RAPID RECONNAISSANCE SOIL SURVEYS OF PART OF TAVETA ESTATES, KENYA

A REPORT PREPARED BY HUNTING TECHNICAL SERVICES LIMITED
FOR
COMMONWEALTH DEVELOPMENT CORPORATION

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SECTION 1

1.1 INTRODUCTION

Rapid reconnaissance soil surveys of the proposed project area (1660 ha) at Taveta Estate were carried out between 7/8/87 and 13/8/87 to establish the availability of suitable land for surface irrigation development.

The Terms of Reference (ToR) for the reconnaissance soil surveys stipulate the following objectives:

(a) Identify and describe the major soil types in the area and assess their overall suitability for surface irrigation.

(b) Collect soil samples from modal profiles for physical and chemical analyses at the LRDC Tropical Soils Analysis Unit in Reading, England.

(c) Determine the extent to which irrigation development could be constrained by potential soil salinity/alkalinity, and water logging problems.

(d) Determine the base infiltration rate on each of the major soil types and carry out hydraulic conductivity tests to determine subsoil drainability.

(e) Assess the area of land available for irrigated and rainfed cropping with due regard to tillage problems and likely trace element requirements.

Time constraints dictated that only a limited field programme could be completed to fulfil these objectives.

A cross-section of soil types were sampled for chemical analyses. Field infiltration and drainage characteristics require a more thorough evaluation than was possible in the given time period.

The following field sampling programme was completed:

- twenty-five routine auger observations to a depth of 1 m, or to the parent material;
- samples taken from auger borings for routine field EC and pH using a 1:5 soil water suspension (69 samples);
- seven profile pits excavated to a depth of 2 m for detailed analyses by horizon at the LRDC laboratories in the UK (24 samples);
- two infiltration and hydraulic conductivity tests on selected sites;
- collection of samples of irrigation water to determine sodium hazard and salinity.

In anticipation of salinity/sodicity being the principal constraint to development of the area a large number of samples were tested for field pH and EC using a 1:5 soil water suspension on air dried samples. Other chemical analyses completed are discussed in Section 4.

1.2 PREVIOUS WORK

A great deal of background information, some dating back to 1931, exists on the soil and water resources of Taveta District. Most of the reports and papers (some of which were not available for review) relate to areas close to the proposed project site or provide a general overview of the geology, soils and water resources.

There is no record of detailed soil surveys having been carried out in the project area though useful analytical data is provided for similar soils at the Kimala Irrigation Scheme (Kenya Soil Survey, 1976). The same report also furnishes information pertaining to leaching requirements, irrigation water requirements and irrigation frequencies, in addition to details of previous work and the history of irrigation development in Taveta District.

The Swynnerton report (1968) deals specifically with Taveta Estates and provides a rough sketch map of land with potential for irrigation which includes the proposed project area. Though rather short on detailed soils information the report summarises many of the soil related problems, including swamp encroachment from the south and the issue of a more regional approach to the drainage of the estate.

Most of the observations made in the Swynnerton report are still relevant to the present time, particularly in view of the fact that the project site lies on the periphery of swamp land where problems of salinity/alkalinity are most acute.

Papers prepared by A.E. Farrant (1966 and 1972) on drainage aspects of Taveta irrigation schemes were not available for review, though every effort should be made to obtain copies of these documents prior to implementation of the project.

Definitive description of the geology of the area is provided by Bear (see Section 1.3).

Michaelides Consultants provided useful drawings and some background information regarding soils and the location of old irrigation furrows.

1.3 GEOLOGY AND TOPOGRAPHY

The geology of the area is described in detail by Bear (1955). His map shows the project area as comprising mainly calcareous tuffaceous grits with outcrops of biotite garnet gneisses and quartzo-felspathic gneisses at Python and Reata Hills respectively. The latter form upstanding rocky hills with a well defined piedmont footslope.

The tuffaceous grits form a generally level plain with an elevation 710 m asl. The slope is barely discernible (<1%) with a southerly aspect. In the west of the area slopes are slightly steeper at 1-2 per cent. The soils are dominantly brown well structured clays with an overall depth of 120 cm to parent material.

The more elevated areas surrounding the gneissic hills are more limited in extent being confined to a narrow belt of land (piedmont) surrounding Python Hill in the south-centre of the project area. These parent materials impart a coarse texture to the piedmont fan soils. The main constituent is a yellowish red gritty sandy clay loam with a generally weak structure.

A shallow, poorly drained alluvial depression extending from west to east covers approximately 40-50 per cent of the project area. This depression is hydrologically related to the swamp areas west of the Kileo river, Toll Hill, and swamp areas immediately south of Python Hill. In the east and south east wetland areas associated with the Lumi river also extend into the area.

The fringes of the depression are more or less coincident with the 712 m (2,350 ft) contour, as shown on the existing topo-maps, with the better drained areas in the east and north of the project. Maximum slope gradient appears to be south, and south west into the depression.

Evaporation in the depression area exceeds the natural supply of water for leaching resulting in soils that are saline and alkaline. Natural drainage lines south into Lake Jipe are impeded by the gradual silting of channels and outlets resulting in the encroachment of swamp lands from the south into the project area. Surplus irrigation water has naturally contributed to high watertables in these areas with concomitant effects upon the soils.

1.4 NATURAL VEGETATION AND LAND USE

The existing vegetation reflects varying degrees of human interference and both natural and induced drainage problems. The distribution of vegetation associations and their composition does, however, provide a reliable indication of soil type, particularly with regard to salinity and drainage.

The natural vegetation of the area is an open savanna woodland with dominant *Acacia* tree species. Approximately 60 per cent of the project area has been subjected at some time in the past to clearing for the cultivation of sisal. The general decline in sisal production in recent years has resulted in regrowth of *Acacia* species of up to 20 years in age between the rows of sisal.

Natural plant species tolerant of high salinity (halophytes) are common on saline soils and depression areas, providing a means of identifying the limits of the poorly drained soils in the south and east of the project area.

Principal halophytic species include Doum Palms *(Hyphaene* spp.) and *Salvadore persica* (saltbush), associated with perennial grasses dominated by *Digitaria* spp., *Cyperus* spp. and *Cynodon* spp.

On more elevated better drained soils *Acacia mellifera* and *Acacia tortilis* are common, in association with *Aristida* spp. grasses.

Four main vegetation formations are identified. More detailed soil and land use surveys would provide a more reliable indication of their relationship to soil type, drainage and human interference.

Vegetation formation	**Soil type**
- sisal with dense acacia regrowth - sisal with mature (>20 years) regrowth	mostly on well drained clays
- halophytic associations on depression alluviums	halomorphic depression soils
- mixed fringe vegetation on the periphery of the depression	fringe/marginal soils on edge of depression

Approximately 30 per cent of the area is currently cleared of natural bush and secondary regrowth in the centre of the project area for the cultivation of french seed beans using surface irrigation. The principal remaining areas of sisal with secondary regrowth are in the extreme west and east with halophytic associations occurring mainly in the south and east.

SECTION 2

SURVEY METHODOLOGY

2.1 OFFICE METHODS

The ToR stipulate survey requirements consistent with those for detailed soil surveys. Because of the limited availability of field time some of the normal procedures used for detailed surveys had to be circumvented.

There was no general access to air photography of the area. Aerial reconnaissance in a light aircraft only proved to be of limited value.

Base data mainly comprised a 1:50,000 scale topo map (1975), a 1:12,500 scale drawing provided by Michaelides Consultants, a small sketch map included in the Swynnerton report (1968) and the geological map by Bear (1955).

Maps and existing data were reviewed in the office in order to identify the principal landforms. Field observation sites were then located by ground checking; further observation/pit sites were located as the pattern of soil distribution within the area became evident.

Field observations were plotted onto the Michaelides map then transferred to the 1:50,000 scale topo maps enlarged to 1:30,000 scale on a photocopier for final inclusion in the report.

2.2 FIELD METHODS

Routine observations were made using a standard riverside, or five inch Jarrett auger head according to soil conditions. Dutch augers were used in the moist depression soils.

Field procedures adopted at each site were broadly similar, variations in observation density being a function of the complexity of soil distribution.

Detailed surveys normally require an observation density of 1 - 10 ha per site, which, for a 1660 ha site would require approximately 166 observations.

A total of twenty-five auger sites and seven profile pits were described. Auger sites were ordinarily completed to a depth of 1 m; profile pits were excavated to a depth of 2 m.

Sites were located on the ground using free survey techniques, involving the use of external features such as landforms and vegetation to identify the most representative areas. For detailed soil surveys controlled location on traverses will be required, particularly in dense thicket.

All sites were described on standard field proformas, recording colour, texture, structure, consistency, depth, root distribution and drainage characteristics. Supplementary information included geology, vegetation/land use, slope and parent material.

2.3 SAMPLING AND LABORATORY ANALYSIS

Samples were taken at all the auger sites for analysis of pH and EC using 1:5 soil water suspension. The depth of the samples was, ordinarily, 0-25 cm, 25-50 cm, and 50-100 cm. This standard was occasionally varied according to circumstances.

Further samples were taken at six representative pit sites, by horizon, for analysis of:

- texture (sand, silt, clay)
- pH water 1:5
- electrical conductivity of saturation extract
- exchangeable cations (calcium, magnesium, sodium, potassium)
- cation exchange capacity (CEC)
- copper, manganese, zinc and boron
- total nitrogen
- available phosphorus and potassium

All of the pit samples were processed and analysed at the LRDC laboratory at Reading. Samples were also taken of irrigation water for determination of calcium, magnesium and sodium.

2.4 FIELD SOIL TESTS

Ring infiltrometer tests were carried out at sites PT1 and PT5 (in triplicate) using rings fabricated from an oil drum.

Measurements of horizontal saturated hydraulic conductivity using the pour-in auger hole method were also conducted at these sites. The results of these tests are summarised and discussed in Section 5.

2.5 MAPPING

Final mapping for soils and irrigable land suitability classes was completed onto 1:50,000 scale topographic maps enlarged to 1:30,000 scale. Mapping of soil boundaries was interpolated between observation sites visually using vegetation patterns.

SECTION 3

GENERAL DESCRIPTION OF SOIL TYPES AND CLASSIFICATION

3.1 INTRODUCTION

The soils of the area are broadly divided into three distinctive types: the well drained reddish brown - brown calcareous clays developed over calcareous tuffaceous grits; the well drained yellowish red sandy clay loams derived from biotite garnet gneisses; and the poorly drained halomorphic soils of the central depression.

These soils are provisionally classified and mapped using the FAO system.

The main differentiating criteria for the soil mapping units are those properties most relevant to the proposed development, principally soil drainage, degree of salinity/alkalinity, soil texture and structure, and parent material.

3.2 REDDISH BROWN CALCAREOUS CLAYS (Chromic, calcic and vertic luvisols) Map Unit Lc/Lv

The principal soil types considered most suitable for development are the deep well drained strongly structured, dark reddish-brown - brown clays and silty clays developed over calcareous tuffaceous grits. (PT1, PT6 and PT7, Appendix A).

These soils occupy the most elevated part of the catenary sequence north and south of the main irrigation canal.

In the centre of the project area the soils have been surface irrigated to produce french seed beans. In the north west, north east and areas north of the canal the soils support a secondary regrowth, in old sisal fields, estimated to be 20 years in age.

Field observations in profile pits show differences in physical and chemical properties between irrigated (PT1) and non-irrigated (PT6 and PT7) soils. On irrigated land the soil has undergone some structural deterioration. Observation of the degree of aggregation suggests that after a number of years of surface irrigation there is a reduction in overall aggregate size and stability. There is also an increase in exchangeable sodium and salinity at depth.

Soils supporting a 20 year regrowth have a dry strongly structured subsoil with a relatively impermeable weakly structured horizon at 1 m depth.

The soils locally exhibit vertic properties indicating a clay fraction dominated by montmorillonitic clays. Surface cracking is evident in most years to varying degrees.

The soil reaction is very variable ranging form strongly alkaline (observation sites T19, 20 and 22, Appendix B), with very high pH values, to moderately alkaline, and, in places, slightly saline. pH generally increases with depth, lower horizons (50-100 cm) normally having a pH >8.0.

3.3 YELLOWISH RED SANDY CLAY LOAMS (Eutric Regosols) Map Unit Re

These soils occupy an elevated area south of the depression around Python Hill. They comprise a deep, well drained unconsolidated mantle of yellowish red (5YR 4/6) sandy clay loam derived from gneissic parent materials, (PT4, Appendix A). The soils are porous, though weakly structured with an erodible sandy loam topsoil. Poor aggregate stability in surface horizons is due

to the low clay content and low levels of organic matter. Soil pH is neutral (7-7.8) with very low field EC values.

This land is not commandable for surface irrigation but could be utilised for overhead methods.

3.4 WEAKLY STRUCTURED BROWN SILTY CLAY - CLAY LOAMS (Calcic Luvisols) Map Unit Lk

These soils occupy a limited area in the centre of the project site, comprising deep well drained brown (7.5YR 5/4) weakly structured silty clay - clay loams. Surface horizons comprise a very fine silty clay, forming a very fine weakly aggregated dry dust.

Though only occupying a limited area these soils do present special management problems with regard to furrow irrigation. Estate management reported severe difficulties forming ridges on these soils.

The lower permeability, caused by pore blocking, is demonstrated by the results of the field hydraulic conductivity tests. Both permeability and infiltration rates were less than half those on the better structured more porous brown clays.

3.5 HALOMORPHIC SOILS (Depression) (Mollic Solonetz, Sm; Vertic Solonetz, Sv) Map Unit Sm/Sv

The soils of the depression comprise mainly saline and saline alkali alluviums with properties influenced by the presence of soluble salts or sodium ions in the exchange complex, or both. Salinisation of the soil has occurred as a result of the accumulation of soluble salts in the profile by natural processes and the addition of saline drainage water.

The watertable lies within 2 m of the surface resulting in upward migration of salts to surface horizons. Horizons of maximum salt concentration may occur at depth, or at the surface depending on the local level of the watertable, or the degree of leaching.

On the periphery of the depression the soils are saline and very strongly alkaline throughout their depth even though a watertable may not be present. Profile moisture status is, however, influenced by natural seasonal fluctuations in the depth of the watertable within the depression, compounded by the addition of drainage water from surface irrigation upslope.

The saline-alkaline soils of the depression fringes (T13, T15, T16, T21, Appendix B and PT2, PT3, Appendix A) comprise deep moderately well-imperfectly drained clay loam with a black-very dark brown 10YR 2/1-2/2 topsoil, and a brown (7.5YR 5/4) subsoil. Surface horizons display varying degrees of sodium deflocculation which has also resulted in loss of permeability in the textural B horizon. Vertic properties are also present locally.

Field pH and EC values are generally very high, pH levels often exceeding 9.5 (very strongly alkaline) with EC values exceeding 4 mS/cm (1:5 soil water).

