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REPUBLIC OF KENYA

MINISTRY OF AGRICULTURE

LOWER TANA VILLAGE IRRIGATION PROGRAMME

- A TECHNICAL STUDY -

RECONNAISSANCE REPORT

VOLUME I - SOILS

DECEMBER, 1980

GRABOWSKY & POORT B.V.
CONSULTING ENGINEERS
THE NETHERLANDS

1.0 ENVIRONMENT

1.1 Location, Communications and People

The survey area is situated in the south Tana River Division of the Tana River District, Coast Province. It lies between latitude $1^{o}45'S$ and $2^{o}32'S$, and longitude $40^{o}06'E$ and $40^{o}18'E$. The area extends from approximately five kilometres north of Wenje southward along the Tana River to a point approximately three kilometres east of Samikaro, (Figure 1.1). Elevation in the project area decreases from about 70 metres (amsl) at Wenje to 10 metres (amsl) at Samikaro. The total area investigated is approximately 64,000 hectares, of which 4,000 hectares consists of river, lakes, roads, villages and other non-agricultural surfaces.

Road transport serves as the major means of communication. The main national trunk roads from Malindi to Garissa and Lamu pass through the project area, forking at Garsen where there is a ferry crossing on the Tana to Lamu. Within the project area are a number of minor roads and tracks. All roads have a loose surface and are frequently impassable during and after a heavy rain or flash flood. The Tana River also acts as a major communication artery, carrying canoe traffic of people, produce and supplies.

There are dry-weather air strips at Garsen, Mchelelo (near Wenje), Ngao and Wema. Garsen has telephone and postal services as well as a dispensary and treated water supply. Ngao has a hospital and there is a Government secondary school at Tarasaa. There are a number of dispensaries and primary schools in the project area.

The Pokomo are the most numerous people in the project area. They are cultivators and keep very few grazing animals. The second largest group of people are the Orma. They are semi-nomadic herders, who own large herds of cattle which they graze throughout the project area. During the rainy season the herds are moved back from the river, returning as the floods recede and the dry season advances. The Orma are found both on the west and east side of the river. On the east side,

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The survey area is situated in the south Tana River Division of the Tana River District, Coast Province. It lies between latitude 1°35'S and 2°32'S, and longitude 40°06'E and 40°18'E. The area extends from approximately five kilometres north of Wenje southward along the Tana River to a point approximately three kilometres west of Samikaro, (Figure 1.1). Elevation in the project area decreases from about 70 metres (amsl) at Wenje to 10 metres (amsl) at Samikaro. The total area investigated is approximately 56 000 hectares, of which 4,000 hectares consists of river, lakes, roads, villages and other non-agricultural surfaces.

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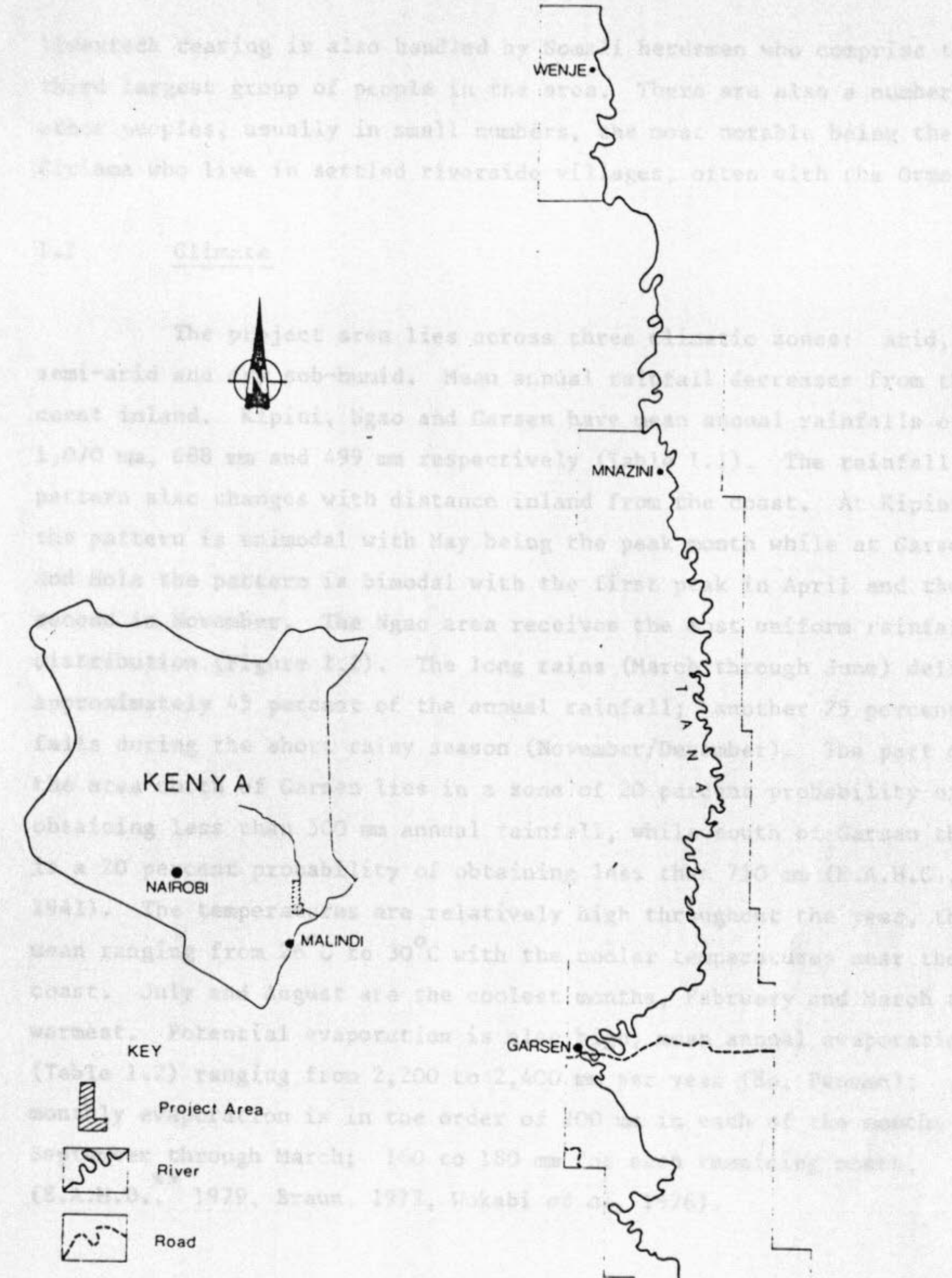

FIGURE 1·1 PROJECT AREA LOCATION MAP

livestock rearing is also handled by Somali herdsmen who comprise the third largest group of people in the area. There are also a number of other peoples, usually in small numbers, the most notable being the Giriama who live in settled riverside villages, often with the Orma.

