	1.5	1.0	1.5	0.5	0.5	0.5	1.5
tions	51.0	49.4	52.9	51.7	45.2	42.5	31.3	27.3	27.2	35.00	42.7
uration. %	100+	100+	100+	100+	100+	97.7	100+	100+	85.5	100+	100+
8.2%	1.3	1.6	14.6	16.0	5.4	9.9	5.3	3.1	2.2	2.4	2.5
ure											
	40	32	32	23	28	33	24	28	26	28	44
	52	34	32	31	32	64	51	44	43	37	31
	8	34	36	46	40	3	25	28	31	35	25
	Sil	CL	CL	C	C/CL	Sil	Sil	CL	CL	CL	L

No. 3 — Profile No.4

	DEPTH						DEPTH					
ers	0 - 2Y	0 - 2YB	2 - 23	23 - 63	63 - 100	100-140	0 - 5	5 - 45	45 - 60	60 - 85	85 - 105	105 - 120
20)	9.5	9.5	8.9	10.2	10.1	10.3	8.8	9.8	10.2	10.1	10.1	9.7
a CaCL2	9.4	9.5	8.8	10.0	9.9	10.1	8.1	9.5	9.7	10.0	9.9	8.8
m at 250C	92.0	92.0	42.0	5.2	3.2	4.5	1.9	9.4	7.1	7.0	3.0	1.1
100g	91.0	110.0	55.0	35.0	64.0	36.0	47.0	53.9	50.4	51.3	36.5	27.8
a me/100g	14.0	16.0	11.0	11.0	11.0	10.0	34.0	6.0	11.0	10.0	11.0	18.0
g me/100g	0.3	0.3	0.5	1.6	1.6	1.6	12.3	1.6	4.1	3.30	4.1	4.9
la me/100g	313.0	313.0	53.9	27.8	21.7	22.6	12.2	40.0	67.8	62.6	54.8	19.1
me/100g	6.6	6.6	6.6	3.6	2.6	2.6	1.3	1.5	0.8	0.6	0.5	0.3
Cations	333.9	335.9	72.0	44.0	36.9	36.8	57.3	49.2	83.7	76.5	70.4	42.3
turations %	100+	100+	100+	100+	58.0	100+	100+	53.9	100+	100+	100+	100+
pH 8.2%	100+	100+	98.0	79.0	33.0	63.0	26.0	74.0	100+	100+	100+	69.0
exiure												
	2	2	16	26	26	24	36	28	27	24	22	45
	33	33	38	29	27	41	42	22	12	22	12	30
	65	65	46	45	47	35	22	50	61	54	64	25
	C	C	C	C	C	CL	L	C	C	C	C	L

Profile No.5 | Profile No.6

	DEPTH				DEPTH		
s	0 - 2	2 - 30	30 - 65	65 - 100	5 - 40	40 - 80	80 - 100
)	8.4	8.7	8.7	9.4	8.3	7.8	8.2
CaCL2	8.3	8.0	8.2	8.7	7.2	7.1	7.4
at 250C	72.0	3.1	2.5	2.2	0.1	0.2	0.3
0g	22.0	26.0	32.0	30.0	29.0	30.0	30.0
me/100g	53.0	12.0	7.0	12.0	11.0	15.0	24.0
me/100g	5.8	3.3	5.8	9.1	9.1	7.4	6.6
me/100g	104.3	13.9	11.7	11.3	0.6	0.8	0.7
me/100g	7.7	4.1	3.6	3.1	1.5	1.5	1.5
ations	170.8	33.3	28.1	35.5	22.2	24.8	32.9
urations %	100+	100+	88.0	100+	76.0	82.5	100+
H 8.2%	63.0	100+	53.0	37.0	2.0	2.8	2.3
ture							
	33	36	29	35	34	38	44
	50	39	28	43	28	10	34
	17	25	43	21	38	52	22
	L	L	C	L	CL	C	L

No. 7

	DEPTH						
ers	0 - 5	5 - 20	20 - 40	40 - 60	60 - 80	80-100	100-120
20)	8.1	7.8	8.4	8.4	8.6	8.4	7.6
01m CaCL2	7.1	6.7	7.0	7.2	7.5	7.2	7.4
m at 250 C	0.4	0.1	0.2	0.3	0.3	0.3	0.3
100g	30.4	34.8	27.8	27.0	27.0	29.6	28.7
Ca me/100g	17.0	15.0	15.0	13.0	13.0	13.0	15.0
g me/100g	14.9	4.9	5.6	4.9	4.1	10.7	4.9
Na me/100g	1.0	0.7	6.1	6.5	6.5	6.1	6.1
me/100g	4.1	2.6	3.2	2.6	2.6	3.2	3.2
Cations	27.0	23.2	29.2	27.0	26.2	33.0	29.2
turation %	88.9	66.7	100+	100+	97.0	100+	100+
pH 8.2 %	3.4	2.0	22.0	24.0	24.0	20.6	21.2
exture							
	38	34	30	30	30	31	34
	4	21	28	47	49	37	30
	Sil	L	CL	C	C	CL	CL