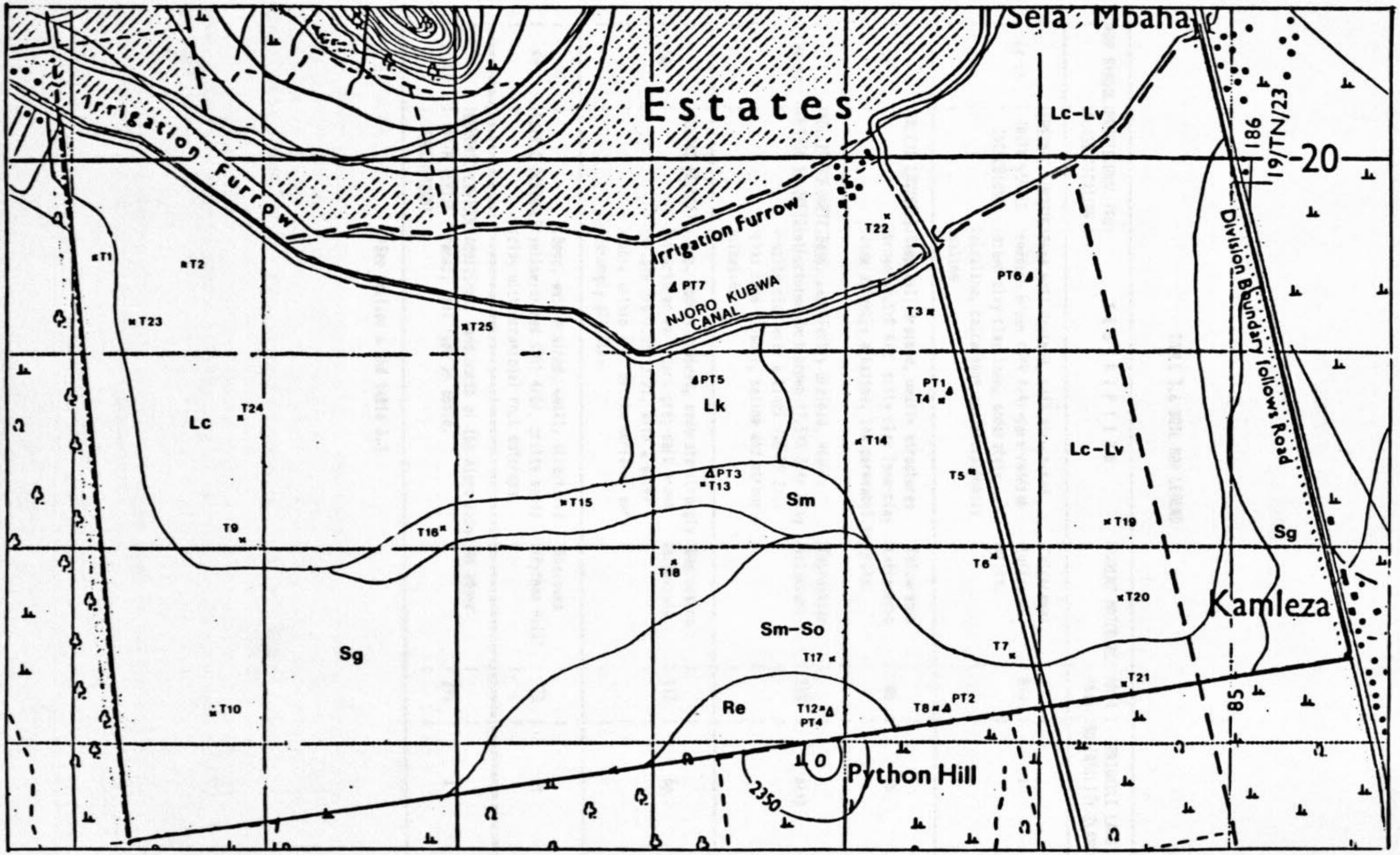
The prismatic structures in the B horizon and high exchangeable sodium percentage (ESP) qualifies these soils for the Solonetz order in the FAO classification system.

3.6 SOIL MAP LEGEND

The distribution of the respective soil types and the location of auger hole and pit sites is shown on the accompanying soil map (see Figure 3.6).

The soil legend is given on the adjoining page with a brief description of the main soil properties. Results of soil chemical analyses from auger hole and pit sites is given in Appendices A and B, and is discussed in detail in Section 4.

FIGURE3.6 RECONNAISSANCE SOIL MAP OF PROJECT AREA SHOWING LOCATION OF PROFILE PITS AND ROUTINE AUGER OBSERVATIONS



Scale 1:30,000

TABLE 3.6 SOIL MAP LEGEND

MAP SYMBOL	PROVISIONAL FAO CLASSIFICATION	DESCRIPTION	PARENT MATERIAL	AREA (ha)	IRRIGABLE LAND SUITABILITY CLASS*
Lc/Lv	CHROMIC LUVISOL (WITH VERTIC INCLUSIONS)	Deep well drained, well structured reddish brown (5YR 4/4)-dark reddish brown clay-clay loam, moderately alkaline, calcareous and occasionally saline	Calcareous tuffaceous grits.	840	1
Lk	CALCIC LUVISOLS	Deep well drained, weakly structured brown (7.5YR 4/2) silty clay loam-clay loam slightly alkaline, low permeability	Calcareous tuffaceous grits.	80	3b
Sm/So	MOLLIC SOLONETZ ORTHIC SOLONETZ	Deep, imperfectly drained, weakly structured dark brown (7.5YR 3/4) clay -silty clay with a black (10 YR 2/1) clay loam topsoil, saline and strongly alkaline.	Depression alluviums	268	6axp
Sg	GLEYIC SOLONETZ	Deep, poorly drained, moderate-strongly structured very dark grey-dark brown (7.5YR 3/0-7.5YR 3/2), with a water table within 1 m. of the surface, very strongly alkaline.	Depression alluviums	447	6p
Re	EUTRIC REGOSOLS	Deep, well drained, weakly structured yellowish red (5YR 4/6), gritty sandy clay with occasional rock outcrops.	Gneisses (Python Hill)	25	2t
Lc/Lv	CHROMIC LUVISOL (WITH VERTIC INCLUSIONS)	Additional land north of the Njoro Kubwa canal, soil type as above.	As above	290	1

*See section 6 and table 6.3

SECTION 4

SOIL CHEMICAL CHARACTERISTICS

4.1 INTRODUCTION

Samples were collected from seven representative profile pits excavated to a depth of 2 m, and from routine auger hole observations dispersed throughout the project area.

Field analyses of texture, EC and pH are supplementary to samples collected (by horizon) from profile pits, and serve to identify soil chemical constraints to the development of irrigated agriculture in the project area. The sites from which samples were taken are marked on the accompanying soil map (Figure 3.6) and results of analyses given in Appendices A and B.

Soil chemical characteristics having the most relevance for irrigation development are:

- pH
- Alkalinity (ESP)
- Salinity (EC)
- Cation Exchange capacity (CEC)

Laboratory analyses also included; trace elements, copper manganese, zinc and boron, and tests for available phosphorus, potassium, total nitrogen and organic carbon.

4.2 SOIL pH

Soil pH (acidity/alkalinity) was measured in a 1:5 soil water suspension in the field using a portable pH meter, and in the laboratory (on profile pit samples only) using a 1:5 soil water suspension and 1:5 potassium chloride solution. The latter tends to yield values somewhat lower, of the order of 1.0 - 2.0 units.

Ranges used for the interpretation of pH data are:

Extremely acid	below 4.5	Neutral	6.6 - 7.3
Very strongly acid	4.5 - 5.0	Mildly alkaline	7.4 - 7.8
Strongly acid	5.1 - 5.5	Moderately alkaline	7.9 - 8.4
Medium acid	5.6 - 6.0	Strongly alkaline	8.5 - 9.0
Slightly acid	6.1 - 6.5	Very strongly alkaline	9.1 +

Soil pH affects the availability of nutrients to plants, though the tolerance limits of different crops varies greatly. For most crops a neutral range is the most suitable with pH values between 6.6 and 7.3.

The proposed development considers maize and french seed beans as the principal crop for the project area. Maximum yields for maize normally occur at pH 6.0 and above. Nutrient deficiencies are least likely to occur where the crop is grown for a maximum yield within the pH range 5.6 to not more than 7.5. Beans generally have a pH tolerance within the same range.

Field determinations of pH values yielded results tending towards the mildly - strongly alkaline, with very strongly alkaline soils occurring in the central depression area and the depression fringe soils.

In the well drained clays (map unit Lc) pH values generally increase with depth, particularly on recently irrigated land (T4, 5 and 6, Appendix B).

pH values greater than 8.5 indicate a high exchangeable sodium percentage, i.e. an exchange complex saturated with sodium ions, and an increasing alkali hazard. Field determinations of pH (Appendix B) provide a broad indication of the distribution of the alkali hazard throughout the project area.

4.3 ALKALINITY

The degree of alkalinity in soils is most commonly expressed in terms of exchangeable sodium percentage (ESP) as a measure of the percentage of the exchange complex occupied by exchangeable sodium. The main effect of high ESP values is the dispersion of clay, causing the soil to be dense and difficult to work, reducing the permeability and infiltration rates, and, in general, making it a poor medium for plant growth.

A soil is considered alkali when the ESP exceeds 15 per cent. Although widely quoted in the literature this value is somewhat arbitrary since the effects of increasing ESP are progressive, and the limit beyond which deterioration in soil structure occurs depends upon the type of clay mineral present.

ESP values obtained for the depression soils were very high >50% PT2 and 3), and generally very low (<2% PT1, 5, 6 and 7) on the well drained clays. Alkalinity in the subsoil increases with depth on irrigated soils and progressively downslope with increasing drainage impedence. Increasing alkalinity is accompanied by observable changes in soil structure and colour (cf. PT 6 and PT3).

Suggested soil amendments for saline-alkali soils are discussed in Section 4.10.

4.4 SALINITY

The quantity, nature and distribution of soluble salts is perhaps one of the most important factors affecting irrigation development.

EC measured in a saturation extract most closely simulates salinity conditions in the root zone, however, this method was impractical for field conditions and the simpler method of determining EC using a 1:5 soil water solution was used. Since the soil solution is more dilute interpretation of field EC data must be multiplied upwards by a factor of approximately 6.4 to obtain an estimated equivalent saturated extract value.

Field and laboratory EC data results are supplied in Appendices A and B.

Both field and laboratory EC data yield very high values for the depression periphery soils in the south and south west of the project area. Profile pits PT2 and PT3 are moderately saline and strongly saline (ECe 8 mS/cm and 36 mS/cm respectively). Other profiles, notably sites T7, 15, 16, 17 and 21 also yielded relatively high values, using a field conductivity bridge. All of these sites are concentrated in or immediately adjacent to encroaching swamp lands.

In evaluating soils for sustained irrigation the importance of the initial level of salt varies according to the ease with which salts can be leached from the root zone. The presence of high salt contents in soils of limited permeability presents particular problems for leaching. In the project area the relatively fine textures occurring in juxtaposition to an extensive area of poorly drained soils will render reclamation difficult and costly.

There is some evidence of increases in subsoil salinity on more recently irrigated land (Site PT1) and sites adjacent to the depression (T7). This indicates that salinity levels are rising from the base of the profiles as groundwater levels within the depression encroach on the better drained soils.

Soils on more elevated sites, particularly the brown calcareous clays generally have very low salinity levels. Provided adequate drainage is provided to prevent salinisation of profiles these soils have very high development potential.

4.5 SALINE-ALKALI SOILS

The USDA (1954) define three soil groups with regard to salinity-alkalinity:

- saline soils
- saline-alkali soils
- non-saline alkali soils

Saline soils have a conductivity of the saturation extract of more than 4 mS/cm at 25°C and an ESP of less than 15. Ordinarily the pH is less than 8.5.

Saline-alkali soils are soils with a conductivity of the saturation extract greater than 4 mS/cm and an ESP >15%, pH is normally >8.5.

Non-saline alkali soils have a conductivity of the saturation extract less than 4 mS/cm and an ESP >15%; pH is in the range 8.5 - 10.0.

Except where appreciable quantities of gypsum are present in the soil the leaching of saline-alkali soils leads to the formation of non-saline alkali soils. This latter group of soils in time develops characteristic morphological features.

The soils of the central depression periphery fall into the saline-alkali group with mainly alkali soils occurring within the depression. Reference to field EC and pH data in Appendix B provides an indication of the distribution of salinity/alkalinity within the project area. More detailed surveys would define the precise soil boundaries of the saline-alkali soil groups.

4.6 EXCHANGEABLE CATIONS

(I) Cation Exchange Capacity

The cation exchange capacity (CEC) is a measure of the ability of the soil to adsorb and retain cations against leaching. It is dependent upon the amount of organic matter present, the type and amount of clay, and pH.

Ratings for the interpretation of CEC values are as follows:

CEC me/100 g of soil	rating
>40	Very high
25-40	high
15-25	medium
5-15	low
<5	very low

Values obtained for project area soils fall into the high-very high range, reflecting the high clay content.

Exchangeable forms of calcium magnesium and potassium constitute the major sources for plant nutrition. Calcium is the dominant cation followed by magnesium potassium and sodium, in descending order. The levels of exchangeable cations and their relationship to each other generally provide a more meaningful indication of fertility than the CEC value per se.

(ii) Exchangeable Calcium, Magnesium and Potassium

Exchangeable calcium levels in the project area are very high and reflect the calcareous nature of the parent material (Section 1.3). Levels of exchangeable potassium are also very high. Interpretation of absolute exchangeable Ca and Mg levels are, however, distorted by the presence of appreciable quantities of free carbonates, which are taken into solution.

Antagonisms may occur between nutrients if the Mg/K ratio is less than two, or the Ca/K ratio is less than five, due to excessive absorption of potassium by the plant.

All the soils in the project area, including the depression soils have exchangeable calcium levels in excess of 50 me/100 g.e.d.s. These values are considerably inflated by the presence of free carbonates, and estimates of possible nutrient imbalances induced by high levels of calcium are not, therefore, attainable.

The high proportion of free calcium in all the soils in the project area may render residual phosphates less available to plants by conversion of phosphate to calcium phosphate. Micronutrients may also be adversely affected, and growing crops should be examined for nutrient deficiency symptoms.

(iii) Exchangeable Sodium

The exchangeable sodium percentage (ESP) is calculated from the exchangeable sodium content as a percentage of the cation exchange capacity. Appreciable quantities of exchangeable sodium occur in the depression and depression fringe soils giving very high ESP values (PT2 and 3). These values would normally be expected to have adverse effects on soil structure.

4.7 ORGANIC CARBON AND NITROGEN

Soil nitrogen is frequently the most important single nutrient element limiting crop yields. The chief natural source of soil nitrogen is decaying organic matter. Clearance of natural forest vegetation and subsequent cultivation generally results in reductions in N necessitating the application of nitrogeneous fertilisers.

Values obtained for project area topsoils are generally moderate in the well drained brown clays (0.17 - 0.21 per cent) to high in the depression soils.

Organic carbon levels in topsoils are low on the well drained soils (1.3 - 1.88 per cent) and low on the depression soils (2.01 - 3.44 per cent).

Carbon nitrogen ratios are of the order of 8 - 10 which are generally considered to be rather low.

4.8 AVAILABLE PHOSPHORUS

Phosphorus is second in importance only to nitrogen as a crop nutrient. Available phosphorus was measured on soil samples using the Bray and Olsen methods. The Olsen method is however more appropriate for soils with pH >7.0.

Established norms for the interpretation of available P data are as follows:

<5 ppm	extremely deficient
5-15 ppm	deficient
15-25 ppm	average
>25 ppm	adequate to high

Measured values on project area topsoils vary from deficient (PT5 and 7) to adequate-high (PT1, 2, 3 and 6). For maize these levels are generally considered to be adequate though under surface irrigation the application of phosphatic fertilisers will be required.

4.9 MICRONUTRIENTS

The soils were analysed for copper, manganese, zinc and boron, using DTPA extractant.

(i) Zinc:

Zinc deficiency is likely to occur when available levels are below 1 ppm. Zinc decreases in availability on soil flooding and disorders are common on calcareous soils with a high pH.

All the project area soils are deficient in zinc with values falling as low as 0.4 ppm in topsoils (PT5) to 0.2-0.3 ppm in the subsoil. Zinc deficiency in maize normally manifests itself in the form of chloritic fading of the leaves with broad whitish areas. These may develop during early maturity.

(ii) Copper:

Maize is particularly sensitive to copper deficiency. Deficiencies are common in soils with less than 1 ppm. Values obtained for the project area soils are satisfactory though availability may be reduced with increasing pH. The range of values tends to be of the order of 2-3 ppm.

(iii) Manganese:

Available manganese not less than 10-15 ppm is essential for normal plant growth. Plant available manganese is dependent upon pH decreasing markedly at approximately pH 7.0 in calcareous soils.

Manganese levels in the project area are adequate in the top 0-50 cm but decrease markedly in the subsoil. Levels range from 18-29 ppm in the topsoil to as little as 2-3 ppm in some subsoils.