1.2 Climate

The project area lies across three climatic zones: arid, semi-arid and dry sub-humid. Mean annual rainfall decreases from the coast inland. Kipini, Ngao and Garsen have mean annual rainfalls of 1,070 mm, 688 mm and 499 mm respectively (Table 1.1). The rainfall pattern also changes with distance inland from the coast. At Kipini the pattern is unimodal with May being the peak month while at Garsen and Hola the pattern is bimodal with the first peak in April and the second in November. The Ngao area receives the most uniform rainfall distribution (Figure 1.2). The long rains (March through June) deliver approximately 45 percent of the annual rainfall; another 25 percent falls during the short rainy season (November/December). The part of the area north of Garsen lies in a zone of 20 percent probability of obtaining less than 500 mm annual rainfall, while south of Garsen there is a 20 percent probability of obtaining less than 750 mm (E.A.H.C.,* 1941). The temperatures are relatively high throughout the year, the mean ranging from 26°C to 30°C with the cooler temperatures near the coast. July and August are the coolest months, February and March the warmest. Potential evaporation is also high, mean annual evaporation (Table 1.2) ranging from 2,200 to 2,400 mm per year (Eo, Penman); monthly evaporation is in the order of 200 mm in each of the months September through March; 160 to 180 mm for each remaining month, (E.A.M.D.,** 1979, Braun, 1977, Wokabi *et al*, 1976).

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* East African High Commission

** East African Meteorological Department

Station	Lat(S)	Long(E)	Alt (m)	Mean Ann. Temp. (°C)	Mean Ann. Evap. Eo(mm)	Mean Monthly Rainfall (mm) J	F	M	A	M	J	J	A	S	O	N	D	Ann.	R/E_o %	Years of Observation
Hola	1°29'	40°01'	91	30	2413	26	15	40	79	59	41	19	19	16	32	103	52	491	20	14
Garsen	2°16'	40°01'	30	28	2275	18	11	25	88	81	53	30	24	16	21	88	44	499	22	14
Ngao	2°25'	40°12'	15	27	2231	23	12	40	90	122	64	44	41	56	45	88	63	688	31	25
Bellazoni	2°32'	40°21'	-	-	-	23	7	32	108	253	148	76	54	47	59	38	83	930		22
Kipini	2°31'	40°32'	3	26	2174	27	8	42	141	340	134	75	41	54	54	70	85	1070	49	27

TABLE 1.2 SUMMARY OF MEAN MONTHLY EVAPORATION (mm) AT THREE SITES NEAR THE PROJECT AREA

Station	Lat(S)	Long(E)	Alt (m)	Pan	Mean Monthly Evaporation (mm) J	F	M	A	M	J	J	A	S	O	N	D	Ann.	Ann Mean Temp. °C Max.	Min.	Years of Observation
Garissa	00°28'	39°38'	137	B	200	208	243	218	243	224	232	249	256	259	206	167	2705	34	23	9
Hola	01°29'	40°01'	91	A	218	196	221	194	201	191	194	215	226	234	206	176	2472	33	22	9
Malindi (Gedi)	03°16'	40°03'	91	A	189	181	197	157	142	128	143	151	171	168	155	169	1951	29	21	8

Source: East African Meterological Department (E.A.M.D.), 1974

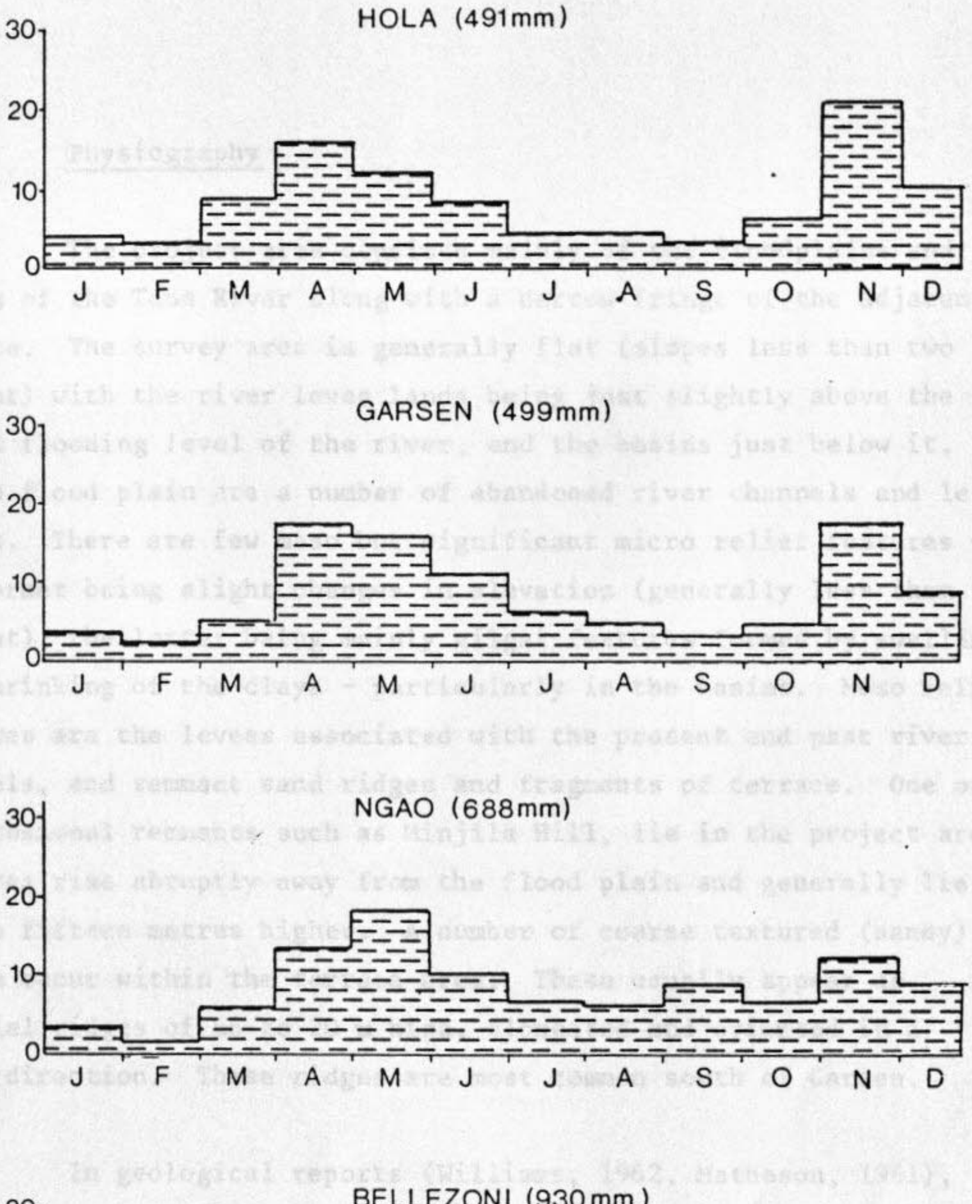

FIGURE 1·2 MONTHLY RAINFALL AS PERCENTAGE OF THE ANNUAL RAINFALL FOR THE PROJECT AREA

1.3 Physiography

The project area consists mainly of the floodplains and levees of the Tana River along with a narrow fringe of the adjacent terrace. The survey area is generally flat (slopes less than two percent) with the river levee lands being just slightly above the normal flooding level of the river, and the basins just below it. In the flood plain are a number of abandoned river channels and levee ridges. There are few meso but significant micro relief features - the former being slight changes in elevation (generally less than two percent), the latter being mainly gilgai features formed by swelling and shrinking of the clays - particularly in the basins. Meso relief features are the levees associated with the present and past river channels, and remnant sand ridges and fragments of terrace. One or two erosional remnants such as Minjila Hill, lie in the project area. Terraces rise abruptly away from the flood plain and generally lie ten to fifteen metres higher. A number of coarse textured (sandy) ridges occur within the terrace area. These usually appear as parallel ridges of up to 20 m high, elongated and oriented in a NE-SW direction. These ridges are most common south of Garsen.