8

	DEPTH										
	0 - 5	5 - 20	20 - 40	40 - 60	60 - 80	80 - 100	100-120	120-140	140-160	160-180	180-200
	8.3	8.1	8.1	7.8	8.1	8.4	8.3	8.7	8.9	9.0	9.1
CaCL2	7.4	7.4	7.1	7.2	7.5	7.8	7.7	7.6	7.8	7.9	8.2
t 250 C	0.2	0.4	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
g	37.0	35.0	33.0	30.0	31.0	30.0	33.0	30.0	31.0	35.0	34.0
e/100g	21.0	19.0	17.0	18.0	17.0	18.0	17.0	17.0	18.0	19.0	21.0
e/100g	9.1	9.9	9.9	8.2	7.4	7.4	5.6	9.9	6.6	7.4	7.4
ae/100g	0.3	0.7	0.7	0.7	5.6	6.1	7.0	7.0	7.8	1.7	1.7
/100g	5.1	3.2	2.1	2.1	2.1	3.2	3.2	3.2	3.2	3.2	3.2
tions	35.5	32.8	29.7	29.0	32.6	34.6	34.7	32.8	35.6	31.3	33.3
ration %	96.0	93.6	90.0	97.0	100+	100+	99.4	100+	100+	89.0	98.0
8.2 %	0.8	1.9	2.0	2.3	18.0	20.3	21.2	23.3	25.0	4.9	5.0
ure											
	35	40	34	28	36	36	42	48	37	32	34
	56	51	35	36	37	31	28	36	38	40	27
	9	9	31	36	27	33	30	16	25	28	39
	Sil	Sil	CL	CL	L	CL	CL	L	L	CL	L

Profile NO.9

	DEPTH (cm)			
rs	0 - 3	3-50	50-110	110-150
0)	7.1	7.0	8.3	9.6
CaCL2	6.9	7.3	7.9	8.9
at 250C	72.0	10.9	6.9	2.0
00g	16.0	39.0	42.0	43.0
me/100g	101.0	28.0	16.0	10.0
me/100g	49.3	14.0	14.0	12.3
mc/100g	67.0	13.9	16.5	14.8
me/100g	3.6	3.1	2.1	0.9
Cations	220.90	59.0	48.6	38.0
aturation. %	100+	100+	100+	88.4
H 8.2%	100+	35.6	39.0	34.4
xture				
	39	40	33	26
	45	41	53	28
	16	19	14	48
	L	L	SIL	C

ile No. 10

eters	0-10	10-30	30 - 50	50 - 70	70 - 90	90 - 110	110-130	130-150	150-170	170-190	190-210
	DEPTH										
(H2O)	6.9	7.5	7.0	7.5	7.8	8.5	8.7	9.5	9.1	9.2	8.6
.01m CaCL2	6.8	7.3	6.9	7.5	7.6	7.9	7.8	8.0	8.0	8.1	7.8
/cm at 25OC	11.6	4.9	4.1	3.6	2.3	1.6	1.0	0.8	0.6	0.5	0.5
e/100g	38.3	37.4	34.8	35.7	34.8	33.9	36.5	37.4	34.8	35.7	34.8
Ca me/100g	34.0	29.0	20.0	20.0	19.0	21.0	23.0	21.0	18.0	15.0	20.0
Mg me/100g	13.2	9.9	9.9	10.7	12.3	12.3	13.2	13.2	14.0	14.0	22.2
Na me/100g	7.8	4.2	3.5	4.2	4.2	4.2	4.2	4.2	4.2	3.5	4.2
K me/100g	5.1	4.1	3.2	3.6	3.6	3.2	3.2	3.2	2.6	2.1	2.6
of Cations	60.1	43.2	36.6	38.5	39.1	40.7	43.6	41.6	38.8	34.6	49.0
Staturation. %	100+	100+	100+	100+	100+	100+	100+	100+	100+	96.8	100+
at pH 8.2%	20.4	11.0	10.0	11.8	12.0	12.4	11.5	11.0	12.0	9.8	12.0
Texture											
nd	37	42	40	38	39	46	40	38	38	40	36
t	50	42	52	45	42	37	37	32	28	31	29
ay	13	16	8	17	19	17	23	30	34	29	35
S	Sil	L	Sil	L	L	L	L	CL	CL	CL	CL

Profile NO.11

meters	0-3	3-50	50-90	90-120	120+
	DEPTH				
(H20)	7.7	8.2	9.8	9.4	9.7
.01m CaCL2	7.7	8.1	9.4	9.4	9.1
S/cm at 25OC	22.0	11.0	2.5	3.0	1.6
me/100g	36.5	40.0	39.1	41.7	39.1
. Ca me/100g	48.0	23.0	13.0	9.0	10.0
. Mg me/100g	12.3	9.9	8.2	6.6	5.8
. Na me/100g	23.5	18.3	18.3	20.9	17.4
c/ K me/100g	3.1	1.5	1.0	0.5	1.0
of Cations	86.9	52.7	40.5	37.0	34.2
e Staturation. %	100+	100+	100+	88.8	87.5
at pH 8.2%	64.4	45.8	46.8	50.0	44.5
l Texture					
nd	36	40	33	28	43
ilt	48	48	19	26	33
lay	16	12	48	46	24
SS	L	L	C	C	L