(iv) Boron:

Hot water extractable boron determinations were carried out on all profile pit samples. Toxic levels of boron are often present in saline-alkali soils and results show toxic concentrations in excess of 11 ppm in profile PT3 and potentially toxic concentrations in profile PT2. These levels are, however, confined to the lower half metre of subsoil.Levels of boron in the well drained soils are satisfactory for most crops.

4.10 SOIL AMENDMENTS

If reclamation of the saline-alkali soils of the depression and depression fringe is to be considered, certain soil physical and chemical amendments will be required.

Gypsum is the most commonly used amendment to replace sodium in the exchange complex, though irrigation water may sometimes dissolve sufficient calcium to decrease the sodium hazard appreciably. This process may be enhanced by adding acid or acid forming amendments such as sulphur or iron sulphate. These amendments have the overall effect of bringing calcium into the soil solution facilitating the replacement of sodium in the exchange complex.

Applications of gypsum should be accompanied by measures to maintain structure and permeability including deep ploughing, subsoiling and profile inversion. Saline alkali soils are generally flocculated and permeable at the start of reclamation whereas alkali soils are not. Soils within the depression are likely to require different treatments to those on the periphery.

In addition to chemical amendments the only practical means of reducing soil salinity/alkalinity is by leaching. The depth at which the watertable should be maintained depends on the hazard of upward movement of salts; the range of depth recommended for maize and beans is 1.5-2.0 m.

4.11 IRRIGATION WATER QUALITY

Analysis of irrigation water from Homers and Njoro Kubwa springs gave results in the C2-S1 range using the USDA classification for irrigation water. This gives water of medium salinity hazard and low sodium hazard, which can be used if a moderate amount of leaching occurs. EC levels in profiles on existing irrigated lands show increased in EC with depth. Over a period of time these salts are likely to build up to harmful levels in the root zone unless provision is made for field drainage.

Analysis of drainage water at site T18 shows medium-high salinity drainage water with high levels of sodium. Results of the water analyses are given in Appendix E.

4.12 AGRONOMICS

The proposed development anticipates a maize culture followed by french seed beans using surface irigation.

(i) Maize

Maize generally requires a more fertile soil for good yields than most other crops having a particularly high uptake of nutrients, particularly potassium. The most significant elements for nutrient availability to maize are pH, organic carbon, P(Olsen), exchangeable potassium and nitrogen.

Nitrogen is the most important nutrient though this may interact significantly with irrigation and plant populations. Ammonium ions are preferred over nitrate ions by the young maize plant but at a later stage nitrate ions are taken up much more readily, some from organic sources.

Because the maize plant uses nitrogen throughout its growth period applications of nitrogenous fertilisers will be required at Taveta at an approximate rate of 70 - 120 kg/ha.

Though P levels are adequate in some profiles maintenance applications of P_2O_5 are recommended under surface irrigation at a rate of 45-80 kg/ha. P responses in maize are, however, difficult to predict because of other interrelated factors. Large applications of P may induce zinc deficiency; P uptake may also be adversely affected by excessive levels of calcium.

Responses to applications of K_2O are not considered likely in view of the very high residual levels of potassium.

Generally, because of their high fertility status the brown clays are well suited to a maize culture. On the marginal soils subsoil waterlogging, salinity/alkalinity and boron toxicity will limit production.

(ii) French seed beans

Under irrigated conditions applications of N at a rate of approximately 70-80 kg/ha are recommended with 50-60 kg P_2O_5 per ha. Supplementary side dressings of N are recommended at a rate of 20-30 kg/ha. Nitrogen requirements can, however, be substituted by treating the seed with the correct race of RHIZOBIUM inoculant if available.

Full benefits from fertiliser applications will be accrued mainly from good seedbed preparation, favourable moisture conditions and efficient control of pests and weeds. For maize delayed planting before the rains tends to reduce yields significantly often leaving young plants growing in saturated soils.

In addition to chemical amendments the only practical means of reclaiming soil salinity/alkalinity is by leaching. The depth at which the watertable should be maintained depends on the hazard of upward movement of salts; the range of depth recommended for maize and beans is 1.5-2.0 m.

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Analysis of drainage water at site T18 shows medium-high salinity drainage water with high levels of sodium. Results of the water analyses are given in Appendix 5.

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Full benefits from fertiliser applications will be accrued mainly from good seedbed preparation, favourable moisture conditions and efficient control of pests and weeds. For maize delayed planting before the rains tends to reduce yields significantly, often leaving young plants growing in saturated soils.

SECTION 5

SOIL PHYSICAL PROPERTIES AND MANAGEMENT

The physical properties of the principal soil types identified were evaluated visually in the field according to FAO guidelines whilst workability was qualitatively assessed during pit excavation and infiltration tests.

Time constraints did not permit a detailed investigation of the physical properties of the soils in the field or the laboratory.

In order to facilitate evaluation of the soils for development of surface irrigation a number of assumptions are made using information extracted from standard tables and available technical literature. These are discussed below under separate but interrelated headings.

5.1 SOIL AGGREGATION

Soil aggregation is the process whereby a number of soil particles are held together to form units or peds of varying characteristic shapes. Stability of the aggregates is dependent upon clay content, organic matter and degree of cementation. The presence of sodium in appreciable quantities on the exchange sites weakens the bonding between clay particles causing deflocculation. Aggregates thus become soft floury and generally unstable on wetting dry soil.

Of the principal soil types, particularly around site PT3 (see Appendix A) and on the margins of the depression (T15 and T16, Appendix B) deflocculation of surface horizons is evident. Eluviation of clay particles into lower horizons has contributed to loss of pore space and a general deterioration of soil structure (PT3, PT5, Appendix A). Cultivation in very dry conditions thus results in the production of many dust particles.

The gradual decline in waterstable aggregates precipitated by this process is also evident when comparing profiles excavated on more recently irrigated land with profiles opened on later abandoned irrigated land.

5.2 SOIL STRUCTURE

Soil structure is the combination or arrangement of primary soil particles into secondary particles, units or peds. These units are characterised and classified on the basis of size, shape and degree of distinctness into classes, types and grades respectively. The solid structure of the peds or aggregates is less important than the spaces between them through which roots may penetrate.

Soil structure also determines the level of compaction with resultant effects upon the infiltration of applied moisture.

The strongly structured brown clays generally have favourable structural properties to a depth of 1 m with medium-coarse sized peds between which roots can easily penetrate. Cracks and surfaces of weakness that separate natural aggregates are generally well developed, and though the peds are relatively dense they readily absorb applied moisture.

Soil structure is poorly developed in the halomorphic soils (PT3, Appendix A). Distinct peds are almost absent on exposed soil faces and the soil contains many fine pores too small for root penetration which do not readily release soil moisture to plants.

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Of the principal soil types, particularly around site PT8 (see Appendix A) and on the margins of the drainage lines (PT5 and PT10, Appendix B) deflocculation of surface horizons is evident. Eluviation of clay particles into lower horizons has contributed to loss of pore space and a general deterioration of soil structure (PT5, PT8, Appendix A). Cultivation in very dry conditions thus results in the production of many dust particles.

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Soil structure is poorly developed in the halomorphic soils (PT5, Appendix A). Distinct peds are almost absent on exposed soil faces and the soil contains many fine pores too small for root penetration which do not readily release soil moisture to plants.

In some areas however, these soils exhibit strong structure with polygonal cracking (vertic properties) in surface horizons.

Under surface irrigation topsoil structure is ephemeral and unstable, particularly if sodium is present in the soil. Whereas tillage practices aim to improve deficiencies in topsoil structure this can have the opposite effect resulting in enhanced dispersion and eluviation of clay particles. Soil aggregates become smaller, clog larger pores and reduce infiltration.

5.3 WORKABILITY

Workability is a function primarily of soil consistence, density, structure, moisture content and aggregate stability. Some of these attributes can be controlled directly or indirectly using surface irrigation.

The clayey soils of the project area have a generally sticky and plastic consistence rendering them difficult to manage when wet. Careful management of irrigation applications is therefore required to ensure that land preparation techniques minimise soil structural deterioration, principally through the effects of smearing when the soil is too wet.

Workability may also be limiting during and after the rains. Tillage during this period should be limited to days when the soil is moist (but not wet) and friable to achieve optimum working conditions.

In a moist condition the soils are firm - friable depending on clay content and levels of organic matter. Topsoils under mature regrowth generally tend to have more favourable workability characteristics.

Clayey soils are easily formed into ridges, though some soil structural deterioration is anticipated over time. On the calcareous soils with unstable topsoil structures maintenance of ridges will be more problematic(see section 3.4). Relatively low ridges (15 cm) are recommended to avoid accumulation of harmful salts on the apex of the ridge during the early growth stages. Field experimentation would be required to determine the optimum spacing but 80-90 cm may be used as a rule of thumb.

Timely subsoiling and/or ripping will help to alleviate panning and facilitate the downward penetration of applied moisture and leaching fractions.

5.4 MOISTURE RETENTION AND AVAILABILITY

The available water capacity (AWC) of a soil is that portion of the total waterholding capacity which is available to roots to sustain plant life. The principal forces which restrict the uptake of moisture are caused chiefly by surface tension within the soil pores and osmotic tension due to salts dissolved in the soil solution.

Laboratory data on available moisture at different suctions was not determined on the soils at Taveta. However, based on field texture and particle size class data, AWC was determined as a depth of water per unit depth of soil from standard tables.

Most of the soils in the Project area have high available water capacities. Indicative values for silty clay loam - clay loams are of the order of 150 - 170 mm/m of soil. Given that the textural profile is relatively uniform from the surface these values can be taken as indicative of all horizons with a clay loam - silty clay loam texture.

Because of a preponderance of smaller pores in some of the finer textured silty clay loams, which release water more slowly, drainable water capacity is reduced. This reduces the leachability of soils with less favourable macro and micro structural properties, particularly the halomorphic soils.

From the point of view of irrigation management, it remains important that soil water tensions are kept low if crop moisture stress is to be maintained within reasonable limits. Laboratory determinations of available water capacity based on matric suctions in combination with osmotic suctions are required if this objective is to be achieved.

5.5 INFILTRATION

Infiltration refers to the vertical intake of water into a soil at the soil surface.

Ring infiltration tests can only provide a broad indication of soil behaviour under surface irrigation. Basic rates determined by this method can be expected to decrease with time with successive irrigations.

Ring infiltration test results are also often skewed with a greater chance occurrence of relatively high rates.

Two ring infiltration tests were conducted (in triplicate), using water from the main feeder canal, at pit sites PT1 and PT5. Site 1 was slightly moist, site 5 dry throughout.

The field methodology used is described in Appendix C and the results summarised and related to soil types and textures in Table 5.6. Curves of cumulative infiltration and intake rates are illustrated in Appendix C.

Basic infiltration rates >6.5 cm h^{-1} are normally considered marginal for surface methods. Measured rates at site PT1, which were in excess of 10 cm h^{-1}, would be expected to decrease with cropping. The FAO (1979a) cites an upper limit of 10-12 cm h^{-1} for surface methods.

Excessive losses through deep percolation would not be considered problematic in this case and basic intake rates are considered to be within an acceptable range for surface methods.

Measured rates at test site PT1 were optimum for surface irrigation (3.5 cm h^{-1}).

Infiltration is aided by large pores and favourable soil structure and is therefore a particularly sensitive indicator of changes in soil structure and porosity. Variations in basic infiltration rates between individual tests and different soil types are, therefore, indicative of differences in texture, structure and porosity within the main soil groups. The slower rates at site PT5 compared to site PT1 reflect the generally weaker structural properties and reduced permeability.

Prior to development more detailed investigation of infiltration rate variation within and between the different soil types is recommended, particularly on the virgin calcareous brown clays and soils affected by sodium deflocculation.

5.6 SUBSOIL PERMEABILITY AND DRAINAGE CHARACTERISTICS

Soil permeability is that quality of a soil that enables it to transmit water or air. When defined quantitatively the term hydraulic conductivity (K) expressed in m/day is used as an indication of the drainability of the soil.

Within the depression the watertable lies within 2.0 m of the soil surface. In the south west standing water is present on the soil surface. Although locally distorted by irrigation the watertable is a natural feature related to swamp areas west of Toll Hill in the south west of the project area, and the Kimorigo irrigation scheme in the south east.

Detailed drainage investigations were not carried out at these sites but observation in auger hole and profile pit sites show the substratum to be comprised of heavy clay soils with a

TEST SITE	SOIL CLASS	TEXTURAL PROFILE	SOIL MOISTURE STATUS AT START OF TEST	AV. INF RATE AFTER 4 HRS (cm/hr)	BAS. INF. RATE AFTER 4 HRS (cm/hr)	INFILT. CATEGORY	DEPTH OF MOISTURE PENETRATION (cm) AT TERMINATION OF TEST	SURFACE TREATMENT	REMARKS
PT1	Lc	0-25 SiC 25-70 SiC 70-125 SiC 125-170SiC	SLIGHTLY MOIST SURFACE IRRIGATED 3 WEEKS BEFORE START OF TEST.	10.64	8.0	MOD. RAPID	102	LIGHTLY DUG WITH HOE BEFORE START OF TEST	MODERATELY WELL STRUCTURED POROUS CLAYS ALLOWING GOOD MOISTURE PENETRATION
PT5	Lk	0-15 SiC 15-50 SiC 50-110 SiC 110-160SiC	DRY SOFT IN SURFACE HORIZONS, DRY AND SLIGHTLY HARD IN LOWER HORIZONS	3.79	2.5	MOD.	62	LIGHTLY DUG WITH HOE BEFORE START OF TEST	WEAKLY STRUCTURED POWDERY SURFACE

TEST SITE	INITIAL K. m/day	PERMEABILITY CLASS	FINAL K AFTER 80 MINS. m/day	PERMEABILITY CLASS
PT1	1.2	MODERATE	0.35	MOD. SLOW
PT5	0.8	MODERATE	0.16	SLOW

TABLE 5.6 SOIL INFILTRATION AND POUR-IN HYDRAULIC CONDUCTIVITY TEST RESULTS.

slow - moderately slow (0.05-0.5 m/day) K value. Detailed drainage studies would be required on these lands prior to reclamation.

To determine the hydraulic characteristics of the better drained soils in the north of the project site where the watertable is absent, pour-in tests were carried out at sites PT1 and PT5. The results show a generally slow - moderately slow permeability (see Table 5.6) requiring relatively close drain spacings.

Under surface irrigation, even on more elevated lands, the slow subsoil permeabilities could produce associated drainage problems of the root zone, with watertables rising to unacceptable levels, particularly along the southern boundary of the project area.

There is no evidence in profile pits of subsoil waterlogging on existing irrigated areas though further investigation is recommended. However, it is considered likely that field drainage would be required on these lands to ensure waterlogging of the root zone, by temporary rise of watertables, would be avoided.

Since the irrigation water is slightly saline (250-400 μS/cm) the soil solution will become more concentrated as evapotranspiration depletes soil moisture below field capacity. As a consequence the EC of the soil water will rise and leaching will be required, necessitating removal of leaching water by drainage.

With regard to drainage, successful development of the area will be dependent upon:

- design of a suitable drainage system to prevent watertables rising in the more elevated soils in the north of the project site;

- design of a suitable system for removing surplus water through the depression area and beyond the estate boundaries. Without this the encroachment of swamp areas from the south into the project site can be expected to continue;

- monitoring of groundwater levels and subsoil salinity/alkalinity to ensure the continued maintenance of a favourable medium for plant growth;

- detailed topographic surveys: field evaluation of topography indicates the main drainageways will be south west and south east.

SECTION 6

LAND SUITABILITY FOR IRRIGATION

6.1 INTRODUCTION

Land classification is the systematic appraisal of lands and their designation into land classes on the basis of similar physical and economic characteristics. Within each land class there are subclasses which identify the deficiency or deficiencies.