In geological reports (Williams, 1962, Matheson, 1961), the area is mapped as recent alluvium with bands of older sand and clay ridges. These ridges were deposited during various oceanic phases and become progressively younger towards the coast. Recent deposits in the area consist of sands, muds and silt deposited during the biannual flooding of the Tana River. The origin of much of this material is in the highlands to the west and north. Away from the river recent deposits are less pronounced and the soils of the higher terraces are essentially developed on older Pleistocene deposits, mainly of marine origin. The erosional remnants are usually reddish brown sands which in places may be observed to be underlain by coarse grained sedimentary and metamorphosed bed rock.

1.5 Natural Vegetation

Various vegetation associations exist in the project area. The following is a brief description of these associations and their dominant species. Reference was made to Pratt *et al* (1966) in defining the units.

1.5.1 Grassland

This is composed of grasses and grass-like plants and may contain up to two percent bushes and trees. In the project area there are two types of grassland: the sedge grassland where Cyperus is the dominant genus *(Cyperus rotundus* or *C. esculentus)* and the grassland with occasional woody vegetation. In the latter the dominant grasses include *Hyparrhenia spp., Echinochloa haploclada, Cynodon dactylon* and *Digitaria scalarum*. *Acacia zanzibarica* is the most frequent woody inclusion.

1.5.2 Bushed Grassland

This association consists predominantly of grassland with up to thirty percent inclusions of bushes and small trees. The woody vegetation is most frequently *Acacia zanzibarica,* while the dominant grass species are the same as for the grassland unit.

1.5.3 Wooded Grassland

This association consists mainly of grassland with up to thirty percent inclusions of woody vegetation (trees) greater than six metres in height. The most prominent trees are either *Borassus aethiopum* or *Hyphaine coriacea*. Dominant grasses are those of the grassland unit.

1.5.4 Bushland

This association consists of mixed woody vegetation of less than six metres in height with occasional trees (over six metres tall) and frequent open grassland patches. The bush portion of the association

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1.5.4 Bushland

This association consists of mixed woody vegetation of less than six metres in height with occasional trees (over six metres tall) and frequent open grassland patches. The bush portion of the association is between thirty and seventy percent. The dominant woody species include *Salvadora persica, Dobera glabra, Terminalia brevipes, Commiphora africana* and *Cordia spp. (C. gharef* or *C. ovalis). Poa spp.* and *Setaria verticillata* are common grasses. The term "open bushland" is used when the bushes are well spaced and of lower percentage composition.

1.5.5 Bushland Thicket

This association is composed of either a mixed species bushland with occasional trees but very few open grassland patches, or a dense, often mono-specied stand of low bushes. In the former, *Acacia brevispica, A. mellifera, A. reficiens, A. clavigera, A. tortilis, Commiphora spp.* and *Euphorbia robecchii* are predominant species. In the latter *Commiphora spp.* often dominate. This latter association is most frequently found adjacent to old river channels that are relatively low-lying and seasonally flooded. The density of woody vegetation cover varies from seventy to one hundred percent.

1.5.6 Riparian Forests

This is an association of multistoried vegetation found as remnants adjacent to the Tana River and older channels. The predominant tree species are *Acacia elatior, Populus ilicifolia* and *Ficus sycomorus. Elaeis guinaensis, Croton spp. (C. pseudo-pulchellus* or *C. sylvaticus)* and *Commiphora riparia* dominate the understorey.

1.6 Present Land Use

The land use pattern in the Tana flood plain is dominated by the rise and fall of the floods twice yearly. Where the land is cultivated the main crops are bananas, maize, green gram *(Vigna aureus)* and rice; minor crops include tobacco, tomatoes, cow peas *(Vigna sinensis)*, sugar cane and cassava. Less than one percent of the area is cultivated with nearly all cropping done on the flood plain (Cnoops, 1978). Annual crop production is largely traditional with few, if any, inputs.

Food and cash crops predominantly occur on the elevated areas (recent and older levees). The relative height above the high flood water level determines which crop is grown. Levees close to or on the river bank are used for banana cultivation. Higher levees are planted to mango and occasionally coconut. Maize, beans and grams, as well as a variety of minor crops, are grown on the transition of the levee/basin after the recession of the flood. Usually rice is grown in the depression (basins and oxbows), but it is also grown on some river banks. Because of the risk of no flood or of too high a flood, rice is transplanted, not sown. This crop is planted in a staggered way following the flood recession, in order to keep pace with the lowering of the water level. Mango, pawpaw and vegetables are grown in and around the homestead while cassava is grown on the sandy soils on the ridges or terraces.

With the exception of small patches of cultivation near the river and the very dense thickets and woodland, lands near the villages are used for grazing the few cattle, goats and sheep owned by the Pokomo, and the livestock herds of the Orma and Somali. Permanent or temporary, villages are always located on high lying land, either on the sand ridges, levees or the terrace.

Fish from the river and some of the lakes are a main part of the diet.

In the four existing irrigation schemes (Wema, Hewani, Oda and Ngao) rice is the main crop grown during the long rains. Yields are very low and highly variable. Irrigated rice yields average 1,400 kg/ha (with a standard deviation of 700 kg/ha). This variation is primarily due to land preparation and to water management but can also be explained by level of inputs. Rainfed rice is also grown in the schemes with yields of less than 1,000 kg/ha (Budelman, 1978).

In the short rainy season other crops are grown. Maize is the main crop with highly variable yields that average about 500 kg/ha. Banana is important both as a food and as a cash crop. Average yields are in the order of 10-12 tons per hectare (Budelman, 1978, 1979).

Budelman (1980) suggests that irrigated rice yields of 3,500 kg/ha should be attainable by at least 75 percent of the farmers using improved management techniques but without using fertiliser. At the same time yields of 1,200, 500 and 20,000 kg/ha are projected for maize (mixed with pulses - mainly green gram and cow pea), pulses mixed with maize, and for bananas respectively.

1.7 Wildlife

Within the project area is the Tana River Primate National Reserve, but throughout the area a large variety of animals range. Warthog, dik-dik, waterbuck, topi, zebra, gazelle and baboon are the most common land animals while hippo and crocodile are very common along the river. Elephant, buffalo, oryx, giraffe, lesser kudu, lion, cheetah, hyena, hunting dog, silver-backed jackal and vervets are often seen. These and other animals appear to be in harmony with the environment. Hippo and baboon, however, do cause the farmers severe problems.

An extremely large variety of wild birds, ranging from the sparrow to the ostrich, also inhabit the project area. Some of these birds may also be seen as pests.