ile No. 12

meters	0-5	5-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	165+
	DEPTH									
(H20)	8.5	9.4	9.6	9.7	9.8	9.8	9.9	9.8	9.6	9.8
01m CaCL2	8.5	9.1	9.4	9.5	9.6	9.6	9.6	9.6	9.2	9.2
S/cm at 250C	26.0	20.5	19.5	20.0	17.0	16.5	16.5	7.5	6.8	2.0
e/100g	48.7	50.4	36.5	47.8	48.7	73.0	56.5	56.5	61.7	25.2
. Ca me/100g	37.0	15.0	10.0	11.0	13.0	10.0	5.0	10.0	11.0	13.0
. Mg me/100g	4.1	2.5	2.5	4.1	3.3	3.3	1.6	3.3	4.1	2.5
. Na me/100g	47.8	74.8	66.1	66.1	54.8	69.6	69.6	55.7	36.4	14.8
K me/100g	3.2	2.5	1.5	1.5	1.5	1.5	1.0	1.0	0.5	0.5
of Cations	92.1	94.4	80.1	82.8	72.6	84.4	77.3	70.0	52.1	30.8
Staturation. %	100+	100+	100+	100+	100+	100+	100+	100+	84.4	100+
at pH 8.2%	98.0	100+	100+	100+	100+	95.0	100+	98.6	59.2	58.7
Texture										
nd	23	43	25	31	42	26	25	26	29	64
lt	48	37	20	35	22	26	23	16	5	14
ay	29	20	55	34	36	52	52	56	66	22
S	CL	L	C	CL	CL	C	C	C	C	SCL

ile No. 13

meters	0 - 5	5 - 30	30 - 50	50 - 70	70 - 90	90 - 110	110-130	130-150	150+
	DEPTH								
- (H20)	8.6	9.6	9.7	9.7	9.9	9.9	9.8	9.9	9.9
0.01m CaCL2	8.2	9.1	9.3	9.4	9.5	9.5	9.4	9.4	9.1
S/cm at 250 C	14.0	2.7	2.9	2.6	2.5	2.5	2.3	3.3	1.6
me/100g	44.0	43.0	42.0	42.6	42.0	38.0	42.6	39.0	38.0
n. Ca me/100g	25.0	7.0	5.0	8.0	7.0	11.0	12.0	12.0	13.0
. Mg me/100g	10.7	4.9	4.1	4.9	3.3	4.1	"4.1	3.3	4.1
. Na me/100g	34.8	21.7	26.1	24.3	23.5	25.2	22.6	26.1	18.3
. K me/100g	3.6	21.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0
of Cations	74.1	35.1	36.7	38.7	35.3	41.8	40.2	42.9	36.4
e Saturation %	100+	82.0	87.5	90.9	84.0	100+	94.4	100+	95.8
at pH 8.2 %	79.0	50.5	62.0	57.0	56	66.0	53.0	67.0	48.0
l Texture									
and	30	25	32	34	34	40	36	40	70
ilt	48	15	13	14	14	15	18	18	14
lay	22	60	55	52	52	45	46	42	16
SS	L	C	C	C	C	C	C	C	SL

Profile NO.14 . Profile No. 15

rs	DEPTH 0 - 10	10 - 40	40 - 70	70 - 100	100-160	160-220	220-280	DEPTH 0 - 30	30 - 60	60 - 90	90 - 120
0)	-	8.3	8.4	8.2	8.1	8.7	9.0	7.7	8.0	7.9	8.1
0lm CaCl2	-	8.0	8.2	8.1	8.1	8.4	8.4	3.7	7.7	9.9	7.9
s at 250 C	-	2.5	9.2	13.7	18.2	13.7	4.5	0.4	1.6	2.8	3.6
100g	-	40.0	33.0	30.0	29.0	30.0	24.0	43.0	40.0	38.0	36.0
s me/100g	26.0	27.0	44.0	71.0	21.0	21.0	15.0	34.0	28.0	39.0	68.0
g me/100g	26.3	14.0	14.0	15.6	9.9	9.9	4.9	9.9	13.2	14.8	11.5
s me/100g	64.3	6.1	17.4	24.3	28.7	36.5	14.8	1.6	3.5	3.5	4.2
me/100g	3.2	1.5	17.4	1.5	0.5	0.4	0.5	5.1	4.6	4.6	4.6
ations	119.8	48.6	2.1	112.4	60.1	67.8	35.2	50.6	49.3	61.9	88.3
uration %	-	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+
H 8.2 %	-	15.0	53.0	81.0	99.0	100+	"63.0	3.7	8.8	9.2	11.7
ture											
		36	30	31	46	72	86	38	29	34	31
		39	67	64	51	15	11	49	32	39	64
		25	3	5	3	13	3	13	39	27	5
		L	Sil	Sil	Sil	SL	LS	L	CL	L	Sil