Many land classification systems for irrigated agriculture are based on the comprehensive system developed by the United States Bureau of Reclamation (USDI, 1953) for the specific purpose of establishing the extent and degree of suitability of lands for sustained irrigation. Fundamental consideration are the productive capacity of the land, the costs of crop production and land development, associated with the physical factors of soil, topography and drainage.

It is not always appropriate, however, to apply this system rigidly to areas outside the US. It is often necessary to modify details of the physical and economic criteria adopted if the resulting land classification is to be of maximum value.

Provided the necessity for these modifications can be justified within the context of the project area, and that fundamental concepts of the land classification system are adhered to, the USBR system provides a valuable though flexible framework for irrigated land classification studies.

Its application is advocated at Taveta in anticipation of more detailed soil and land classification surveys being required in the future.

The definition of the land classes is summarised below:

Class 1 Lands that are highly suitable for irrigation farming, being capable of producing sustained and relatively high yields of a wide range of climatically adapted crops. These lands potentially have a relatively high payment capacity.

Class 2 Lands of moderate suitability for irrigation farming, being measurably lower than Class 1 in productive capacity. They are not so desirable nor of such high value as lands of Class 1 because of certain correctable or non-correctable limitations. The Class 2 lands have intermediate payment capacity.

Class 3 Lands that are suitable for irrigation development but are approaching marginality for irrigation and are of distinctly restricted suitability because of more extreme deficiencies in the soil, topographic or drainage characteristics than those described for Class 2 lands. under proper management Class 3 lands are expected to have adequate payment capacity.

Class 4 Lands are included in this class only after special economic and engineering studies have shown them to be arable. They may have an excessive, specific deficiency or deficiencies susceptible of correction at high cost, but are suitable for irrigation because of contemplated intensive cropping such as vegetables or fruits. In addition, they may have one or more excessive non-correctable deficiency thereby limiting their utility to meadow, pasture, orchard or other relatively permanent crops. Class 4 lands may have a range in payment capacity greater than that for the associated arable lands.

Class 6 Lands that are considered non-arable under the existing project or project plan because of failure to meet the minimum requirements for the other classes of land. Class 6 lands do not have sufficient payment capacity to warrant consideration for irrigation.

6.2 LAND CLASS CRITERIA

The framework of the Land Classification System is based on the system developed by the United States Bureau of Land Reclamation (1953), modified where necessary to accommodate local conditions. The general soil conditions specified by the USBR for profitable sustained irrigation are used to classify the lands in the Project Area. However, only those conditions that are considered particularly limiting in the area are isolated as primary criteria and given a coding in the sub-class legend. Soils, for example, must have an adequate supply of plant nutrients and a favourable cation exchange capacity. The base status of the soil parent materials is adequate to maintain this nutrient supply in all the soils of the Study Area. Thus it is not considered necessary to isolate nutrient supply or inherent soil fertility as a limiting factor for irrigated agricultural development. Nevertheless, it is likely that yields from all soils would be improved if dressings of nitrogen and phosphate were applied. The primary criteria used to differentiate land subclasses are shown in Table 6.3 and described below in detail.

6.2.1 Soil

After reviewing the physical characteristics of the soils and their immediate environment, the following primary criteria were selected and given a letter or numerical subscript indicating the nature and degree of limitation.

Soil texture	s
profile drainage	p
effective depth	d
soil structure	b
alkalinity	a
salinity	x

(i) Soil texture (s)

Soil texture influences bulk density, pore space, permeability, profile drainage, structure, available moisture capacity and infiltration rate of a soil.

Textures in all the major soil groups are generally clayey with high water holding capacities. Soil texture is not therefore considered limiting.

(ii) Profile drainage (p)

This factor comprises entry into and passage through the soil by water, and is related to soil texture, structure and clay mineralogy. Where extensive wet season flooding occurs or where high groundwater levels occur the land is downgraded.

The soils in the project area are poorly drained in the south and east, passing into imperfectly drained on the depression periphery to well drained in the more elevated areas.

(iii) Effective depth (d)

The depth of soil that will allow adequate root expansion is an important factor to be considered in selecting land for irrigation.

Effective soil depth was determined from maximum limit of auger penetration, but was also assessed in profile pits.

Two types of limiting layer are identified in the project area; tuffaceous grits and impermeable clay horizons.

Classes for soil depth to a limiting layer are given as:

Very deep	> 100 cm
deep	75 - 100
mod. deep	50 - 75
shallow	25 - 50
very shallow	< 25 cm

All the soils in the project area fall into the very deep (> 100 cm) category though parent material is present within 60 cm (mod. deep) of the surface on the north west side of the project area.

Relatively impermeable horizons (> 100 cm depth) in the brown clays (PT7) may present limitations for drainage.

(iv) Soil structure (b)
Soil structure is included as a possible limitation because of the adverse effects of sodium deflocculation. Where structural deterioration was observed land has been downgraded.

(vi) Alkali hazard (a)
The alkali hazard in soils is expressed in terms of exchangeable sodium percentage (ESP) and is the percentage of the cation exchange capacity occupied by exchangeable sodium.

Conventionally, a soil is considered to have an alkali hazard when ESP exceeds 15, although the threshold value of ESP for a decrease in permeability depends upon the type of clay mineral present.

Class limits for land classes 1, 2 and 3 were set at ESP values of 5, 10 and 15 respectively. In the final assessment ESP values were found to be very high though the limitations imposed are of varying severity.

(vii) Salinity (x)
Analyses of soil samples has shown that natural salinity levels in the project area are quite high. The quality of the irrigation water is slightly saline, and, provided sufficient water is applied to meet the leaching requirements, coupled with good drainage in the subsoil, then salinity build-up subsequent to irrigation should be reduced.

Class limits have been defined for each irrigable land suitability class although in practice salinity is correctable by leaching.

6.2.2 Topographic Factors

(i) Slope (t)
This factor refers to the slope at the investigation site in percent. The quantitative slope classes used are shown in Table 6.3.

Except for the area around Python Hill and a small area in the west slopes generally do not exceed 1 per cent. Slopes in the west of the project area are 2 per cent and around Python Hill 1-2 per cent>

(ii) Flood hazard (f)

The flood hazard is most common in the east and south west of the Project Area where waterlogging in the surface is present. Flooding due to local seepage from the canal appears to be significant in some parts of the project area in addition to drainage water from smallholder irrigation plots.

(iii) Runoff, erosion hazard (e)

Erosion was virtually absent in the project area though the implementation of suitable conservation measures may be required during development.

6.2.3 Derived Characteristics

(i) Available water holding capacity (AWC)

AWC is a particularly important soil characteristic used in day to day irrigation scheduling and management. Detailed laboratory evaluation prior to development is, therefore, considered to be of paramount importance.

The soils of the project area are generally of relatively uniform texture (clay loam - silty clay loam) with favourable water retention characteristics. Coarser textured soils may present particular problems of deep percolation and excessive leaching of fertilisers. This may become a problem if soils derived from gneissic parent materials are utilised.

(ii) Subsoil permeability

Class limits for topsoil permeability have been set at 0.3 - 0.1 m/day. In the subsoil limits are set at 0.01 - 0.03 (slow - moderately slow conductivity classes). Detailed drainage investigations will be required to refine these limits further.

In the project area preliminary indications are that the generally clayey substratum in both the well drained and poorly drained soils will require relatively close drain spacings because of the low subsoil hydraulic conductivity.

(iii) Infiltration

Basic infiltration rates provide a useful indication of suitability for surface irrigation though only two tests were possible in the time available.

Class limits are set in Table 6.3 but require further field investigation. The FAO quotes 12.5 cm h-1 as the upper limit for surface irrigation. Measured rates achieved upto 10.5 cm h^{-1} on existing irrigated land.

6.3 ALLOCATION OF LAND SUITABILITY CLASSES

Land suitability classes based on the criteria discussed in Chapter 6 have been assigned to each of the soil mapping units.

Land suitability subclasses have been used and divisions are distinguished by the nature of the limitations.

The irrigable land suitability map is shown as Figure 6.3 and the proposed framework (Table 6.3) and accompanying legend is tentatively proposed for future more detailed soil survey and land classification work.

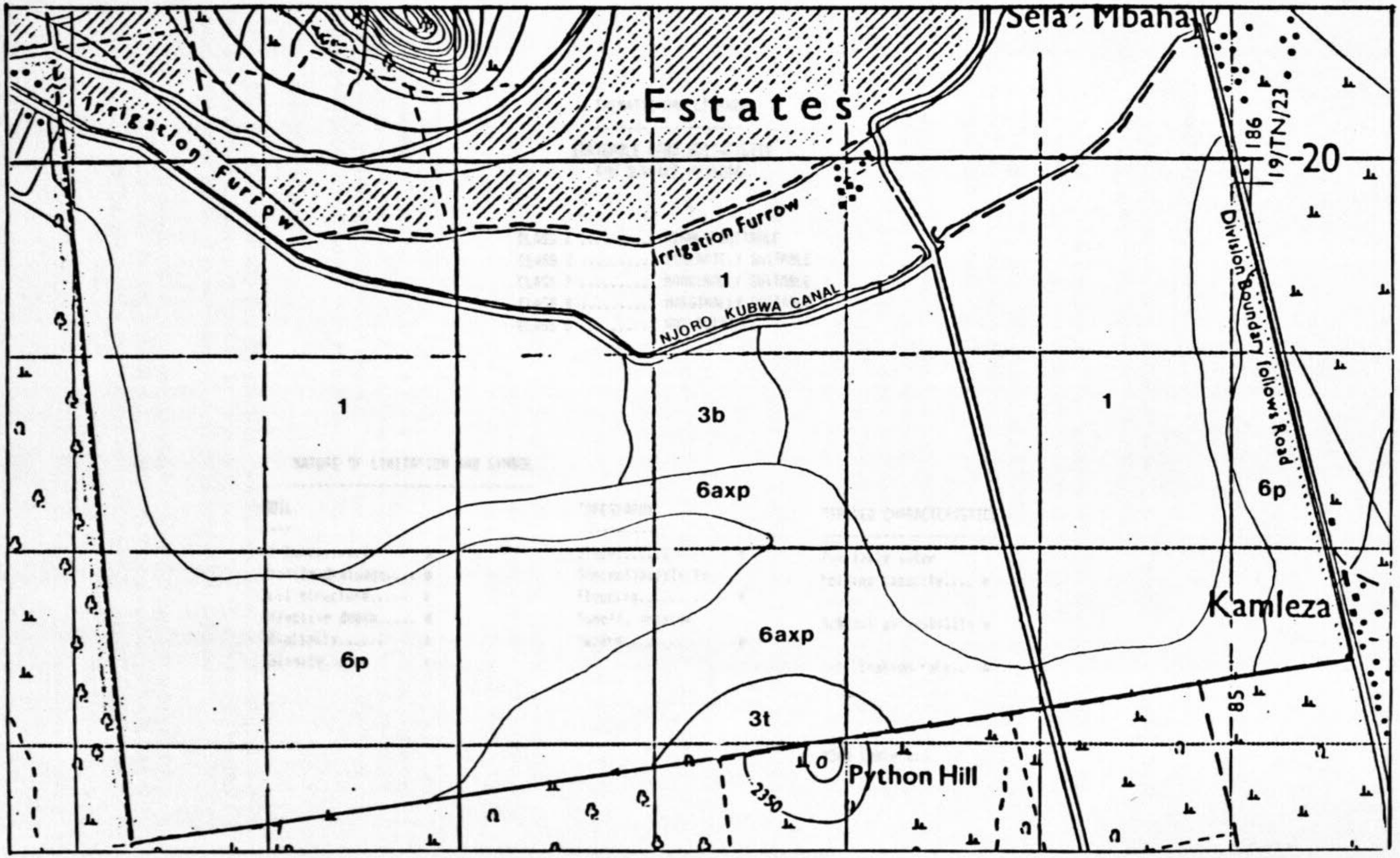
TABLE 6.3 PROVISIONAL LAND SUITABILITY SPECIFICATIONS FOR SURFACE IRRIGATION AT TAVETA ESTATES, KENYA.

LAND CHARACTERISTIC	SYMBOL	CLASS 1 HIGHLY SUITABLE	CLASS 2 MODERATELY SUITABLE	CLASS 3 MARGINALLY SUITABLE	CLASS 4	CLASS 6 NOT SUITABLE
SOIL						
Texture	t	Fine sandy loam to clay or medium texture	Med. sandy loam-permeable clay	Loamy sand (less than 15% clay) to slightly permeable clay	Variable loamy sand-permeable clay	Land which fails to meet the minimum requirements of other classes.
Profile drainage	p	Well-excessively well	Moderately well or better	Imperfect	Poor-very poor	-
Soil structure	b	Well structured	Well-moderately well	Moderately well	Serious problem with sodic hardpan	-
Effective depth (to rock or impermeable clay)	d	>0.9m	0.6 to 0.9m	0.3-0.6m	-	-
Alkalinity (exchangeable sodium percentage ESP)	a	0-5%	5-10% from 1m -1.5m	10-15% to 1.0m 15-25% from 1-1.5m	>15%	>15%
Salinity (ECe mS/cm sat extract)	s	<4mS/cm	4mS/cm to 1m, 4-8mS/cm 1-1.5m	4-8 mS/cm from 0.5-1.0m, 8 mS/cm from 1.0-1.5m	8-12 mS/cm	>8 mS/cm
TOPOGRAPHIC FACTORS						
Slope	t	<2%	<2%	<4%	Variable	-
Susceptibility to flooding	f	None	Slight	Periodic but relatively infrequent floods of short duration.	Serious	-
Runoff erosion hazard	e	None	Occasional	Frequent	Frequent	Frequent

TABLE 6.3 PROVISIONAL LAND SUITABILITY SPECIFICATIONS FOR SURFACE
(cont.) IRRIGATION AT TAVETA ESTATES, KENYA.

DERIVED CHARACTERISTICS						
Available water holding capacity (AWC) mm/m of soil	m	120	80-120	50-80	-	-
Permeability in upper 1.0m (m/day)	m	0.3-0.10	0.3-0.10	Less than 0.03	-	-
Permeability in subsoil (m/day)	m	0.03-0.10	0.01-0.03	Less than 0.01	-	-
Basic infiltration rate (cm/hr).	m	0.7-3.5	3.5-6.5	6.5-12.5	12.5-25.0	>25.0

FIGURE 6.3 PRELIMINARY IRRIGABLE SUITABILITY MAP FOR PROJECT AREA



Scale 1:30,000

SECTION 7

CONCLUSION

7.1 DEVELOPMENT POTENTIAL

The objective of field surveys at Taveta Estates was to demarcate and classify lands considered to have potential for development of surface irrigation.

The terms of reference emphasise, in particular, identification of areas considered less suitable for development due to high watertables and the associated problems of salinity/alkalinity.

Table 3.6 gives the approximate areas of land suitability classes relative to soil type, and, by reference to Table 6.3 the nature of the limitations. Attention is also drawn to the soil map and preliminary irrigable suitability maps (Figure 3.6 and Figure 6.3 respectively).

These results show that of the 1,660 ha of commandable land south of the Njoro [illegible] canal approximately 840 ha (51 per cent) of the area is Class 1 (land highly suitable for surface irrigation) typified by profiles PT1, 6 and 7. Inclusion of similar soils between the existing canal and the old irrigation furrow adds a further 290 ha. This additional area, however, will necessitate the pumping of water to higher elevations. Similar sites further [illegible] could be investigated if the area for cropping is to be expanded.

The yellowish red soils around Python Hill, by virtue of their rather limited extent and topographic position, are not considered to have high development potential for surface irrigation.

The distribution of saline/sodic soils is determined by localised drainage impedance, local seepage from irrigation canals, small scale irrigation, and topographic position. The more poorly drained soils occur in the south west and east. Overall it is estimated that up to 715 ha of land is affected by salinity/alkalinity and/or high watertables. Approximately 290 ha of well-imperfectly drained soils appear to be severely affected by sodicity with resultant structural deterioration. Reclamation of these soils will be dependent upon improved drainage for leaching and application of gypsum.