3.0 SOILS

3.1 Previous Work

A number of soil surveys have been undertaken within the project area by the Kenya Soil Survey (KSS). These surveys have been both preliminary regional evaluations and detailed surveys for irrigation schemes. Two preliminary soil surveys were carried out on the Marembo-Garsen (Sombroek *et al*, 1973) and the Tana delta (Wokabi *et al*, 1976) areas. Both of these were aerial photo interpretation maps supported by a limited number of observation sites, and were produced at 1:50,000 and 1:100,000 scales respectively.

The detailed surveys were undertaken in connection with the establishment or extension of irrigation schemes. These surveys covered the Wema, Hewani and Ngao schemes at a scale of 1:5,000 (Kanake and Mugai, 1977; Kanake 1980) and the Mnazini and Oda schemes at a scale of 1:2,500 (Kanake and Mugai, 1977; Kanake, in preparation). The results from these surveys were used to familiarise the team with the project area.

3.2 General Properties and Characteristics

The soils of the project area are located on the present flood plain of the Tana River and on the adjacent level plain through which the river has cut. The soils of the flood plain are developed on recent alluvium and can be broadly divided into those of the lower lying or basin areas and those of the levees adjacent to present or past river or overflow channels. The basin soils are usually uniform and strongly vertic clays that have colour and mottling characteristics which reflect their relative position in the landscape and consequent degree of inundation during the seasonal floods. They typically support vegetation that ranges from tussock grasses and sedges in the lower areas, to moderate or thick bush with palms where the land has a slightly higher altitude. The levee soils are less frequently flooded, are more variable and stratified and have a much higher proportion of medium and coarse textured horizons. Their associated vegetation is equally variable and includes grassland, medium bush and high riparian forest.

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At the edge of the present flood plain the land rises abruptly some three to ten metres up to the adjacent plain or terrace which is composed of old alluvial deposits probably laid down in a marine environment. The soils are highly sodic and frequently highly saline, vertic clays which are associated with smaller outcrops of compacted medium and coarse textured soils which are also often sodic and saline. The vegetation is usually bushland thicket and open bushland with significant areas of bare soil associated with sheet wash.

Within both the terrace and the present flood plain there are some areas of soil, particularly south of Garsen, that appear to predate both the recent and older alluvial soils described above. These are composed of deep, loose, non saline and non sodic sands or loamy sands that are generally associated with bushland or bushland thicket vegetation and gently undulating to hilly relief.

A further feature in the flood plain south of Garsen is a series of ridges parallel to the coast and above the present maximum flood water level. These appear to be of lacustrine or marine origin and related to previous beach lines. The soils are usually coarse textured, compacted, sodic and highly saline with bushland or bushland thicket vegetation.

In the northern part of the project area, the relative distribution of the main groups of differently derived soils within the project area is straightforward. The basin and levee soils developed on recent alluvium occur immediately adjacent to the river and these are flanked by the slightly higher terrace soils. However, in the southern half of the area the distribution pattern becomes more fragmented and complex as progressive erosion by the river has isolated within the flood plain many islands, ridges and erosional remnants of both the terrace and the sandy ridges.

Present agriculture, both rainfed and irrigated, chiefly occurs on the soils developed from recent alluvium and it is these soils that have the greatest potential for future development.

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3.3 Soil Classification

The soil classification system used was based on the FAO Soil Legend (FAO 1974) as modified by the Kenya Soil Survey (Siderius and van der Pouw, 1980). This classification recognises 26 major soil groups (analogous to great groups) which are in turn divided into 106 sub-groups. The groups and sub-groups present in the project area are outlined in Table 3.1.

The soils of the project area have been separated into three major physiographic divisions which reflect both their properties and their origins. The largest division (36,800 ha) has soils developed on recent alluvial deposits laid down by the Tana river and to which sediments are still being added. The major soil group in this division is the Fluvisols, in which two sub-groups have been identified. The second division (20,200 ha) has soils developed on old alluvial deposits, probably in a marine or lacustrine environment. Three major soil groups have been identified in this division: Solonetz (of which there are two sub-groups), Cambisols and Arenosols. The third division (3,000 ha) has soils developed on sands and sandstone remnants. The major soil group here is Arenosols, but Ferralsols have also been provisionally identified.

TABLE 3.1

Soil Classification

Physiographic Division	Major Soil Groups	Sub-Groups
Recent alluvial deposits	Fluvisols	Vertic Fluvisols Eutric Fluvisols
Old alluvial deposits	Solonetz Cambisols Arenosols	Vertic Solonetz Orthic Solonetz Calcic Cambisols Cambic Arenosols
Sands and sandstone remnants	Arenosols Ferralsols	Ferralic Arenosols Orthic Ferralsols