No. 16

ers	DEPTH 0 - 3	3 - 20	20 - 40	40 - 60	60-80	80-100	100-120	120-130
20)	9.6	9.5	9.4	9.6	9.6	9.6	9.6	9.6
0lm CaCl2	9.2	9.0	8.7	8.9	8.9	9.0	9.0	8.9
m at 250C	63.0	8.9	2.3	2.1	2.4	2.5	2.2	2.4
100g	41.7	40.00	38.3	33.0	36.5	34.8	36.5	39.1
a me/100g	69.0	20.0	9.0	10.0	12.0	11.0	13.0	14.0
g me/100g	21.4	3.3	4.9	5.8	6.6	6.6	6.6	6.6
a me/100g	121.7	13.9	13.9	13.9	14.8	13.9	15.7	14.8
me/100g	8.7	3.6	4.1	4.1	4.1	3.1	3.1	2.6
Cations	220.8	40.8	31.9	33.8	37.5	34.6	38.4	38.0
aturation. %	100+	100+	83.0	100+	100+	99.4	100+	97.2
pH 8.2%	100+	35.0	36.0	42.0	40.5	40.0	43.0	38.0
xture								
	17	35	34	34	38	40	38	34
	37	13	31	31	27	25	28	39
	46	52	35	35	35	35	34	27
	Sil/CL	Sil	CL	CL	L	L	CL	CL

ofile No. 17 | Profile No. 18

rameters	0 - 5	10 - 40"5	30 - 50	50 - 70	70 - 90	90-110	110-130	130+	0-10	10-50	50-80
	DEPTH								DEPTH		
- (H2O)	7.8	8.1	8.1	8.1	8.1	8.4	8.3	8.3	8.5	8.6	8.6
- 0.01m CaCL2	7.8	7.9	7.9	8.1	8.1	8.2	8.0	6.3	7.5	7.8	8.2
mS/cm at 250 C	68.0	14.0	15.5	15.0	15.0	9.2	7.8		0.2	0.5	4.7
C me/100g	38.0	73.0	55.0	82.0	87.0	110.0	82.0	31.0	46.0	45.0	31.0
ch. Ca me/100g	70.0	34.0	28.0	30.0	27.0	26.0	31.0	20.0	39.0	28.0	15.0
ch. Mg me/100g	31.3	14.0	16.4	16.4	19.7	"20.6	18.9	16.4	5.6	8.2	9.1
ch. Na me/100g	104.3	34.8	33.0	28.2	27.8	23.5	16.5	14.8	6.5	3.5	18.3
ch. K me/100g	7.7	7.2	6.1	5.6	5.6	5.1	4.1	3.2	4.1	2.1	1.5
m of Cations	213.3	90.0	83.5	80.7	80.1	75.2	70.5	54.5	55.2	41.8	43.9
se Saluration %	100+	100+	100+	98.0	92.0	68.0	86.0	100+	100+	93.0	100+
P at pH 8.2 %	100+	48.0	60.0	35.0	32.0	22.0	21.0	48.0	14.0	7.0	59.0
il Texture											
Sand	21	21	27	31	29	27	35	39	24	30	26
Silt	62	26	20	63	67	71	47	35	54	34	22
Clay	17	53	53	6	4	2	18	26	22	36	52
LASS	Sil	C	C	Sil	Sil	Sil	L	L	Sil	CL	C

rofile No. 19

arameters	0 - 5	5 - 30	30 - 50	50 - 70	70 - 90	90 - 110	110-130	130-150	150-170
		DEPTH							
- (H2O)	8.1	8.1	8.3	8.1	8.1	8.6	8.2	8.4	8.2
-0.01m CaCL2	8.1	7.9	8.2	7.8	8.1	8.4	8.2	8.3	8.1
C mS/cm at 250C	5.8	21.4	18.0	21.5	28.6	12.5	8.4	4.1	10.4
EC me/100g	46.0	43.5	39.0	41.0	34.0	37.0	33.0	49.0	42.0
xch. Ca me/100g	61.0	48.0	35.0	32.0	22.0	33.0	26.0	17.0	21.0
xch. Mg me/100g	16.4	18.1	18.1	17.3	18.9	28.8	22.1	17.3	16.4
xch. Na me/100g	7.0	38.3	45.2	45.2	57.4	85.2	95.7	27.0	22.6
xch. K me/100g	4.1	5.6	5.6	3.6	3.6	3.6	1.6	2.6	2.1
um of Cations	88.5	110.0	103.9	98.1	101.9	150.6	105.4	63.9	62.1
ase Saturation. %	100+	100+	100+	100+	100+	100+	100+	100+	100+
SP at pH 8.2%	15.0	88.0	100+	100+	100+	100+	100+	67.5	54.0
oil Texture									
Sand	27	27	27	37	39	35	33	31	43
Silt	57	59	28	36	48	57	60	37	39
Clay	16	4	45	27	13	8	7	32	18
LASS	Sil	Sil	C	CL	L	Sil	Sil	CL	L