Principal soil chemical constraints to development are mainly confined to the poor-imperfectly drained soils in the south of the project area. These constraints are mainly related to salinity/alkalinity in depression fringe soils and alkalinity with a high watertable within the depression.

On the well drained sites high levels of calcium may render phosphate and micronutrients less available to plants and careful monitoring of nutrient deficiencies in growing crops will be required. These soils are otherwise considered highly fertile and well suited to the proposed development. Interpretation of chemical data must not however be considered as a static phenomenon but will change under the proposed land use.

7.2 AREAS OF CONCERN

The Swynnerton report (op. cit) accurately summarises some of the existing and potential problems associated with, or likely to be associated with, the rehabilitation of irrigated agriculture at Taveta Estates. The more salient points may be summarised as follows:

- The general rise in soil water levels backing up to an increasing extent from the south into the estate is well documented. The principal cause of this is seen to be the natural silting of Lake Jipe, and inadequate drainage of irrigation water.

THEMATIC MAP LEGEND*

IRRIGABLE LAND SUITABILITY
FOR SURFACE METHODS

CLASS 1 .... HIGHLY SUITABLE
CLASS 2 .... MODERATELY SUITABLE
CLASS 3 .... MARGINALLY SUITABLE
CLASS 4 .... MARGINALLY SUITABLE
CLASS 6 .... NOT SUITABLE

NATURE OF LIMITATION AND SYMBOL

SOIL
Texture........ s
Profile drainage.... p
Soil structure.... b
Effective depth..... d
Alkalinity..... a
Salinity..... x

TOPOGRAPHY
Slope....... t
Susceptibility to
flooding........ f
Runoff, erosion
hazard..... e

DERIVED CHARACTERISTICS
Available water
holding capacity.... m
Subsoil permeability m
Infiltration rate.. m

*See table 6.3

SECTION 7

CONCLUSION

7.1 DEVELOPMENT POTENTIAL

The objective of field surveys at Taveta Estates was to demarcate and classify lands considered to have potential for development of surface irrigation.

The terms of reference emphasise, in particular, identification of areas considered less suitable for development due to high watertables and the associated problems of salinity/alkalinity.

Table 3.6 gives the approximate areas of land suitability classes relative to soil type, and, by reference to Table 6.3 the nature of the limitations. Attention is also drawn to the soil map and preliminary irrigable suitability maps (Figure 3.6 and Figure 6.3 respectively).

These results show that of the 1,660 ha of commandable land south of the Njoro Kubwa canal approximately 840 ha (51 per cent) of the area is Class 1 land (highly suitable for surface irrigation) typified by profiles PT1, 6 and 7. Inclusion of similar soils between the existing canal and the old irrigation furrow adds a further 290 ha. This additional land, however, will necessitate the pumping of water to higher elevations. Similar sites further north should be investigated if the area for cropping is to be expanded.

The yellowish red soils around Python Hill, by virtue of their rather limited extent and topographic position, are not considered to have high development potential for surface irrigation.

The distribution of saline/alkali soils is determined by localised drainage impedance, local seepage from irrigation canals, small scale irrigation, and topographic position. The more poorly drained soils occur in the south west and east. Overall it is estimated that up to 715 ha of land is affected by salinity/alkalinity and/or high watertables. Approximately 260 ha of well-imperfectly drained soils appear to be severely affected by sodicity with resultant structural deterioration. Reclamation of these soils will be dependent upon provision of drainage for leaching and application of gypsum.

Principal soil chemical constraints to development are mainly confined to the poor-imperfectly drained soils in the south of the project site. These constraints are mainly related to salinity/alkalinity in depression fringe soils and alkalinity with a high watertable within the depression.

On the well drained clays high levels of calcium may render phosphate and micronutrients less available to plants and careful monitoring of nutrient deficiences in growing crops will be required. These soils are otherwise considered highly fertile and well suited to the proposed development. Interpretation of chemical data must not however be considered as a static phenomenon but will change under the proposed land use.

7.2 AREAS OF CONCERN

The Swynnerton report (op. cit) accurately summarises some of the existing and potential problems associated with, or likely to be associated with, the rehabilitation of irrigated agriculture at Taveta Estates. The more salient points may be summarised as follows:

- The general rise in soil water levels backing up to an increasing extent from the south into the estate is well documented. The principal cause of this is seen to be the natural silting of Lake Jipe, and inadequate drainage of irrigation water.

The relative contribution of these elements and the extent of encroachment in recent years warrants further investigation.

- As a consequence of rising watertables the development of salinity/alkalinity is seen as a major constraint to irrigated cropping in the south of the estate without the provision of field drainage.

- Utilisation of soils in the upper irrigable areas will further contribute to the problems on lower lying areas and in the depressions unless a suitable drainage system is designed.

- Implementation of a drainage scheme will undoubtedly have a major impact on small scale irrigation within and beyond the estate boundaries.

Successful implementation of the low cost irrigation scheme at Taveta Estates will, therefore, be dependent upon the design of an appropriate drainage system, and a high level of irrigation management. Swynnerton's proposals to overcome the existing and potential problems are reiterated here with some qualification based on recent field visits.

- It would be unwise to consider land which does not command sufficient elevation for deep main drainage or have sufficient gradient to be able to remove surplus water effectively from fields.

- Soils which do not command such a topographic position could be reclaimed by leaching, application of soil amendments such as gypsum, and provision of drainage to lower groundwater levels in depression areas. This solution may well prove to be not feasible on grounds of cost. However some provision must be made for drainage of depression areas in the south if surplus water from more elevated sites is to be removed.

- A more regional view of drainage is required if rising groundwater levels are not to have adverse affects in areas otherwise considered suitable for development. A detailed soil and topographic survey would identify potential problem areas.

To accomplish these objective will require:

- detailed soil surveys with particular emphasis on furrow tests, drainage design and classification of land for irrigation;

- detailed topographic survey and identification of main drainage lines;

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APPENDIX A

SOIL PROFILE DESCRIPTIONS AND ANALYTICAL DATA

PROFILE DESCRIPTION **OBS SITE PT1** **TAVETA, KENYA**

Map Unit:	Lc
Soil Classification:	Chromic Luvisol (Lc)
Irrigable Land Classification:	1
Parent Material:	Calcareous tuffs
Topography:	Generally level with 0-1% slope
Micro Relief:	Even
Slope Gradient:	0-1% southern aspect
Vegetation Land Use:	Furrow irrigated french seed bean field
Salinity/Alkalinity:	Class O; none
Drainage Class:	Well drained

DESCRIPTION

Horizon	**Depth (cm)**	**Description**
Ap	0 - 25	Dark reddish brown (5YR 3/4) dry; 5YR 3/2 moist; clay; moderate, medium-coarse subangular blocky; slightly hard (dry), firm (moist); sticky plastic; common fine pores; many fine roots, pH 8.0; diffuse boundary.
Bt_1	25 - 70	Dark reddish brown (5YR 3/3) moist; clay; moderate, medium-coarse subangular blocky; firm (moist), sticky and plastic; common very fine pores; common fine roots, pH 8.2; diffuse boundary.
Bt_2	70 - 125	Dark reddish brown (5YR 3/3) moist; clay; moderate, medium-coarse subangular blocky; firm (moist); sticky plastic; few common fine pores; common fine roots; pH 8.5; diffuse boundary.
C	125 - 170	Reddish brown (5YR 4/4) moist; gritty clay; moderate medium-fine subangular blocky; firm (moist); sticky, plastic; few fine pores; few fine roots; pH 8.5; clear smooth boundary.
R	170 +	Soft calcareous tuffaceous grits.

Remarks:

(i) Well structured soil allowing very good root penetration.
(ii) Generally well drained, with no mottling present.
(iii) Surface horizon generally dry - whole profile moist and firm throughout.

ANALYTICAL DATA PROFILE PT.1

Laboratory Number		7739	7740	7741	7742
Sample Identity		PT 1 0-25	25-70	70-125	125-170
Moisture % o.d.s.		11.4	11.9	11.9	11.5
W/V Ratio g/cm³ a.d.s.		1.06	0.94	1.02	1.08
pH 1:5 H_2O		8.0	8.2	8.5	8.5
E.C. · ms/cm 1:5 H_2O		0.07	0.10	0.13	0.28
pH 1:5 1M KCl		6.7	7.3	7.6	7.7
Calcium Carbonate %			3.5	9.5	10.5
Soluble Cations me/100 g a.d.s.	Na				
	K				
Exchangeable Cations me/100 g a.d.s. (1)	Na	0.1	0.2	0.9	3.1
	K	5.6	5.2	7.3	6.9
	Mg	10.0	13.7	18.8	22.9
	Ca (2)	29.7	>50.0	>50.0	>50.0
T.E.B. me/100 g a.d.s.		45.4	>69.1	>77.0	>82.9
C.E.C. me/100 g a.d.s.		41.5	36.8	34.7	34.3
Base Saturation %		100	100	100	100
Total N (3) %		0.17	0.08	0.08	0.06
Organic C (4) %		1.30	0.63	0.57	0.45
Hot Water Soluble B ppm		0.6	1.6	2.7	3.5
Available P (Bray) ppm		671	417	285	275
Available P (Olsen) ppm		29	6	17	24
DTPA Extract ppm	Cu	2.0	1.9	1.9	2.1
	Mn	20.6	12.1	9.3	7.5
	Zn	0.6	0.2	0.3	0.3
Saturation Extract % H_2O		67.1	70.6	65.9	68.9
E.C. Saturation Extract ms/cm		0.83	0.65	1.32	3.73
Soluble Cations me/l	Na				
	K				
	Mg				
	Ca				
Available K ppm		2295	2172	2917	2795
Stones %					7
Particle Size Analysis (Percentages in dry mineral soil)	2000 - 50	15	15	16	14
	50 - 2	33	30	31	31
	< 2 µm	52	55	53	55
	Texture	C	C	C	C

PROFILE DESCRIPTION **OBS SITE PT2** **TAVETA, KENYA**

Map Unit:	So
Soil Classification:	Orthic Solonetz
Irrigable Land Classification:	6axp
Parent Material:	Calcareous tuffs
Topography:	Generally level; depression fringe soil
Micro Relief:	Even
Slope Gradient:	1% south
Vegetation Land Use:	Assorted halophytes and palms
Salinity/Alkalinity:	Class 3; strongly affected
Drainage Class:	Moderately well - imperfect

DESCRIPTION:

Horizon	**Depth (cm)**	**Description**
Ap	0 - 15	Brown (10YR 5/3) dry, very dark greyish brown (10YR 3/2) moist; silty clay; strong composite coarse prismatic angular blocky; slightly hard (dry) friable (moist); slightly sticky, slightly plastic; few fine pores; many fine roots; pH 7.8; clear wavy boundary.
$Btnz_1$	15 - 50	Very dark greyish brown (10YR 3/1) dry (10YR 3/1) moist; clay, strong medium crumb; cracks 4 mm wide 15-30 cm depth; slightly hard (dry) firm (moist), very sticky, plastic; many fine pores; many fine few medium roots; pH 9.8; clear smooth boundary.
$Btnz_2$	50 - 120	Dark brown (7.5YR 3/4) moist; silty clay; moderate, medium subangular blocky; friable (moist) sticky plastic; common fine pores, very few fine roots; pH 10.6; clear smooth boundary.
BC	120 - 200	Yellowish red (5YR 4/6) moist; clay; moderate, medium subangular blocky; friable (moist) sticky, plastic; common fine pores; no roots; pH 10.5.
C	200 +	Weathered rock.

Remarks:

(i) Profile is in situ clayey soil developed over calcareous tuffs, overlain by a superficial layer of alluvial material.

(ii) Very moist below 50 cm, possible subsoil waterlogging at certain times of the year.

ANALYTICAL DATA PROFILE PT.2

Property					
Laboratory Number		7743	7744	7745	7746
Sample Identity		PT 2 0-15	15-50	50-100	100-120
Moisture	% o.d.s.	10.3	13.3	12.8	12.8
W/V Ratio	g/cm^3 a.d.s.	1.07	1.05	0.92	0.93
pH	1:5 H_2O	7.8	9.8	10.6	10.5
E.C. mS/cm	1:5 H_2O	0.13	0.91	0.66	0.61
pH	1:5 1M KCl	7.2	7.9	8.9	8.8
Calcium Carbonate	%		3.0	16.0	21.5
Soluble Cations me/100 g a.d.s.	Na				
	K				
Exchangeable Cations me/100 g a.d.s. (1)	Na	0.8	26.4	31.3	27.8
	K	7.3	5.5	6.4	6.1
	Mg	9.5	6.7	7.8	9.3
	Ca (2)	35.0	25.6	>50.0	>50.0
T.E.B. me/100 g a.d.s.		52.6	64.2	>95.5	>93.2
C.E.C. me/100 g a.d.s.		45.7	42.1	34.1	30.6
Base Saturation	%	100	100	100	100
Total N (3)	%	0.27	0.13	0.05	0.04
Organic C (4)	%	2.01	0.84	0.26	0.20
Hot water Soluble B	ppm	1.6	1.2	59	7.5
Available P (Bray)	ppm	2049	1396	178	40
Available P (Olsen)	ppm	29	10	34	33
DTPA Extract ppm	Cu	1.5	2.5	2.9	2.3
	Mn	27.4	29.3	4.3	5.3
	Zn	0.6	0.3	0.3	0.3
Saturation Extract	% H_2O	60.5	77.1	64.5	61.7
E.C. Saturation Extract	mS/cm	1.80	12.06	7.33	5.98
Soluble Cations me/L	Na		110.0	70.0	60.0
	K		1.2	1.0	0.9
	Mg		0.9	0.1	0.1
	Ca		1.6	0.2	0.2
Available K	ppm	2907	2458	2734	2734
Stones	%				12
Particle Size Analysis (Percentages in dry mineral soil)	2000-50	13	12	11	10
	50-2	51	31	42	40
	<2 µm	36	57	47	50
	Texture	ZyCL	C	ZyC	C

PROFILE DESCRIPTION **OBS SITE PT3** **TAVETA, KENYA**

Map Unit:	Sm
Soil Classification:	Mollic Solonetz (Sm)
Irrigable Land Classification:	6axp
Parent Material:	Depression alluvium overlying calcareous tuffs
Topography:	Level
Micro Relief:	Slightly uneven
Slope Gradient:	1% south
Vegetation Land Use:	Assortedhalophytes on recently cleared land
Salinity/Alkalinity:	Class 3, strongly affected
Drainage Class:	Imperfect

DESCRIPTION:

Horizon	**Depth (cm)**	**Description**
Az	0 - 10	Black (10YR 2/1) moist; silty clay; weak, medium-fine subangular blocky; friable (moist); slightly sticky, slightly plastic; few fine pores; few fine roots; pH 8.0; diffuse boundary.
$Btnz_1$	10 - 45	Very dark brown (10YR 2/2) moist; silty clay; weak, medium-coarse subangular blocky; friable (moist); sticky, plastic; common fine pores; few fine roots; pH 9.9; clear smooth boundary.
$Btnz_2$	45 - 95	Dark brown (7.5YR 3/4) moist; silty clay; weak, medium-coarse subangular blocky; friable (moist); sticky, plastic; many fine pores; few fine roots; pH 10.7; diffuse boundary.
$Btnz_3$	95 - 160	Brown (7.5YR 4/4) moist; silty clay; weak medium-coarse subangular blocky; friable (moist); slightly sticky, slightly plastic; many fine pores; no roots; pH 10.6; clear smooth boundary.
C	160 - 200	Brown (7.5YR 4/4) moist; sandy clay loam comprised weathered rock; friable moist; many fine pores; no roots.
	200 +	Weathered calcareous tuffs.

Remarks:

(i) Very dry dusty surface.
(ii) Generally weakly structured throughout.