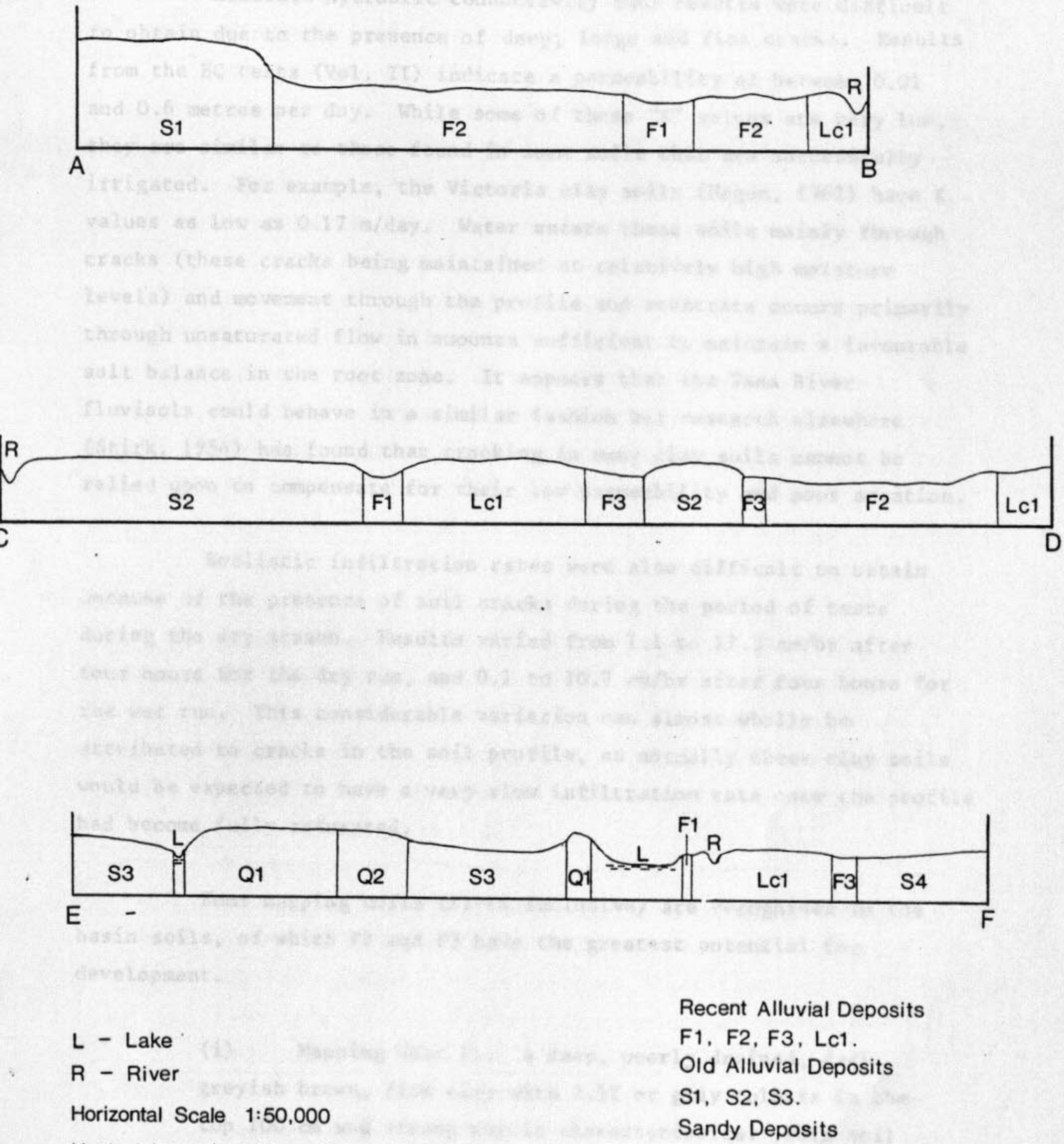

FIGURE 3·1 TYPICAL SOIL CROSS-SECTIONS

(ii) Mapping Unit F2. A deep, imperfectly drained, dark greyish brown, firm clay without 2.5Y or gley colours in the top 100 cm but with strong vertic characteristics. This soil is usually calcareous and non-saline but some profiles were observed to be slightly saline at depth. Exchangeable sodium percentage may also exceed 15 at depth. Soil reaction is neutral to moderately alkaline but can be alkaline at depth. This soil occurs on fairly level, moderately low lying sites, but rarely in depressions. The area of this soil unit is approximately 10,800 ha. The dominant vegetation is grassland, but sedges or Acacia bush may occur. The modal land classification is 2d/3sd (rice/general crops) but land class may also be 3dt, 3dT and 6dtT for rice and 3sdt, 6sdt, 6sdtT or 6sdT for general crops, depending on relief, drainage and vegetative cover (Section 4).

(iii) Mapping Unit F3. A deep, moderately well to imperfectly drained, strong brown, firm to friable clay with 7.5YR hues dominant in the top 100 cm and strong vertic characteristics. The profile is usually non calcareous, slightly acid to moderately alkaline in reaction, and non saline although at depth it may be slightly saline and slightly sodic. This soil occurs on fairly level, moderately high lying sites in the flood plain and on raised levees adjacent to old river channels. In extent, the unit covers about 11,100 ha. Vegetation associations vary from grassland to bushed grassland or woodland. The modal land classification is 1/2sd but may be class 3 or 6 for either rice or general crops, depending on additional limiting factors (Section 4). This unit generally has the best potential for irrigation development within the vertic fluvisols.

(iv) Mapping Unit F4. A deep, moderately well to imperfectly drained, dark yellowish brown, firm clay with strong vertic characteristics and a coarse textured, poorly drained topsoil of up to 50 cm depth. The profile is strongly mottled at the interface between the topsoil and the subsoil. This is a soil unit of minor extent, covering approximately 50 ha near Mnazini. It occurs on fairly level, moderately high lying sites near the river. The coarse surface may be the result of overwash that results from the river breaking through the leveè. The dominant vegetation is grassland but woodland also occurs. The modal land classification is 6sd/6sd due to the seasonally perched water table above the subsoil (Section 4).

3.5.2 The Soils of the Levee Areas

The fluvisols associated with the levee areas (designated Lc) consist of a complex of deep, stratified and highly variable soils that are less homogeneous than those of the basins and are usually eutric but may also be vertic. These soils range in texture from light sands to clays. On average they are medium textured, although the lower part of the profile is more commonly a firm clay. The profile is strongly and irregularly stratified, micaceous and, because of its position, well drained. Chemically the eutric fluvisols have a neutral to moderately alkaline reaction and are non saline, non sodic and non calcareous through the finer textured soils frequently tend to be calcareous. They have a relatively high content of 2:1 lattice clays but variable CEC levels. Available phosphorus levels are high but exchangeable potassium levels are medium to low. pH is generally between 6.5 and 7.5. Mottling is generally absent. As a result of the wide range in soil texture, the infiltration and HC rates are also highly variable (2.6 to 19.4 cm/hr and 0.5 to 18.9 m/day respectively). Two mapping units are recognised.

(i) Mapping Unit Lc1. This is a complex of deep, stratified and highly variable, well to moderately well drained soils. The profile is usually non saline, non calcareous and non sodic with topsoil textures ranging from sand to clay. The lower part of the profile is frequently firm clay. The profile is usually rich in mica and neutral

(iv) Mapping Unit F9.4 deep, moderately well to imperfectly drained, dark yellowish brown, firm clay with strong vertic characteristics and a coarse textured, poorly drained topsoil of up to 50 cm depth. The profile is strongly mottled at the interface between the topsoil and the subsoil. This is a soil unit of minor extent, covering approximately 30 ha near Mnazini. It occurs on fairly level, moderately high lying sites near the river. The coarse surface may be the result of overwash that results from the river breaking through the levee. The dominant vegetation is grassland but woodland also occurs. The modal land classification is 6ad/6sd due to the seasonally perched water table above the subsoil (Section 4).

3.5.2 The Soils of the Levee Areas

The fluvisols associated with the levee areas (designated Lc) consist of a complex of deep, stratified and highly variable soils that are less homogeneous than those of the basins and are usually eutric but may also be vertic. These soils range in texture from light sands to clays. On average they are medium textured, although the lower part of the profile is more commonly a firm clay. The profile is strongly and irregularly stratified, micaceous and, because of its position, well drained. Chemically the eutric fluvisols have a neutral to moderately alkaline reaction and are non saline, non sodic and non calcareous though the finer textured soils frequently tend to be calcareous. They have a relatively high content of 2:1 lattice clays but variable CEC levels. Available phosphorus levels are high but exchangeable potassium levels are medium to low. pH is generally between 6.5 and 7.5. Mottling is generally absent. As a result of the wide range in soil texture, the infiltration and HC rates are also highly variable (2.8 to 19.4 cm/hr and 0.5 to 18.9 m/day respectively). Two mapping units are recognised.

(i) Mapping Unit Lc1. This is a complex of deep, stratified and highly variable, well to moderately well drained soils. The profile is usually non saline, non calcareous and non sodic with topsoil textures ranging from sand to clay. The lower part of the profile is frequently firm clay. The profile is usually rich in mica and neutral to moderately alkaline in reaction. The landform is usually level to gently undulating, but can be highly dissected and uneven. Topographically it occupies a relatively high position in the flood plain adjacent to the present river channel. The extent of this unit is approximately 8,650 ha. The dominant vegetation is grassland and bushed grassland, but woodland and riparian forest also occur. The modal land classification is 6st/3st (rice/general crops) but under forest becomes 6stT (Section 4).