No. 20

Profile No.21

ers	0 - 25	25 - 55	55 - 115	115-150	0 - 15	15 - 65	65 -130	130-150
	DEPTH				DEPTH			
20)	8.0	8.1	8.1	8.2	9.0	9.7	9.6	9.4
a CaCL2	7.4	7.5	7.5	7.8	8.3	9.4	9.4	9.1
m at 250C	0.5	0.4	0.8	4.9	1.2	7.5	2.9	1.8
100g	64.0	39.0	36.5	29.0	36.5	43.0	46.0	73.0
a me/100g	36.0	30.0	23.2	11.2	21.20	9.20	8.00	9.20
g me/100g	8.4	8.3	12.0	23.2	7.0	2.0	2.7	3.0
a me/100g	0.9	1.4	0.9	20.0	18.4	66.8	57.2	37.8
me/100g	4.1	3.0	2.1	0.5	2.0	1.5	1.4	0.2
Cations	49.4	42.8	48.2	55.2	48.6	78.0	67.9	60.2
aturation. %	77	100+	100+	100+	100+	100+	100+	83.0
pH 8.2%	1.4	3.6	2.4	69.0	100+	100+	100+	66.0
xture								
	33	29	29	35	33	35	25	33
	39	29	19	33	38	19	13	23
	28	42	52	32	29	46	62	44
	CL	C	C	CL	L	C	C	C

NO.22

	DEPTH (cm)						
ters	0 - 10	10 - 60	60-105	105-140	140-160-	160-200	200-250
H20)	8.8	8.2	8.4	8.8	9.3	9.5	9.4
la CaCL2	7.6	8.0	8.1	8.5	8.9	8.9	8.6
cm at 250C	0.4	4.0	14.1	8.3	3.8	1.7	1.2
/100g	73.0	42.0	46.0	52.0	40.0	24.0	30.0
Ca me/100g	33.2	22.0	27.2	16.0	13.2	6.0	11.2
Mg me/100g	14.0	12.0	10.0	6.3	3.0	2.0	4.0
Na me/100g	2.8	33.2	69.6	77.2	43.5	20.0	19.2
K me/100g	2.6	1.0	1.5	1.1	0.5	0.2	0.2
Cations	52.6	68.2	108.3	100.6	60.2	28.2	34.6
tataturation. %	71.0	100+	100+	100+	100+	100+	100+
pH 8.2%	3.8	79.0	100+	100+	100+	83.0	100+
Texiure							
d	27	29	21	21	37	53	73
t	44	28	42	12	25	9	19
y	29	45	37	67	38	38	8
	CL	C	CL	C	CL	SC	SL

23

Profile NO.24

	DEPTH (cm)				DEPTH			
s	0 - 10	10 - 65	65-155	155-200	0 - 10	10 - 50	50 - 85	85-130
)	7.6	8.3	7.7	8.4	8.3	8.4	8.5	8.9
CaCL2	7.5	7.7	7.3	8.2	8.0	8.2	8.3	8.7
t 250C	0.3	1.4	4.0	1.1	9.5	2.4	1.4	1.9
0g	42.0	41.0	43.0	73.0	9.5	2.4	1.4	1.9
e/100g	23.2	13.6	14.0	15.2	91.0	43.5	36.0	31.0
me/100g	7.2	8.3	9.4	11.2	25.2	11.2	8.0	12.0
me/100g	1.6	7.8	15.6	29.6	9.4	4.7	5.0	6.7
e/100g	4.1	1.5	1.0	1.5	1.5	1.0	1.0	1.0
tions	36.1	31.3	40.0	57.5	75.3	52.2	56.7	59.1
uration. %	86.0	76.0	93.0	78.0	83.0	100+	100+	100+
8.2%	3.8	19.0	36.0	41.0	43.0	82.0	100+	100+
ure								
	43	45	37	19	33	21	19	23
	19	31	33	15	36	14	21	19
	38	24	30	66	31	65	60	58
	CL	L	CL	C	CL	C	C	C

APPENDIX C

- 1: RAINFALL DATA AT KIVALWA MALARIA RESEARCH STATION

	F	M	A	M	J	J	A	S	O	N	D
											0.2
	1.7							1.5			0.5
	4.6				5.5						
7			6.4								
3										5.0	
										17.9	
4			6.0								
			25.8							66.4	
			12.2								15.6
0			3.5								14.5
											7.3
		5.0	2.4	0.5				1.0			
6					8.5			4.5			2.4
								3.0			
			1.6								
			1.3								
0			12.6								
0		6.8	27.0		11.3						
		2.1	30.5	16.6							
		4.4	0.9	0.8	10.3			0.9			
		56.9						1.2			
				0.5						3.2	
		32.8								5.6	
										4.0	
		2.5								0.6	
		5.5									7.0
		30.0	1.1						5.1		6.5
		44.8									
		2.0									8.9
		6.0									7.1
	6.3	198.8	104.3	18.4	35.6	0	0	12.1	5.1	102.7	73.0

Table C - 1 RAINFALL DATA
1989

Day	J	F	M	A	M	J	J	A	S
1.					1.2				
2.					5.1				
3.				10.5					
4.									
5.	1.9			5.2		0.5			
6.	2.6			2.9	5.5				
7.				11.5				3.5	
8.		7.7		18.8					
9.		7.9		70.2					
10.				35.2	19.5				
11.				1.8	21.5				
12.	22.1		10.0						
13.	2.0		1.6	0.5					
14.				0.3					
15.			4.7	2.5					
16.			2.4		4.7				
17.			1.0	4.1	2.0				
18.				12.3	23.7				
19.					17.6				
20.				4.5					
21.	27.0				0.6				
22.			29.5						
23.			1.2		1.1				
24.	3.0			9.1					
25.				1.7					
26.									
27.									
28.				4.4		2.0			
29.			3.1	3.6		3.1			
30.			2.7	26.0					
31.					4.9				
	58.6	15.6	56.2	225.1	107.4	5.6	0	3.5	

LE C-2: AVERAGE EVAPORATION DATA (mm) - TAVETA.