ANALYTICAL DATA PROFILE PT.3

Laboratory Number		7747	7748	7749	7750
Sample Identity		PT3			
		0-10	10-45	45-95	95-100
Moisture % o.d.s.		13.7	10.7	10.8	10.3
W/V Ratio g/cm³ a.d.s.		0.80	0.84	0.86	0.95
pH 1:5 H_2O		8.0	9.9	10.7	10.6
E.C. mS/cm 1:5 H_2O		4.64	1.22	1.00	0.63
pH 1:5 1M KCl		7.5	8.2	9.3	9.3
Calcium Carbonate %		6.5	12.0	24.0	33.0
Soluble Cations me/100 g a.d.s.	Na				
	K				
Exchangeable Cations me/100 g a.d.s. (1)	Na	22.6	19.0	21.1	16.5
	K	10.9	13.1	14.3	12.5
	Mg	9.9	6.8	8.0	7.9
	Ca (2)	>50.0	>50.0	>50.0	>50.0
T.E.B. me/100 g a.d.s.		>93.4	>88.9	>93.4	>86.9
C.E.C. me/100 g a.d.s.		44.5	38.5	30.5	23.2
Base Saturation %		100	100	100	100
Total N (3) %		0.40	0.21	0.09	0.06
Organic C (4) %		3.44	1.62	0.64	0.34
Hot Water Soluble B ppm		2.4	1.5	11.9	11.9
Available P (Bray) ppm		1090	636	5	3
Available P (Olsen) ppm		40	9	20	22
DTPA Extract ppm	Cu	0.9	1.2	1.5	0.6
	Mn	8.9	10.9	4.5	2.5
	Zn	1.1	0.4	0.3	0.1
Saturation Extract % H_2O		70.0	65.6	64.9	56.8
E.C. Saturation Extract mS/cm		69.6	24.9	15.05	9.33
Soluble Cations me/L	Na	600.0	220.0	130.0	80.0
	K	60.0	20.0	10.0	10.0
	Mg	75.9	5.0	0.2	0.1
	Ca	153.6	6.4	0.2	0.1
Available K ppm		6346	6034	6555	5826
Stones %					8
Particle Size Analysis (Percentages in dry mineral soil)	2000-50	13	12	9	19
	50-2	49	50	47	54
	<2 µm	38	38	44	27
	Texture	ZyCL	ZyCL	ZyC	ZyL

PROFILE DESCRIPTION	OBS SITE PT4	TAVETA, KENYA

Map Unit:	Rc
Soil Classification:	Eutric Regosols
Irrigable Land Classification:	2t
Parent Material:	Gneisses
Topography:	Sloping piedmont footslope associated with gneissic outcrops
Micro Relief:	Even
Slope Gradient:	2% north
Vegetation Land Use:	Overgrazed acacia scrub
Salinity/Alkalinity:	None
Drainage Class:	Well drained - somewhat excessively well drained

DESCRIPTION:

Horizon	Depth (cm)	Description
Au	0 - 15	Yellowish red (5YR 4/6) dry, (5YR 4/6) moist; sandy loam; weak fine-medium subangular blocky, soft (dry) friable (moist) non sticky, non plastic; many fine pores; many fine roots; pH 7.0; diffuse boundary.
Bt_1	15 - 75	Yellowish red (5YR 5/8) dry, (5YR 3/2) moist; gritty, coarse sandy clay loam; weak fine-medium subangular blocky; soft (dry), friable (moist); slightly sticky, slightly plastic; many fine pores; many fine roots; pH 7.8; diffuse boundary.
Bt_2	75 - 120	Yellowish red (5YR 5/8) dry; (5YR 3/2) moist; gritty, coarse sandy clay loam - sandy loam; weak, medium-fine subangular blocky, soft (dry), friable (moist); slightly sticky, slightly plastic; many fine pores; many fine roots; pH 8.0; diffuse boundary.
BC	120 - 200	Reddish brown (5YR 5/4) dry; (5YR 4/4) moist; gritty sandy clay loam; weak medium-fine subangular blocky, soft (dry), friable (moist); slightly sticky, slightly plastic; many fine pores; few fine roots; weathered rock fragments.

Remarks

(i) Horizons not sampled.
(ii) 120 - 200 containing weathered gneiss.

PROFILE DESCRIPTION **OBS SITE PT5** **TAVETA, KENYA**

Map Unit:	Lk
Soil Classification:	Calcic Luvisol
Irrigable Land Classification:	3b
Parent Material:	Calcareous tuffaceous grits
Topography:	Generally level
Micro Relief:	Even
Slope Gradient:	0 - 1%
Vegetation Land Use:	Furrow irrigated field left fallow. Furrows somewhat denuded due to poor aggregate stability in surface horizons
Salinity/Alkalinity:	Class O; none
Drainage Class:	Well drained

DESCRIPTION:

Horizon	Depth (cm)	Description
Apk	0 - 15	Dark brown (7.5YR 4/2) dry, dark brown (7.5YR 3/2) moist; silty clay; strong coarse angular blocky structure; slightly hard (dry), friable (moist); slightly sticky, slightly plastic; few fine pores, common fine roots; pH 8.5; diffuse boundary.
Btk_1	15 - 50	Brown (7.5YR4/2) dry, (7.5YR 3/2) moist; silty clay; moderate, medium-coarse subangular blocky; soft (dry), friable (moist); slightly sticky, slightly plastic; common fine pores; common fine few coarse roots; pH 8.7; clear smooth boundary.
$Bntk_2$	50 - 110	Brown (7.5YR 5/4) dry, dark brown (7.5YR 3/2) moist; silty clay; weak-moderate, medium subangular blocky; slightly hard (dry), firm (moist); slightly sticky, slightly plastic; few fine pores; very few fine roots; pH 8.9; clear smooth boundary.
BC	110 - 160	Strong brown (7.5YR 5/6) dry, (7.5YR 4/6) moist; silty clay; containing fragments of weathered rock; weak-moderate subangular blocky; slightly hard (dry), firm (moist); slightly sticky, slightly plastic; few fine pores; no roots; pH9.2; diffuse boundary.
	160 - 200	Weathered calcareous tuffs.

Remarks:

(i) Very powdery dusty surface.
(ii) Profile very dry throughout.
(iii) Aggregate stability in surface horizons low, therefore difficult to bund the soil to make furrows.

ANALYTICAL DATA PROFILE PT.5

Laboratory Number			7751	7752	7753	7754
Sample Identity			PT 5 0-15	15-50	50-110	110-160
Moisture		% o.d.s.	10.9	11.2	10.9	10.1
W/V Ratio		g/cm^3 a.d.s.	1.01	0.96	1.00	1.10
pH		1:5 H_2O	8.6	8.7	8.9	9.2
E.C.		mS/cm 1:5 H_2O	0.11	0.11	0.17	0.20
pH		1:5 1M KCl	7.7	7.7	7.8	8.0
Calcium Carbonate		%	8.6	16.5	18.0	26.0
Soluble Cations me/100 g a.d.s.	Na					
	K					
Exchangeable Cations me/100 g a.d.s. (1)	Na		0.3	0.7	0.9	1.4
	K		6.4	5.6	10.8	13.1
	Mg		15.3	19.2	22.1	20.2
	Ca (2)		>50.0	>50.0	>50.0	>50.0
T.E.B. me/100 g a.d.s.			>72.0	>75.5	>83.8	>84.7
C.E.C. me/100 g a.d.s.			41.2	34.9	32.7	26.6
Base Saturation		%	100	100	100	100
Total N (3)		%	0.19	0.12	0.09	0.05
Organic C (4)		%	1.85	1.07	0.74	0.27
Hot water Soluble B		ppm	1.0	1.1	1.4	2.4
Available P (Bray)		ppm	417	27	10	5
Available P (Olsen)		ppm	11	5	6	6
DTPA Extract ppm	Cu		1.7	1.7	1.5	1.5
	Mn		14.8	12.1	4.8	3.5
	Zn		0.4	0.1	0.1	0.1
Saturation Extract		$\%H_2O$	62.6	68.3	63.3	56.5
E.C. Saturation Extract		mS/cm	0.59	0.74	1.41	1.87
Soluble Cations me/L	Na					
	K					
	Mg					
	Ca					
Available K		ppm	2479	2162	4304	5324
Stones		%				18
Particle Size Analysis (Percentages in dry mineral soil)	2000-50		12	9	10	11
	50-2		48	42	56	49
	<2 µm		40	49	34	40
	Texture		ZyC	ZyC	ZyCL	ZyC

PROFILE DESCRIPTION — OBS SITE PT6 — TAVETA, KENYA

Map Unit:	Lc
Soil Classification:	Chromic Luvisol
Irrigable Land Classification:	1
Parent Material:	Calcareous tuffaceous grits
Topography:	Level clay plain
Micro Relief:	Even
Slope Gradient:	0 - 1%
Vegetation Land Use:	Very mature secondary regrowth possibly up to 20 years old
Salinity/Alkalinity:	Class O; none
Drainage Class:	Well drained

DESCRIPTION:

Horizon	Depth (cm)	Description
A	0 - 20	Dark reddish brown (5YR 3/2) dry; (5YR 3/2) moist; heavy clay loam; weak-moderate medium crumb; slightly hard (dry), friable (moist); very sticky, very plastic; many fine pores; many fine roots; pH 8.0; clear smooth boundary.
Bt_1	20 - 80	Reddish brown (5YR 4/4) dry, (5YR 3/2) moist; clay; strong, coarse prismatic, with cracks 20 - 80 cm depth, 0.5 cm wide; hard (dry), firm (moist) very sticky very plastic; many fine pores; common fine roots; pH 8.2; clear smooth boundary.
Bt_2	80 - 135	Reddish brown (5YR 4/4) dry, (5YR3/2) moist, clay; moderate-strong medium, subangular blocky; hard (dry), firm (moist); very sticky plastic; few fine pores; few fine roots; pH 8.4; few hairline cracks to 120 cm depth; diffuse boundary.
BC	135 - 200	Reddish brown (5YR 4/4) dry, (5YR 3/2) moist; gritty clay; weak, fine-medium subangular blocky; hard (dry), firm (moist); sticky, plastic; few fine pores; few fine roots; pH 8.6; fragments of weathered rock.

Remarks:

(i) Very well structured soil to 80 cm depth with moderate structure to 135 cm depth.
(ii) Relatively impermeable layer at 135 cm depth to 200 cm.

ANALYTICAL DATA PROFILE PT.6

Laboratory Number		7755	7756	7757	7758
Sample Identity		PT6 0-20	20-80	80-135	135-200
Moisture % o.d.s.		14.0	14.7	14.2	12.3
W/V Ratio g/cm^3 a.d.s.		1.02	0.97	1.04	1.09
pH 1:5 H_2O		8.0	8.2	8.4	8.6
E.C. ms/cm 1:5 H_2O		0.05	0.09	0.10	0.10
pH 1:5 1M KCl		7.1	7.4	7.7	7.8
Calcium Carbonate %			2.0	7.0	18.0
Soluble Cations me/100 g a.d.s.	Na				
	K				
Exchangeable Cations me/100 g a.d.s. (1)	Na	0.2	0.3	0.5	0.4
	K	6.6	5.8	7.1	6.8
	Mg	14.2	16.8	24.4	24.4
	Ca (2)	31.5	47.9	>50.0	>50.0
T.E.B. me/100 g a.d.s.		52.5	70.8	>82.0	>81.6
C.E.C. me/100 g a.d.s.		49.5	47.0	41.1	34.7
Base Saturation %		100	100	100	100
Total N (3) %		0.17	0.13	0.06	0.05
Organic C (4) %		1.38	1.05	0.55	0.37
		1.0	0.6	0.7	0.9
Available P (Bray) ppm		1465	1020	532	180
Available P (Olsen) ppm		27	4	9	15
DTPA Extract ppm	Cu	2.4	2.7	2.3	2.3
	Mn	19.7	20.1	10.1	9.2
	Zn	0.4	0.2	0.2	0.2
Saturation Extract $\%H_2O$		71.9	73.9	72.3	69.4
E.C. Saturation Extract ms/cm		0.61	0.75	0.62	0.47
Soluble Cations me/l	Na				
	K				
	Mg				
	Ca				
		2642	2387	2754	2785
Stones %				5	15
Particle Size Analysis (Percentages in dry mineral soil)	2000 - 50	9	7	8	10
	50 - 2	31	29	29	27
	<2 µm	60	64	63	63
	Texture	C	C	C	C

PROFILE DESCRIPTION | **OBS SITE PT7** | **TAVETA, KENYA**

Map Unit:	Lc
Soil Classification:	Chromic Luvisol
Irrigable Land Classification:	1
Parent Material:	Calcareous tuffaceous grits
Topography:	Level
Micro Relief:	Even
Slope Gradient:	0%
Vegetation Land Use:	Recently cleared land north of the canal
Salinity/Alkalinity:	Class O; none
Drainage Class:	Well drained

DESCRIPTION:

Horizon	**Depth (cm)**	**Description**
A	0 - 25	Dark reddish brown (5YR 3/2) dry, (5YR 3/2) moist; clay loam; strong, medium crumb; slightly hard (dry), friable (moist); very sticky, plastic; many fine pores; very many fine roots; pH 8.3; clear smooth boundary.
Bt_1	25 - 75	Dark reddish brown (5YR 3/3) dry, (5YR 3/2) moist; clay; strong medium-coarse composite subangular blocky, prismatic; hard (dry), firm moist; very sticky, plastic; many fine few medium pores; many fine roots; pH 8.4; diffuse boundary.
Bt_2	75 - 135	Reddish brown (5YR 4/4) dry, (5YR 3/2) moist; clay; moderate, medium subangular blocky; very hard (dry), firm (moist); very sticky plastic; common fine pores; few fine roots; pH 8.5; diffuse boundary.
BC	135 - 200	Reddish brown (5YR 4/4) dry, (5YR 3/2) moist; clay; moderate medium subangular blocky; very hard (dry), firm moist; very sticky, plastic; few fine pores; few fine roots; pH 8.6.