(ii) Mapping Unit Lc2. The soils of this unit are again variable and complex, although less so than in unit Lc1. The profile is deep, stratified, moderately well to imperfectly drained, medium to fine textured and frequently calcareous and slightly saline. This unit is also topographically high in the flood plain on usually level to gently undulating levees adjacent to old river channels. The area of this unit is approximately 400 ha, mostly covered with remnant riparian forest. The modal land classification for this unit is 6sT/6sT (Section 4).

3.6 Soils Developed on Old Alluvial Deposits

These are soils developed on marine influenced sediments that with time have lost their fluvic characteristics and, except where truncated by erosion, exhibit a mature profile. They occur primarily on the terrace lands adjacent to the present flood plain but also within the flood plain where there are terrace inliers or lacustrine ridges. Most of the soils meet the criteria for classification as vertic solonetz but in addition there are less extensive areas of orthic solonetz, calcic cambisol and cambic arenosol.

3.6.1 Vertic Solonetz

These soils are composed of vertic clays with strongly developed blocky or prismatic structure with slickensides. They are generally sodic and may also include high levels of soluble salts. The clays present are dominated by 2:1 lattice minerals with high CEC

levels. Available phosphorus and exchangeable potassium levels are moderate to high.

The difficulties of conducting field tests on these strongly cracking vertic soils during the dry season have resulted in highly variable measured infiltration and hydraulic conductivity rates. Infiltration varied between 0.3 and 17.4 cm/hr with an average of 4.1 cm/hr after four hours for the dry run and between 0.01 and 9.5 cm/hr with an average of 1.4 cm/hr after four hours for the wet run, and hydraulic conductivity K values were in the slow to very slow range (0.01 and 0.26 m/day). The movement of water through these soils, particularly when they are fully saturated during the wet season, will therefore be very slow indeed and the absence of any distinct inped mottles suggests that any such movement is likely to be restricted to structural cracks and fissures. Application of water to broken peds from subsoil horizons almost invariably caused slaking and a breakdown of both structure and porosity.

Two mapping units are recognised.

(i) Mapping Unit S1. A deep greyish brown, very firm, highly saline and usually sodic clay that is calcareous, has a pH usually between 8.0 and 8.9 and that is slowly permeable. There is frequently a thin (less than 30 cm) topsoil that is medium or coarse textured and non-saline. This is the largest soil unit mapped, covering some 13,000 ha of level to very gently undulating plain. This unit occupies nearly all of the higher terrace that borders the flood plain in the project area. The dominant vegetation is bushland. The modal land classification for this unit is 6sd/6sd (Section 4).

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Two mapping units are recognised.

(i) Mapping Unit S1. A deep greyish brown, very firm, highly saline and usually sodic clay that is calcareous, has a pH usually between 8.0 and 8.9 and that is slowly permeable. There is frequently a thin (less than 20 cm) topsoil that is medium or coarse textured and non-saline. This is the largest soil unit mapped, covering some 13,000 ha of level to very gently undulating plain. This unit occupies nearly all of the higher terrace that borders the flood plain in the project area. The dominant vegetation is bushland. The modal land classification for this unit is 6sd/6sd (Section 4).

(ii) Mapping Unit S2. A deep, greyish brown, very firm, vertic and slowly permeable clay. The profile is sodic but not highly saline. Reaction in the top meter usually is strongly alkaline and commonly exceeds pH9. There is frequently a medium textured, non saline topsoil of less than 30 cm depth. This unit has an area of about 1,900 hectares and is most often located at the edge of the present flood plain on level to undulating terrace. The vegetation is either bushland or bushland thicket though it may also be grassland. The modal land classification is 6sd/6sd (Section 4).

3.6.2 Orthic Solonetz.

These soils are generally coarse to medium textured, alkaline, saline to highly saline, sodic and calcareous. Most profiles appear to be well drained, but some show signs of imperfect drainage. When wetted, the soil rapidly slakes. The CEC is usually moderate to low, dependent on soil texture, but levels of available phosphorus and exchangeable potassium usually high. Only one mapping unit is recognised and may be found intermixed with vertic Solonetz.

(i) Mapping Unit S3. A deep, greyish brown, coarse to medium textured soil that is slowly permeable and usually compacted. The topsoil is frequently loamy sand. The 3,000 ha of this unit is usually located on level to undulating low ridges that extend into the present flood plain. The dominant vegetation is bushland thicket. The modal land classification is 6sd/6sd (Section 4).

3.6.3 Calcic Cambisol/Cambic Arenosol Complex

These are non-saline, non sodic soils of coarse to medium texture. They are characteristically hard and compacted. They are found inter-mixed with the Solonetz units and likely have their origin in the coarser deposits of the old alluvium, perhaps even remnant sand dunes that were long ago reworked and levelled. The CEC is moderate, 12-15 m.eq/100g,

(ii) Mapping Unit S2. A deep, greyish brown, very firm, vertic and slowly permeable clay. The profile is sodic but not highly saline. Reaction in the top meter usually is strongly alkaline and commonly exceeds pH9. There is frequently a medium textured, non saline topsoil of less than 30 cm depth. This unit has an area of about 1,900 hectares and is most often located at the edge of the present flood plain on level to undulating terrace. The vegetation is either bushland or bushland thicket though it may also be grassland. The modal land classification is 6sd/5sd (Section 4).

3.6.2 Orthic Solonetz

These soils are generally coarse to medium textured, alkaline, saline to highly saline, sodic and calcareous. Most profiles appear to be well drained, but some show signs of imperfect drainage. When wetted, the soil rapidly slakes. The CEC is usually moderate to low, dependent on soil texture, but levels of available phosphorus and exchangeable potassium usually high. Only one mapping unit is recognized and may be found intermixed with vertic Solonetz.

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These are non-saline, non sodic soils of coarse to medium texture. They are characteristically hard and compacted. They are found inter-mixed with the Solonetz units and likely have their origin in the coarser deposits of the old alluvium, perhaps even remnant sand dunes that were long ago reworked and levelled. The CEC is moderate, 12-15 m.eq/100g, and the levels of available phosphorus and potassium are high. Only one mapping unit is recognised.

(i) Mapping Unit S4. This small unit (700 ha), is deep, greyish brown, coarse to medium textured, slowly permeable and slightly alkaline. This unit is found on level to slightly undulating relief at the edge of the present flood plain, and is usually covered by bushland thicket or bushland. The modal land classification is 6sd/6sd (Section 4).

3.6.4 Complex Unit on old Alluvial Deposits

This is a complex of mapping units S1 to S4, so mapped because the intermix of two or more of these profiles is such that it is not possible to separate them at a mapping scale of 1:50,000. About 1,600 ha have been mapped as this unit.

(i) Mapping Unit Sc. A complex with variable amounts of mapping units S1 to S4.

3.7 Soils Developed on Sandy Deposits

These are soils developed on sandstone and possibly on some former beach deposits. As a result they are typically coarse textured (sand to sandy loam) and somewhat excessive to excessively drained, deep and relatively infertile. The CEC, total nitrogen and organic carbon levels are low and the available phosphorus and exchangeable potassium are moderate. Infiltration rates in these soils are moderate to rapid, ranging from 13.5 to 44.5 cm/hr for the dry run and 2.2 and 14.7 cm/hr for the wet run. Hydraulic conductivity K values are slow to moderate, ranging from 0.89 to 4.26 m/day. Two mapping units have been provisionally identified: ferralic Arenosols (designated Q1) and a complex of ferralic Arenosols and orthic Ferrasols (designated Q2). Because of their rapid infiltration and low available water holding capacity, neither unit is considered suitable for irrigation.