J	F	M	A	M	J	J	A	S	O	N	D
175	175	175	150	140	135	135	145	165	185	175	175
140	140	140	120	112	108	108	116	132	148	140	140
4.5	5.0	4.5	4	3.6	3.6	3.5	3.7	4.4	4.8	4.7	4.5

urce: Berger and Kalders (1983)

BLE C-3: MAXIMUM DISCHARGE OF CAPILLARY RISE IN MM/DAY FROM GROUND WATER

	Distance to ground water level (cm)			
Soil	50	75	100	150
Clay	1.0	0.5	0.2	0
Clay loam	>5.0	4.0	3.0	1.0
Loam	>5.0	>5.0	>5.0	4.0
Sandy loam	>5.0	1.0	0.3	0
Sand	>5.0	3.0	1.0	0.2

ource: MOA (1984)

APPENDIX D - HYDRAULIC CONDUCTIVITY

) Hydraulic conductivity determination

Hydraulic conductivity was determined in the field sing the augerhole and the inverted augerhole methods. th the augerhole method, the hydraulic conductivity may be lculated for three different cases:

) In areas where the augerhole reaches the petrolcalcic or aliche layer as shown in Fig.1-1, the formula used ccording to Van Beers (1963) and Eijkelkamp (1983) s;

$$= \frac{3600\, r^2}{(H + 10r)\,(2-y/H)\, y} \; * \; dy/dt \;.......(22)$$

ii) In areas where the impermeable layer is at a depth S > 1/2H, the formula used is;

$$= \frac{4000 r^2}{(H + 20r)(2-y/H)\, y} \; * \; dy/dt \quad ...(23)$$

here,

r = radius of auger -hole,(cm),

H = depth of hole below the ground water table,

y = distance between groundwater and the average level of the water in the hole for time interval dt, (s),

s = depth to impermeable layer, in this case caliche,

dy = the rise of water level in the hole during measurement, (cm),

dt = time interval, (s).

(iii) For areas with layered soils, a graphical method can be used (Van Beers, 1963).

In the diagram,

) = depth of the augerhole, (cm)

W = depth of groundwater level, (cm)

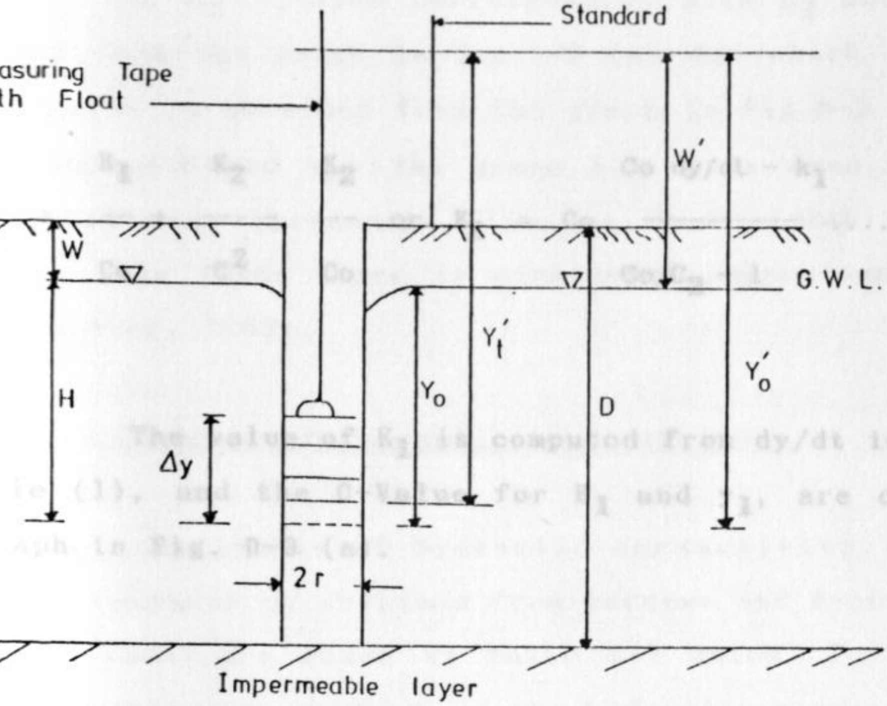
y^1 = tape reading at groundwater level, (cm)

yo' = tape reading of water surface elev - at t= 0

Y_t = tape reading at different water surface elevation at times t = 0

yo = distance between groundwater level and the elevation of the water surface in the hole after removal of water at the time of the first reading, (cm).