Remarks:

(i) Reduced permeability with depth, particularly below 75 cm.
(ii) Very well structured topsoil down to 75 cm depth.
(iii) Peds very porous with well developed clay skins.
(iv) Termite chambers below 1 m depth.
(v) Good root penetration

ANALYTICAL DATA PROFILE PT.7

Laboratory Number		7759	7760	7761	7762
Sample Identity		PT 7			
		0-25	25-75	75-135	135-20[illegible]
Moisture	% o.d.s.	12.5	12.1	13.1	12.5
W/V Ratio	g/cm^3 a.d.s.	1.06	0.97	1.01	1.05
pH	1:5 H_2O	8.3	8.4	8.5	8.6
E.C. mS/cm	1:5 H_2O	0.09	0.10	0.13	0.13
pH	1:5 1M KCl	7.5	7.6	7.7	7.7
Calcium Carbonate	%	3.5	6.5	7.5	9.0
Soluble Cations me/100 g a.d.s.	Na				
	K				
Exchangeable Cations me/100 g a.d.s. (1)	Na	0.1	0.2	0.4	0.5
	K	7.4	7.7	9.8	9.9
	Mg	11.1	15.1	17.4	19.4
	Ca (2)	>50.0	>50.0	>50.0	>50.0
T.E.B. me/100 g a.d.s.		>68.6	>73.0	>77.6	>79.8
C.E.C. me/100 g a.d.s.		44.2	40.0	38.8	37.6
Base Saturation	%	100	100	100	100
Total N (3)	%	0.21	0.11	0.08	0.07
Organic C (4)	%	1.88	1.08	0.76	0.66
Hot water Soluble B	ppm	0.8	1.2	2.4	2.6
Available P (Bray)	ppm	802	487	473	352
Available P (Olsen)	ppm	7	8	9	11
DTPA Extract ppm	Cu	2.5	2.4	2.3	2.3
	Mn	17.9	15.7	9.9	9.3
	Zn	0.5	0.3	0.3	0.2
Saturation Extract	% H_2O	67.5	68.2	68.5	72.0
E.C. Saturation Extract	mS/cm	0.83	0.61	0.85	0.88
Soluble Cations me/L	Na				
	K				
	Mg				
	Ca				
Available K	ppm	2856	2275	3754	3703
Stones	%				
Particle Size Analysis (Percentages in dry mineral soil)	2000 - 50	8	9	9	7
	50 - 2	33	31	35	33
	<2 µm	59	60	56	60
	Texture	C	C	C	C

LABORATORY ECe and pH RESULTS SITE T.18

Laboratory Number		7763	7764	7765
Sample Identity		T18		
		0-10	10-40	40-80
Moisture % o.d.s.				
W/V Ratio g/cm^3 a.d.s.				
pH 1:5 H_2O		8.5	9.8	10.5
E.C. ms/cm 1:5 H_2O		0.10	0.36	0.72
pH 1:5 1M KCl		7.4	7.7	8.8
Calcium Carbonate %		0.5	3.0	6.5
Soluble Cations me/100 g a.d.s.	Na			
	K			
Exchangeable Cations me/100 g a.d.s. (1)	Na			
	K			
	Mg			
	Ca (2)			
T.E.B. me/100 g a.d.s.				
C.E.C. me/100 g a.d.s.				
Base Saturation %				
Total N (3) %				
Organic C (4) %				
Hot Water Soluble B ppm				
Available P (Bray) ppm				
Available P (Olsen) ppm				
DTPA Extract ppm	Cu			
	Mn			
	Zn			
Saturation Extract % H_2O		74.2	79.4	91.4
E.C. Saturation Extract ms/cm		2.01	2.25	5.35
Soluble Cations me/l	Na			
	K			
	Mg			
	Ca			
Available K ppm				
Stones %				
Particle Size Analysis (Percentages in dry mineral soil)	2000 - 50			
	50 - 2			
	<2 μm			
	Texture			

APPENDIX B

FIELD AUGER HOLE DATA, pH and EC RESULTS (1:5 SOIL WATER SUSPENSION) for 25 AUGER SITES

OBS No	Depth (cm)	Colour	Field Texture	EC ($\mu S\ cm^{-1}$ 1:5)	pH (1:5 Soil Water)		Profile Drainage Class
T1	0-30	10YR 3/2	Clay Loam (Heavy)	1200	9.6	Saline - V. Strongly Alkaline	Poor
T2	0-25	5YR 4/6	Sandy Clay Loam	160	7.38		Well
	25-50	5YR 4/6	Sandy Clay Loam	200	7.35		Well
T3	0-25	7.5YR 3/2	Silty Clay Loam	550	8.24	Mod. Alkaline	Well
	25-50	7.5YR 4/4	Silty Clay Loam	600	8.10	Mod. Alkaline	Well
	50-100	7.5YR 4/4	Silty Clay Loam	1050	8.20	Saline-Mod. Alkaline	Well
T4	0-25	5YR 3/3	Clay Loam	180	8.06		Well
	25-50	5YR 3/3	Silty Clay Loam	180	8.80	Strongly Alkaline	Well
	50-100	5YR 3/3	Silty Clay Loam	300	8.60	Strongly Alkaline	Well
T5	0-25	5YR 4/6	Sandy Clay Loam	475	7.01		Well
	25-50	5YR 4/6	Clay Loam	900	7.80		Well
	50-100	5YR 4/6	Clay Loam	700	8.22	Mod. Alkaline	Well
T6	0-25	5YR 4/6	Fine Sandy Clay Loam	180	7.47		Well
	25-50	5YR 4/6	Fine Sandy Clay Loam	180	8.4	Mod. Alkaline	Well
	50-100	5YR 4/6	Fine Sandy Clay Loam	190	9.05	V. Strongly Alkaline	Well
T7	0-25	5YR 4/6	Fine Sandy Clay Loam	500	6.76		Moderately Well
	25-50	5YR 4/4	Silty Clay Loam	2600	6.75	Saline	Moderately Well
	50-100	5YR 3/3	Silty Clay Loam	1000	9.3	Saline Alakline	Moderately Well
T8	0-25	7.5YR 5/4	Fine Sandy Clay Loam	2100	7.55	Saline	Moderately Well
	25-50	7.5YR 3/4	Clay Loam	1500	9.5	Saline - V. Strongly Alkaline	Moderately Well
	50-100	7.5YR 3/4	Clay Loam (Heavy)	1100	>9.5	Saline - V. Strongly Alkaline	Moderately Well
T9	0-25	5YR 3/3	Sandy Clay Loam	150	7.6		Well
	25-50	5YR 4/6	Sandy Clay Loam	200	8.60	Strongly Alkaline	Well
T10	0-35	5YR 3/3	Clay Loam	100	>9.5	V. Strongly Alkaline	Poor
T11	0-25	5YR 4/6	Gritty Sand Clay Loam	1750	8.70	Saline - V. Strongly Alkaline	Well
	25-50	5YR 4/6	Gritty Sand Clay Loam	3500	9.55	Saline - V. Strongly Alkaline	Well
	50-100	5YR 4/6	Gritty Sand Clay Loam	4100	9.6	Saline - V. Strongly Alkaline	Well
T12	0-25	5YR 4/6	Sandy Loam	150	7.0		Well
	25-50	5YR 5/6	Sandy Clay Loam	125	7.8		Well
	50-100	5YR 5/8	Sandy Clay Loam	150	8.0		Well
T13	0-25	10YR 2/1	Silty Clay Loam	4000	8.90	Saline - Strongly Alkaline	Imperfect
	25-50	10YR 3/2	Silty Clay Loam	3000	>9.5	Saline - V. Strongly Alkaline	Imperfect
	50-100	10YR 4/3	Sandy Clay Loam	1400	>9.5	Saline - V. Strongly Alkaline	Imperfect
T14	0-25	5YR 3/3	Silty Clay Loam	200	8.95	Strongly Alkaline	Well
	25-50	5YR 3/2	Silty Clay Loam	375	9.6	V. Strongly Alkaline	Well
	50-100	5YR 3/2	Silty Clay Loam	900	>9.5	V. Strongly Alkaline	Well
T15	0-25	7.5YR 4/4	Sandy Clay Loam	1500	>9.5	Saline - V. Strongly Alakaline	Poor - Imperfect
	25-50	7.5YR 3/2	Clay Loam (Heavy)	1250	>9.5	Saline - V. Stronlgy Alkaline	poor - Imperfect
	50-75	7.5YR 3/2	Clay Loam (Heavy)	1150	>9.5	Saline - V. Strongly Alkaline	Poor - Imperfect
	75-100	7.5YR 3/2	Clay Loam (Heavy)	1050	>9.5	Saline - V. Strongly Alkaline	Poor - Imperfect
T16	0-25	7.5YR 4/4	Silty clay Loam	1100	8.95	Saline - V. Strongly Alkaline	Poor - Imperfect
	25-50	7.5YR 3/4	Clay Loam	2800	>9.5	Saline - V. Strongly Alkaline	Poor - Imperfect
	50-100	7.5YR 3/2	Clay Loam	3400	>9.5	Saline - V. Strongly Alkaline	Poor - Imperfect

OBS No	Depth (cm)	Colour	Field Texture	EC (µS cm-1 1:5)	pH (1:5 Soil Water)		Profile Drainage Class
T17	0-25	7.5YR 5/4	Sandy Clay Loam	5200	7.4	Saline	Well
	25-50	7.5YR 3/2	Sandy Clay Loam	4750	7.98	Saline	Well
	50-100	7.5YR 3/2	Sandy Clay Loam	660	9.46	Strongly Alkaline	Well
	100-150	7.5YR 3/2	Sandy Clay Loam	550	>9.5	Strongly Alkaline	Well
T18	0-10	7.5YR 4/2	Silty Clay Loam	225	8.95	Strongly Alkaline	Poor
	10-40	7.5YR 3/0	Silty Clay Loam	475	>9.5	Strongly Alkaline	Poor
	40-80	7.5YR 3/2	Silty Clay Loam	1100	>9.5	Strongly Alkaline	Poor
T19	0-25	5YR 5/6	Sandy Clay Loam	170	8.5	Strongly Alkaline	Well
	25-50	5YR 5/6	Clay Loam	200	8.53	Strongly Alkaline	Well
	50-80	5YR 5/6	Clay Loam	200	8.85	Strongly Alkaline	Well
T20	0-25	5YR 3/3	Sandy Clay Loam	220	8.48	Mod. Alkaline	Well
	25-50	5YR 4/6	Clay Loam	450	8.17	Mod. Alkaline	Well
T21	0-25	5YR 3/4	Sandy Clay Loam	875	7.6		Imperfect
	25-50	5YR 4/4	Clay Loam (Heavy)	1050	7.65	Saline	Imperfect
	50-80	5YR 4/4	Clay Loam (Heavy)	850	9.00	Strongly Alkaline	Imperfect
T22	0-25	5YR 3/4	Sandy Clay Loam	295	8.57	Strongly Alkaline	Well
	25-50	5YR 3/4	Clay Loam (Heavy)	325	8.50	Mod. Alkaline	Well
	50-100	5YR 3/4	Clay Loam (Heavy)	220	8.65	Strongly Alkaline	Well
T23	0-25	5YR 3/4	Sandy Clay Loam	175	7.6		Well
	25-50	5YR 3/6	Sandy Clay Loam	475	8.4	Mod. Alkaline	Well
	50-90	5YR 3/6	Sandy Clay Loam	1000	8.3	Saline - Mod. Alkaline	Well
T24	0-25	5YR 3/4	Sandy Clay Loam	140	7.97		Well
	25-50	5YR 4/6	Sandy Clay Loam	140	8.12		Well
T25	0-25	5YR 3/4	Clay Loam	140	7.7		Well
	25-50	5YR 4/6	Clay Loam	175	7.45		Well
	50-100	5YR 5/6	Sandy Clay Loam	200	8.66	Strongly Alkaline	Well

APPENDIX C

PRELIMINARY INFILTRATION TEST DATA FOR SITES PT1 AND PT5

FIELD MEASUREMENT OF INFILTRATION

At each site three infiltration rings were installed to a depth of 10 - 15 cm. An approximately constant head of water was maintained in each of the rings, and depth of water entering the soil recorded.

Infiltration rates were measured over a period of 5 hours. It was not practicable to continue the tests beyond five hours because of the difficulties of supplying water.

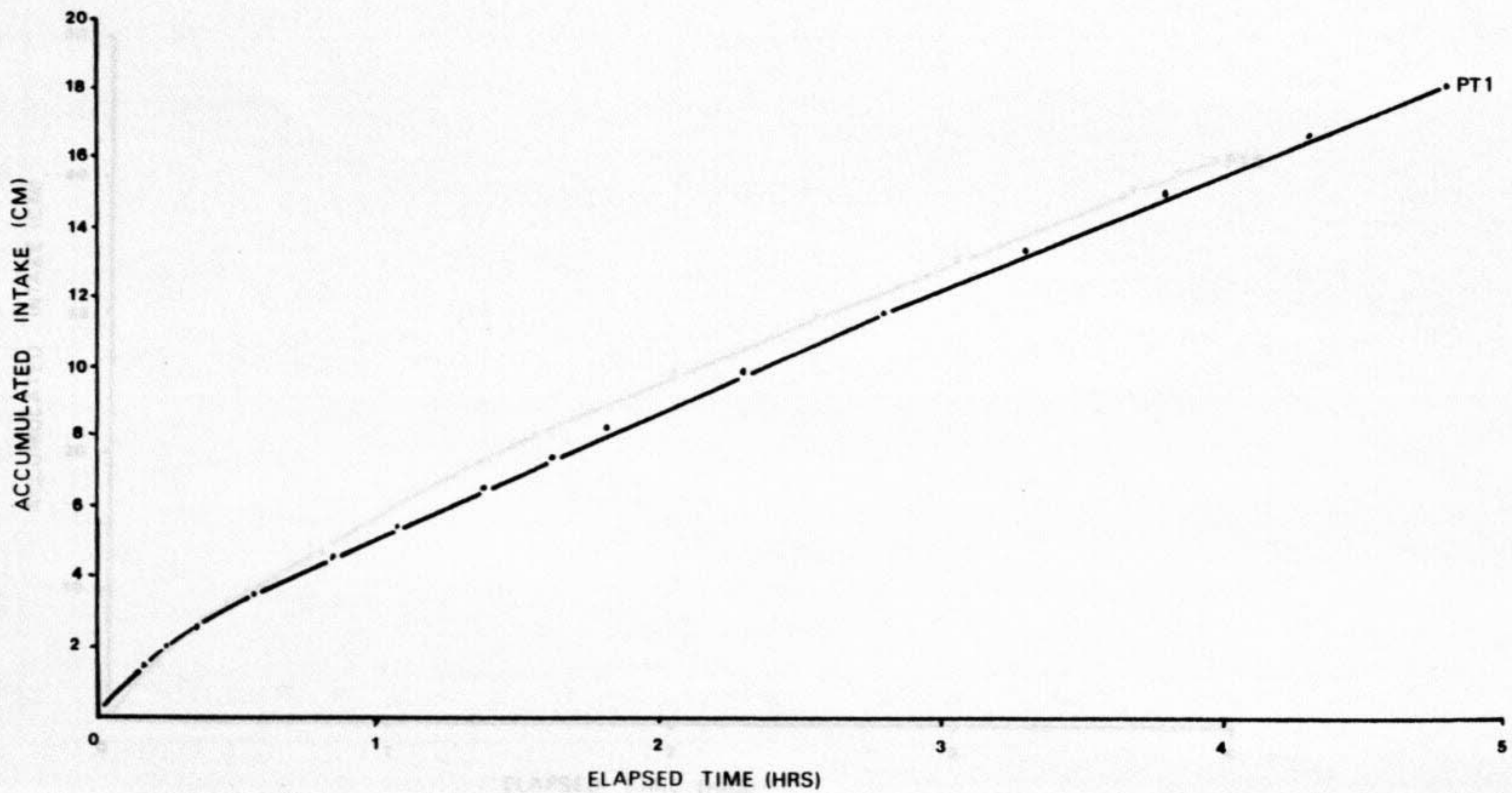
A total of two tests were carried out in the Project area. Curves of cumulative infiltration rates are given overleaf. A summary of data from the tests is given in Section 5.