(i) Mapping Unit Q1. A deep, somewhat excessive to excessively drained, pale brown to reddish brown, apedal, loose to very friable coarse textured soil that is non saline, non calcareous and slightly to very acid (pH less than 6.0). Exchangeable sodium percentage is low. This unit occupies 2,950 ha and occurs on level to undulating low, elongated ridges. The dominant vegetation is bushland or bushland thicket. The modal land classification is 6sT/6sT (Section 4).

(ii) Mapping Unit Q2. The typical profile for this unit is similar to Q1 but is in a lower slope location and apparently truncated. The texture ranges from loamy sand to sandy clay loam. These soils tend to be neutral to slightly alkaline (pH greater than 6) in the topsoil and very alkaline in the subsoil. They also tend to be non saline in the top 50 cm and saline in the lower profile. This may well be related to their generally lower topographic position in the landscape and to their somewhat finer texture (to SCL) at depth. Approximately 50 ha have been mapped along the mid to lower slopes of low undulating ridges. The dominant vegetation is bushland although some areas have been cleared for rainfed subsistence crops. The modal land classification is 6st/6st (Section 4).

4.0 LAND SUITABILITY FOR IRRIGATION

4.1 Classification System

There are a number of different methods of assessing land suitability and many factors that can be considered when establishing a suitability for a specific crop or range of crops. Whatever the method used, modifications are frequently necessary to take into consideration local conditions as well as the availability of, or lack of, certain data. The USBR system for the classification of irrigated land use was chosen as the basis for this study. Modifications made allow for conditions found in the project area and the lack of certain economic data. The land class reflects primarily the physical, and to some extent the chemical constraints of the area. Since flooding is common to all the Fluvisols, it is assumed that flood control will be required before any irrigation can take place, and thus flooding *per se* was not included as a limitation in the land classification, though it is implicit in the drainage limitations. The USBR system allows for six land classes, but for reconnaissance level surveys usually only four classes are used, with all lands that fail to meet the criteria for Classes 1, 2 and 3 (suitable) falling into Class 6 (unsuitable).

Class 1 - lands with little or no limitation to irrigated crop production (basin irrigation of rice and/or basin-furrow irrigation of other crops); lands that potentially have a relatively high payment capacity.

Class 2 - lands with moderate limitations to irrigated crop production (basin and/or basin-furrow); lands that have an intermediate payment capacity.

Class 3 - lands that are suitable for irrigated crop production but are approaching marginality because of their severe limitations; lands that have payment capacity potential which is lower than for Classes 1 and 2.

Class 6 - lands with very severe limitations or that in other ways do not meet the criteria for Classes 1, 2 and 3. These lands are considered not suitable for irrigated crop production.

4.2 Specific Criteria Used

The major limiting factors, after flooding, that restrict the use of the land for irrigation fall into four broad categories: soil, drainage, topography and density of vegetation cover.

4.2.1 Soils

Limiting soil factors (symbol 's') include:-

i) surface and sub-surface texture

ii) type and stability of soil structure

iii) depth to restricting (impermeable) layer

iv) degree of salinity and/or alkalinity

v) natural fertility or degree of ability to hold additives

vi) available water holding capacity

vii) ability of the soil to accept water (infiltration rate)

Of these limitations, (iii) and (v) only influenced the classification of the Arenosols. The other factors each had some influence on all soils.

4.2.2 Drainage

Limiting drainage factors (symbol 'd') include:-

i) presence of natural surface drains or degree of difficulty installing such drains

ii) sub-surface permeability of profile and/or ease with which drains can be installed. This is indicated by hydraulic conductivity measurements and profile characteristics such as mottles.

The relatively level macro topography and the uneven micro topography mean surface drainage in many places may be difficult to install. Subsurface drainage in the vertic Fluvisols varies from moderate to poor, largely because of topographic position, but usually all dry out at least for a short period every year. The cracking on drying then facilitates the re-wetting of these soils, but means that the initial water duty each season is high. Implicit in the drainage factor is the degree and length of flooding as the lower areas that are flooded longest also have the poorest drainage.

4.2.3 Topography

Limiting topographic factors (symbol 't') include:-

i) slope - length and steepness of slope indicate the degree of land forming required

ii) surface - degree of evenness or roughness of the land surface indicates the degree of levelling required to give uniform distribution of water.

Within the project area there are very few places where the slope exceeds two percent and these are usually short, steep slopes adjacent to or into old channels, so slope as such is not a factor in the present land classification. The surface factor is a very important one as the surface is rarely smooth or even gently undulating. Because of the swelling and shrinking of the majority of the soils some form of gilgai is nearly always present, the degree differing from soil type to soil type. In addition, so long as these soils are allowed to dry out after each irrigation, annual levelling could be a continuing exercise in each scheme.

4.2.4 Vegetation

Limiting ground cover (symbol "T"):-

i) the density and type of vegetation on the land indicates the degree of clearing necessary before land preparation can begin. Vegetative cover varies from non restrictive (grasslands) to severely restrictive (riparian forest).

The specific limitations of each land unit in regard to rice and to general crops, are discussed in Sections 4.4 and 4.5.

4.3 Potential Land Suitability

Kenya Soil Survey reports show both present and potential land suitability. Potential land suitability is the land class that can be expected after all "reasonable" modifications to limiting factors have been made. The term "reasonable" varies from place to place and time to time but generally is determined by cost versus return on investment.

Improvements that can be made to lands in the project area are essentially confined to topographic and vegetative limitations. Soil deficiencies cannot be easily modified because the main restrictions

are usually physical rather than chemical. For saline soils, the deficiency cannot be removed easily since leaching of salts will be difficult due to the generally very slow permeability. Drainage limitations, for the same reason, will be difficult to remove, though in some cases installation of surface drainage will reduce the limitation, as will flood protection. But the lower lying soil units (F1 and F2) will likely not benefit from any drainage investment unless it is very high. The limitation most easily removed is the 't', as levelling by light machinery is generally all that is required to smooth the surface. Very little land forming will be necessary. The "T" restriction can be removed by land clearing, though the degree of cost and effort varies with the density and type of vegetative cover. In terms of present versus potential land classes, for the most part, land units with soil and drainage limitations will remain the same. Those units with 't' and/or 'T' limitations can be raised one or two classes depending on whether they are a major or minor limiting factor. Thus Class 3t or Class 3T could be raised to Class 1 by doing the necessary levelling or clearing, but Class 3sdT would be 3sd after clearing.

A summary of the existing land class suitability gradings appropriate to the identified soil types is given in Table 4.1, together with an indication of the types of modification and improvements considered feasible and the ultimate land class potential that is achievable.

4.4 Land Suitability Classes for Rice

Rice is a crop that requires a number of special conditions that are very different from those required by most agricultural crops. Specifically they require a slowly permeable soil, or a soil that can be made slowly permeable (puddled). Thus finer textured and imperfect to poorly drained soils usually have a higher suitability for rice than such crops as maize which likes a deep, well drained soil.