I, dy, r - remain as before



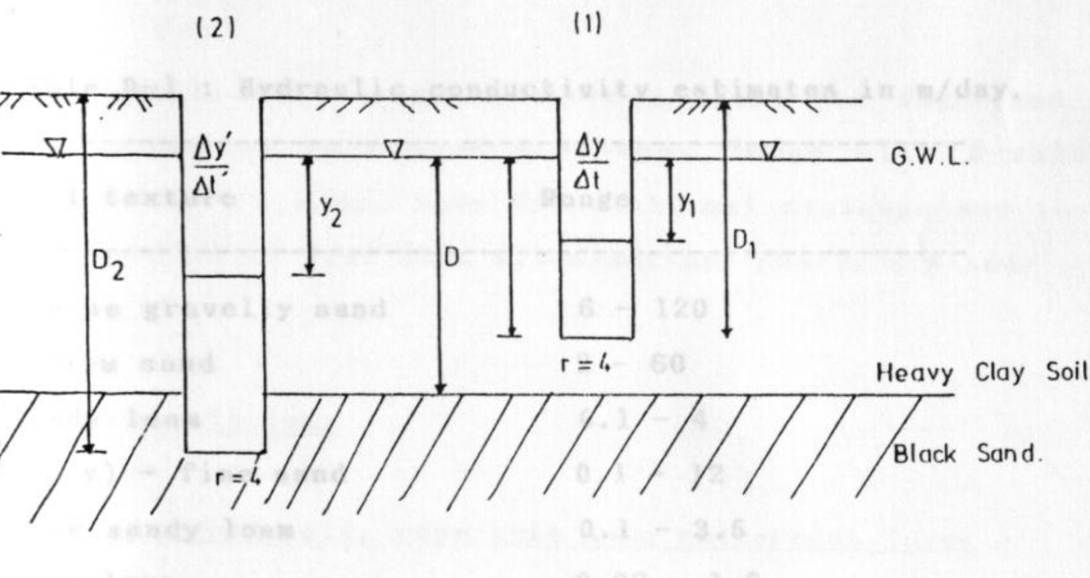
g.D-1: Diagram showing the various parameters in the uger- hole method of determining hydraulic conductivity.

ii) <u>Layered Soil</u> :The diagram in Fig.D-2, shows the rrangement for hydraulic conductivity measurement in a yered soil.

If the hydraulic conductivity of the upper layer is $_1$, and the lower layer K_2, then the rate of rise in the eep hole is given by the equation overleaf;

$$\frac{1}{1} = \frac{K_1}{Co} + \frac{K_2}{C^2} \quad \frac{K_2}{Co} \quad \text{or} \quad K_2 = Co \; \frac{Co\, dy/dt - k_1}{Co/C_2 - 1} \; .....(24)$$

The value of K_1 is computed from dy/dt in the shallow ole (1), and the C-Value for H_1 and y_1, are obtained from raph in Fig. D-3 (a).



ig.D-2: Augerhole arrangement for determination of hydraulic conductivity in a layered soil.

The C_2 - Value corresponding with H_2 and y_2, is also read from the graph in Fig.D-3 (a) for which S > 1/2H. The o-value is obtained from the graph in Fig.D-3 (b) where S = 0, using D and y_2. The graph S = 0 is used in this case, because only horizontal flow has to be taken into the deep hole. The lower layer is considered impervious in this case (Van Beer, 1963).

B). Estimates of hydraulic conductivity.

Estimates of hydraulic conductivity for different soil textures as obtained from Smedema and Rycroft (1983) and FAO (1985), are given in Table D-1 below. In Table D-2, an interpretation is given of the hydraulic conductivity rates.

Table D-1 : Hydraulic conductivity estimates in m/day.

soil texture	Range
coarse gravelly sand	6 - 120
medium sand	2 - 60
sandy loam	0.1 - 4
(very) - fine sand	0.1 - 12
fine sandy loam	0.1 - 3.5
clay loam	0.02 - 1.2
loam	0.05 - 3.5
heavy clay	< 0.001 - 0.5
medium clay	0.002 - 0.6
silt loam	0.01 - 3
gravelly silts to loams	0.005 - 4

ble D-2 : Hydraulic conductivity Classes

-range m/day	Class
> 6	Excessive
4 - 6	Very rapid
1 - 3	Mod. rapid - rapid
0.1 - 1	Mod. slow
0.04 - 0.1	Slow
< 0.04	Very slow

urce: FAO (1985).

Soils with K-values above 1 m/day are described as ving good to very good drainage. Those with K-values tween 0.1 - 1 m/day have fair internal drainage and those th K-valucs of lcss than 0.1 m/day are poorly drained.

mple calculations

Non- layered soil, augerhole upto calcareous layer

The location considered is at well B5 in Kamleza uth scheme. The data obtained during the field measurements e in Table 6.1 below. The calculation procedure and the rious dimensions are in Fig. D-1, App.D.

ble 6.1 : Field data at well B5

servation No. K-B5			Location: Kamleza Scheme
D = 183		W' = 60.4	
W = 28		r = 4	
H = 155		S = 0	
t	dt^1	dyt	
0	100.0		y_o' = 100.0 cm
10	99.6	0.4	
20	99.2	0.4	
30	98.9	0.3	
40	98.5	0.4	
50	98.1	0.4	
60	97.7	0.4	
dy	2.3	2.3	

dy/dt = 2.3/ 60 = 0.038

In order to calculate the K-value, eqn.22 is used (see p.D). The value of y is obtained as follows;

= y_o - 1/2 dy, where y_o = y_o' - W'

By substituting the values of y_o' = 100 cm , W' = .4 cm and dy = 2.3 cm from the above table, we get y = .45 cm.