SITE PT1
TAVETA ESTATES

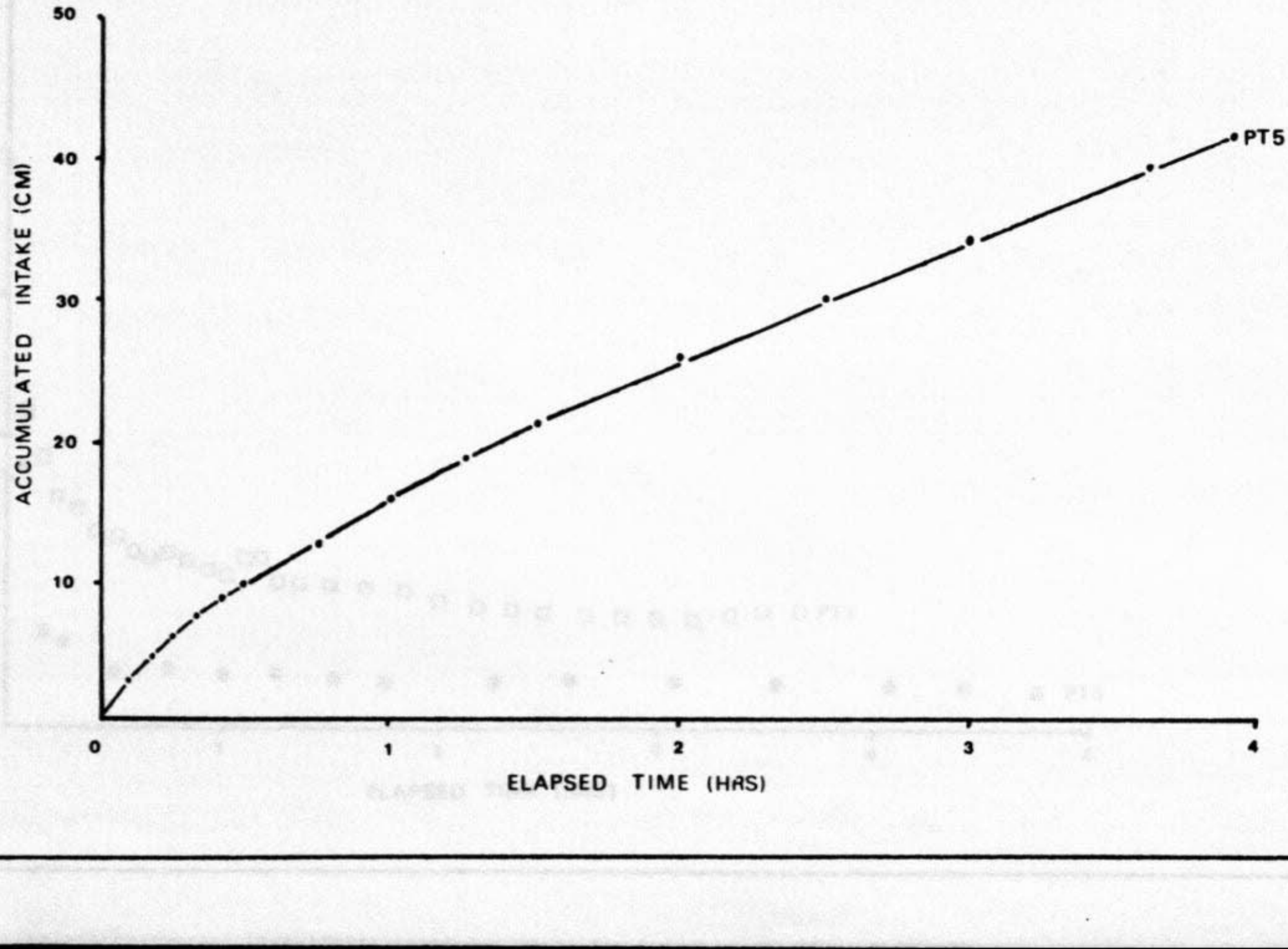
Interval (min)	Cumulative time (min)	Intake (cm)	Cumulative (cm)	IR cm/hr Immediate	IR cm/hr Mean
2	2	2.23	2.23	66.9	66.9
3	5	1.13	3.36	22.6	40.32
5	10	1.56	4.92	18.72	29.52
5	15	1.3	6.22	15.6	24.88
5	20	1.26	7.48	15.0	22.44
5	25	1.13	8.61	13.56	20.66
5	30	1.16	9.77	13.92	19.54
5	35	1.06	10.83	12.72	18.56
5	40	1.0	11.83	12.0	17.74
5	45	1.06	12.89	12.72	17.18
5	50	1.0	13.89	12.0	16.67
5	55	0.96	14.85	11.52	16.2
5	60	0.90	15.75	10.8	15.75
5	65	1.0	16.75	12.0	15.46
5	70	1.0	17.75	12.0	15.21
5	75	0.83	18.58	9.96	14.86
5	80	0.9	19.48	10.8	14.61
10	90	1.8	21.28	10.8	14.18
10	100	1.76	23.04	10.56	13.82
10	110	1.56	24.6	9.36	13.42
10	120	1.46	26.06	8.76	13.03
10	130	1.4	27.46	8.4	12.67
10	140	1.46	28.92	8.76	12.39
10	150	1.36	30.28	8.16	12.112
10	160	1.4	31.68	8.4	11.88
10	170	1.4	33.08	8.4	11.67
10	180	1.33	34.41	7.98	11.47
10	190	1.3	35.71	7.8	11.28
15	205	2.0	37.71	8.0	11.03
15	220	2.0	39.71	8.0	10.83
15	234	2.0	41.71	8.0	10.64

SITE PT5
TAVETA ESTATES

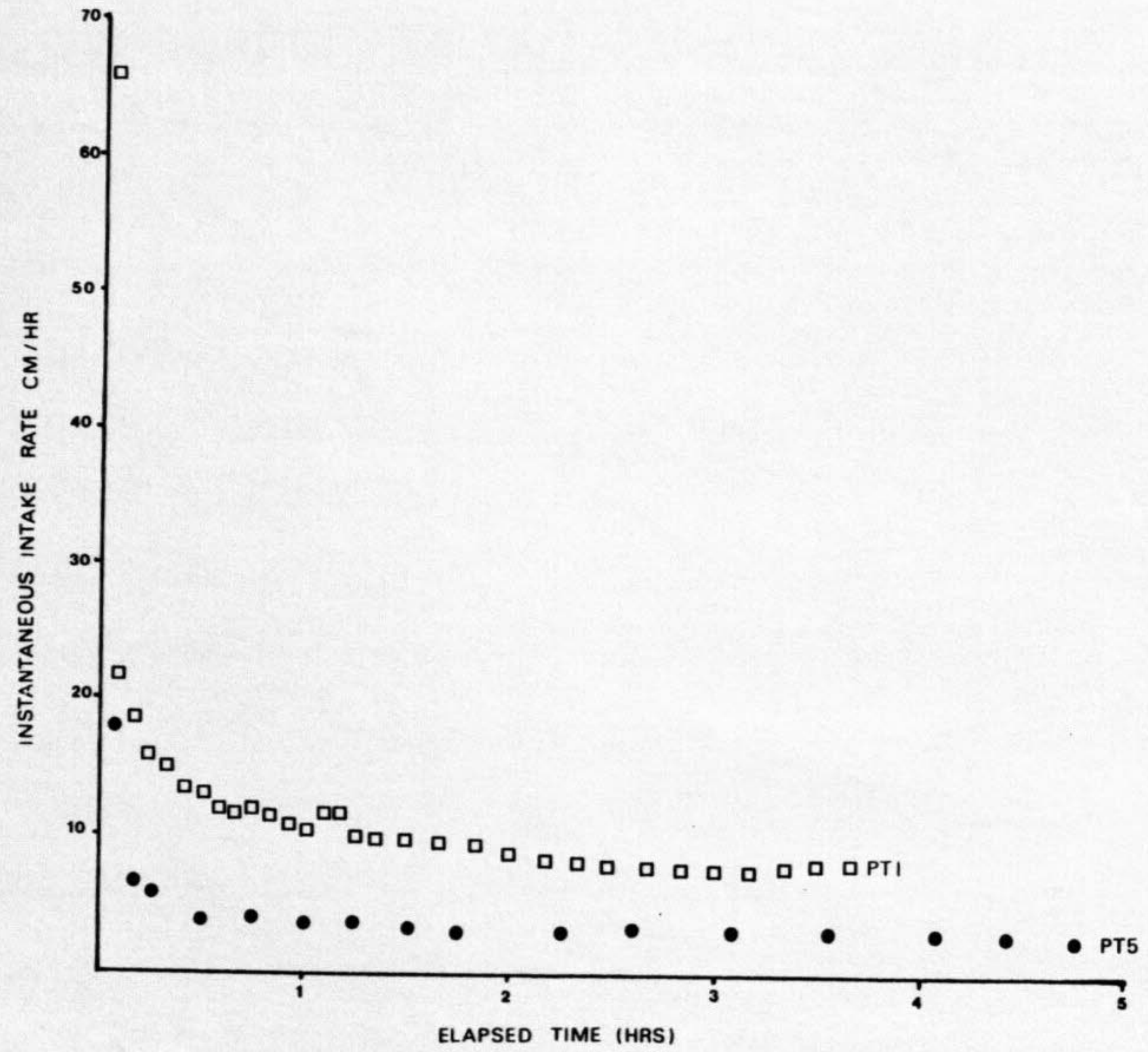
Interval (min)	Cumulative time (min)	Intake (cm)	Cumulative (cm)	IR cm/hr Immediate	IR cm/hr Mean
5	5	1.5	1.5	18.00	18.0
5	10	0.56	2.06	6.72	12.36
5	15	0.5	2.56	6.0	10.24
15	30	0.86	3.42	3.44	6.84
15	45	1.23	4.65	4.92	6.2
15	60	0.93	5.58	3.72	5.58
15	75	1.03	6.61	4.12	5.28
15	90	0.83	7.44	3.32	4.96
15	105	0.86	8.3	3.44	4.74
30	135	1.7	10.0	3.4	4.44
30	165	1.76	11.76	3.52	4.27
30	195	1.76	13.52	3.52	4.16
30	225	1.63	15.15	3.26	4.04
30	255	1.63	16.78	3.26	3.94
30	285	1.25	18.03	2.50	3.79


ACCUMULATED INTAKE (CM)
ELAPSED TIME (HRS)
PT1
0
1
2
3
4
5
2
4
6
8
10
12
14
16
18
20

ACCUMULATED INTAKE AGAINST ELAPSED TIME FOR PROFILE PT.5



INSTANTANEOUS INTAKE RATE CM/HR AGAINST ELAPSED TIME FOR PROFILES PT.1 AND PT.5



APPENDIX D

POUR-IN HYDRAULIC CONDUCTIVITY TEST DATA FOR SITES PT1 AND PT5

PROCEDURE USED IN DETERMINING HYDRAULIC CONDUCTIVITY USING POUR-IN TEST

Where a watertable was absent the pour-in method (shallow well test) was used. The procedure followed is similar to that described by USBR (1953).

An auger hole was bored to about 100 - 120 cm depth or according to layers present in the profile. The radius of the hole was 5.5 cm using a standard jarret auger head. A 2 cm diameter metal pipe was placed in the hole and the hole was then filled with gravel up to approximately 50 cm from the ground surface or until the gravel could be seen from the surface in normal daylight. Care was taken to ensure that the base of the pipe was clear of the bottom of the auger hole. Water was directed into the pipe using a finely adjustable aspirator, the hole being filled with water from below until water was visible at the gravel surface. The water level was then maintained at the surface of the gravel.

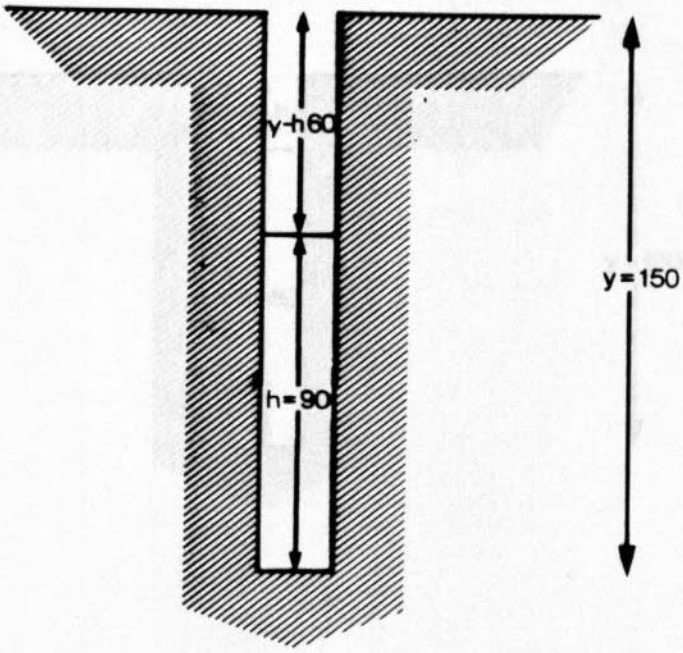
The percolation rate was measured in litres per second by maintaining a constant level of water in the hole over a period of 10 - 15 minutes, then directing the constant flow into a one litre measuring cylinder taking care not to alter the height of the tap throughout the measurements. While the flow rate was measured the constant level of water in the hole was maintained using a jug.

A number of readings were taken over a two hour period until a more or less constant rate was achieved.

Measurements made for obtaining hydraulic conductivity values at the Project site are given on the calculation sheets. Hydraulic conductivity was calculated by reference to nomograms given by USBR (1953).

HYDRAULIC CONDUCTIVITY TEST RESULTS (POUR-IN METHOD) **SITE PT1**

h = 90 cm
r = 5.25
$\frac{h}{r}$ = 17.1 cm

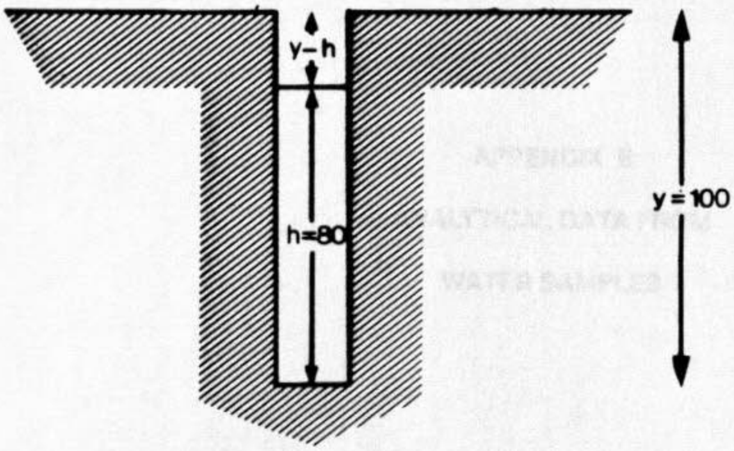


Run	Elapsed Time (min)	Δ Time Secs	Ql min^{-1}	Q m^3 min^{-1}	K.m/day^{-1}	Perm Class
1	5	21	1.43	0.00143	1.20	Moderate
2	10	27	1.11	0.00111	1.00	Moderate
3	15	28	1.07	0.00107	0.90	Moderate
4	20	31	0.96	0.00096	0.70	Moderate
5	25	39	0.94	0.00094	0.70	Moderate
6	36	45	0.66	0.00066	0.40	Mod. slow
7	45	45	0.66	0.00066	0.40	Mod. slow
8	55	52	0.58	0.00058	0.40	Mod. slow
9	65	60	0.5	0.00050	0.35	Mod. slow
10	75	61	0.49	0.00049	0.35	Mod. slow
11	85	69	0.43	0.00043	0.35	Mod. slow

HYDRAULIC CONDUCTIVITY TEST RESULTS (POUR-IN METHOD) **SITE PT5**

h = 80 cm
r = 5.25

$\frac{h}{r} = 15.23$



Run	Elapsed Time (min)	Δ Time Secs	Ql min^{-1}	Q m^3 min^{-1}	K m/day^{-1}	Perm Class
1	5	29.5	1.02	0.00102	0.80	Moderate
2	20	45	0.66	0.00066	0.40	Mod. slow
3	30	50	0.6	0.0006	0.36	Mod. slow
4	40	63	0.44	0.00044	0.30	Mod. slow
5	50	69	0.43	0.00043	0.30	Mod. slow
6	60	65	0.46	0.00046	0.30	Mod. slow
7	70	77	0.39	0.00039	0.28	Mod. slow
8	80	69	0.44	0.00044	0.30	Mod. slow
9	90	77	0.39	0.00039	0.28	Mod. slow
10	100	83	0.36	0.00036	0.16	Slow

APPENDIX E

ANALYTICAL DATA FROM

WATER SAMPLES

ANALYTICAL DATA WATER SAMPLES; TAVETA ESTATES

Laboratory Number		W189	W190	W191	W192				
Sample Identity		Njoro Kubwa Spring	Borehole Taveta Est	Drainage SITE T18	Homers Spring				
pH μS/cm		6.5	7.0	8.1	7.2				
E.C.		240	420	7610	400				
Soluble Cations me/l	Na	0.5	1.0	64.8	0.6				
	K	0.1	0.1	2.3	0.1				
	Mg	1.0	1.8	1.4	1.5				
	Ca	0.7	1.2	0.3	1.0				
Soluble Anions me/l	Cl	<0.5	<0.5	1.1	<0.5				
	SO_4	0.0	0.0	0.3	0.0				
	CO_3	0.0	0.0	23.4	0.0				
	HCO_3	2.3	3.9	58.1	3.0				
Total Dissolved Solids gl^{-1}		0.32	0.21	4.93	0.23				
Total Undissolved Solids gl^{-1}				0.20					