Using eqn. 22 and substituting r = 4 cm, dy/dt = 0.038, = 155 cm, y = 38.45 and y/H = 0.248, we get:

K = 0.17 m/day or 0.2 m/day

) K-calculation in a layered soil

The data used is for site G2 in the Block C area ere the underlying subsoil, was found to having a higher K- ue. Details of dimensions and parameters are given in pendix D, Fig. D-2. The topsoil is heavy clay of thickness cm thick. The texture of the subsoil is fine black sand. le 6.2 contains the field data measurements.

The values of y_1 and y_2 are calculated as in case (1). values are :

= 36.25 cm and y_2 = 24.8 cm

K - values are found as follows:-

The value of $K_1 = C_1 * (dy/dt)_1$, **(see App.D).**
With dy/dt = 0.0018, the value of C_1 can be read from .D-3, App.D, and is found as 6.6. By substituting H1 = 89 and r =4 cm from Table 6.2, and y_1 = 36.25 (from above), get,

$K_1 = 0.0018 \times 6.6 = 0.012$ m/day

Table 6.2: Field data from site G2 (Block C)

Observation No. G2	Location:	Block C Scheme	
D_1 = 141	$W^1{}_1$ = 83.3	D_2 = 185	$W_2{}^1$ = 83.9
W_1 = 52	r = 4	W_2 = 52	r = 4
H_1 = 89	S > 1/2H	H_2 = 133	S > 1/2H

t_1	yt_1'	dyt_1	t_2	yt_2'	dy_t'
0	120.1		0	112.0	
60	119.95	0.15	15	108.5	3.5
120	119.8	0.15	30	105.4	3.1
180	119.7	0.1			
240	119.6	0.1			
300	119.5	0.1			
360	119.4	0.1			
420	119.3	0.1			
480	119.2	0.1			
540	119.1	0.1			
600	119.0	0.1			

$(dy/dt)_2$ = 6.6/30 = 0.22

$y_{o1'}$ = 120.0 cm

$y_{o2'}$ = 112.0 cm

$(dy/dt)_1$ = 1.1/600 = 0.0018

2) The value of K2 can be obtained by using eqn.23, App.D.

i) Using dy^1/dt^2 = 0.22 and H2 = 133 cm, the value of C2 = 6.4 from the graph in Fig.D-3.

ii) Using D =H = 103 cm and $(dy/dt)_2$ = 0.22, the value of C_0 from the graph in Fig.1.3(b) is;

C_0 = 8.5 cm, (S = 0)

ii) By applying eqn.23, and substituting $C_0 = 8.5$, $C_1 = 6.6$, $C_2 = 6.4$, $dy/dt)_2 = 0.22$ and $K_1 = 0.012$ m/day, we get,

$K_2 = $ <u>5.66 m/day.</u>

BLE D-1: HYDRAULIC CONDUCTIVITY VALUES

ite	H (cm)	W (cm)	D (cm)	S (cm)	Ka m/day	Kb m/day
5-A6	97	93	190	>1/2H	1.1	
A6	111	34	145	>1/2H	0.9	
B5	92	49	141	0	0.2	
rofile Pit B5	155	28	183	0	1.2	
5-B6(near drain)	113	40	153	0	1.9	
B6	163	47	210	>1/2H	0.5	
B7	111	96	207	>1/2H	0.9	
CO	136	50	186	>1/2H	0.6	
I-CO	135	48	183	>1/2H	4.5	
C3	94	80	174	0	0.03	
4-C5	49	141	190	0	2.0	
C5	105	62	166	0	11.0	
5-C6	86	67	153	0	3.4	
C6	94	86	180	0	2.0	
C7	80	138	218	>1/2H	2.6	
0-1000	117	176	293	0	0.3	
DO	108	15	118	0	0.2	
1-DO	168	23	191	0	1.06	
D1	94	86	180	0	0.03	
2-C2	58	65	123	0	1.7	
D3	113.5	48	161.5	>1/2H	0.8	
3-5	118	73	191	>1/2H	0.6	
7-1000	136	141	277	>1/2h	0.6	
7-1000	125	20	45	>1/2H	1.2	
"	217	20	210	>1/2H		17
EO	187	10	207	>1/2H	1.8	
E2	86	44	130	0	0.06	
E3	124.5	60	184.5	>1/2H	0.4	
E4	80	56	136	0	0.8	
FO	175	12	187	>1/2H	2.0	
F1	136	141	277	>1/2H	2.7	
F2	59	96	155	>1/2H	0.05	
"	190	96	280	>1/2H		0.03
F3	187	10	207	>1/2H	0.01	
F4	197	93	190	>1/2H	0.7	
G2	89	52	141	>1/2H	0.01	
"	133	52	185	>1/2H		5.7
G3	110	120	230	>1/2H	1.4	
G4	97	73	170	>1/2H	0.8	
G5	121	73	194	>1/2H	0.3	

NB:

Ka = Hydraulic conductivity of upper layer, (m/day).
Kb = Hydraulic conductivity of underlying layer, (m/day).
D = Depth of the augerhole, (cm)
W = Depth of ground water level, (cm)
S = Depth to impermeable layer, in this case, caliche (cm).
H = Depth of augerhole below the groundwater table, (cm).