The Fluvisols of the project area, with the exception of those immediately adjacent to the river, are thus better suited for rice than for general crop production.

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TABLE 4.1

SUMMARY OF PRESENT AND POTENTIAL LAND SUITABILITY

Soil Unit	RICE Present Land Class	RICE Possible Modification	RICE Potential Land Class	GENERAL Present Land Class	GENERAL Possible Modification	GENERAL Potential Land Class
F1	3d	-	3d	6sd	-	6sd
	6dt	-	6dt	6sdt	-	6sdt
F2	2d	-	2d	3sd	-	3sd
	3dt	t	2d	~~3sdT~~	~~T~~	~~3sd~~
	3dT	T	2d	6sdt	-	6sdt
	6dtT	-	6dtT	6sdT	-	6sdT
				6sdT	-	6sdT
F3	1	-	1	2sd	-	2sd
	2t	t	1	2sdT	T	2sd
	2T	T	1	3sdt	t	2sd
	3T	T	1	3sdT	T	3sd
	6tT	-	6tT	6sdtT	-	6sdtT
F4	6sd	-	6sd	6sd	-	6sd
Lc1	3st	t	3s	2st	t	2s
	6s	-	6s	3s	-	3s
	6st	-	6st	3st	t	3s
	6stT	-	6stT	3stT	t,T	3s
				6st	-	6st
				6stT	-	6stT
Lc2	6stT	-	6stT	6stT	-	6stT
S1	6sd	-	6sd	6sd	-	6sd
S2	6sd	-	6sd	6sd	-	6sd
S3	6sd	-	6sd	6sd	-	6sd
Sc	6sd	-	6sd	6sd	-	6sd
Q1	6sT	-	6sT	6sT	-	6sT
	6st	-	6st	6st	-	6st
Q2	6st	-	6st	6st	-	6st

Budelman (personal communication) found that, for rice grown on levee soils, there was a significant decrease in the yield as distance from the field inlet increased. This is essentially a water stress situation as the levee soils tend to drain more rapidly and thus ponding is more difficult to achieve. This becomes particularly crucial where water applications are few and widely spaced during the growing period of the crop. For this reason, these soils, unless known to be of uniform medium to fine texture, are classed as unsuitable for rice crops. Table 4.2 summarises the criteria used in establishing the suitability of the various soils for rice.

4.4.1 Land Class 1

Lands with little or no limitations to irrigated rice production. There are 7,820 hectares of Class 1 rice land in the project area, usually associated with soil mapping unit F3. Since the unit is relatively high lying and supports grassland vegetation, there are essentially no vegetative limitations and flood levels will be fairly low. Some levelling will be necessary.

4.4.2 Land Class 2

Lands with moderate limitations to irrigated rice production that can frequently be modified with an acceptable level of inputs but whose development costs are greater than those lands of Class 1. There are 6,820 hectares of Class 2 rice land in the project area. Flood levels are generally higher in this unit.

The various sub-classes present are as follows:-

i) Class 2d. The 5,995 hectares of this unit are associated with soil mapping unit F2. Drainage is the major limiting factor as these soils are moderately low lying. Some levelling will be necessary but there are no vegetative limitations. Potential Land Class 2d.

TABLE 4.2

LAND CLASSIFICATION CRITERIA FOR RICE

Specifications for Lower Tana River Irrigation Project

Property Symbol	Class 1	Class 2	Class 3
Texture (s)	Clay to clay loam over clay (within 50 cm) non compacted	Clay to clay loam over clay (within 50 cm) non compacted	Clay to clay loam over clay to clay loam (within 50 cm) non compacted
Depth (s)	90 cm plus	90 cm plus	90 cm plus
Reaction (s)	pH <9.0 unless soil is non sodic and calcareous	pH <9.0 unless soil is non sodic and calcareous	pH < 9.0 unless soil is non sodic and calcareous
EC (1:2:5) (s)	< 1 mS/cm to 100 cm	< 1.6 mS/cm to 100 cm	< 2.5 mS/cm to 100 cm
Slope (t)	< 1%	< 1%	< 2%
Micro-Relief (t)	Smooth except for gilgai and minor undulations	Smooth except for gilgai and minor undulations	Somewhat irregular (< 1 m) but no major gulleys or dissection
Vegetation (T)	Up to moderate bush	Up to moderate to thick bush with high palms	Up to dense bush and thicket but excluding continuous high woodland/forest
Drainage (d)	Well to imperfectly drained, may have surface water but only for short periods	Well to imperfect/ poorly drained, may have surface water for several months	Well to poorly drained, may have surface water or be waterlogged for major parts of the year
CLASS 6: Land that does not meet the above criteria			

ii) Class 2t. There are only 540 hectares of this unit mapped in the project area, all associated with soil unit F3. These are sectors where the micro-topography (gilgai) are strong and thus will require considerable land levelling. Where permanent levelling is achieved, these could become Class 1 lands.

iii) Class 2T. The 285 hectares mapped are also associated with soil unit F3 and occur where there is wooded grassland in the flood plain. The vegetation cover is the major limitation and hence clearing could raise these lands to Class 1.

4.4.3 Land Class 3

Lands that are marginally suitable for rice production because of one or more severe limitations and whose payment capacity is less than that of Class 1 and 2 lands. There are 8,030 hectares of this land class in the project area, associated mainly with the vertic Fluvisols. Flood levels vary with the soil mapping unit from deep and prolonged (F1) to low and of short duration (Lc1).

The following sub-classes are present:-

i) Class 3d. 4,135 hectares associated with soil unit F1. No vegetative limitations but levelling required; poor drainage and seasonal standing water are the major limitations. These limitations are not likely to be modified significantly enough to change the land class.

ii) Class 3dt. 1,300 hectares associated with soil unit F2. No vegetative limitations but the levelling and drainage required are the major constraints. Potential Land Class 2d.

iii) Class 3dT. 1,625 hectares also associated with soil unit F2. Vegetation and drainage are the major limitations. Potential Land Class 2d.

iv) Class 3T. There are only 670 hectares of this unit, all associated with soil unit F3, occurring where there is wooded grassland in the flood plain. The vegetation cover is the major limitation; some levelling required. Land has potential to be Class 1.

v) Class 3st. This small unit (300 hectares) is associated with the finer textured levee soils within soil unit Lc1. The variations in the soil profile and topography are the major limitations. Potential Land Class is 3s.

4.4.4 Land Class 6

Lands that are considered unsuitable for irrigated rice production due to very severe deficiencies or which for any reason do not meet the criteria for Land Classes 1, 2 or 3. Sixty-two percent (32,330 hectares) of the land area surveyed fall within this class and no soil mapping unit is exempt. The majority of this land class (about 65 percent) has major soil deficiencies. These include the soils developed on old alluvial and on sandy deposits (soil mapping units S and Q) as well as soils developed on levee sediments (soil unit Lc). Soils developed on basin sediments (soil unit F) have drainage, topography and/or vegetation limitations which have potential to be modified, but these modifications are not considered economic at present.

4.5 Land Suitability Classes for General Crops

The crops in this category - maize, grams, vegetables, bananas, cowpeas, etc., have a wide range of optimum requirements but generally soils selected for irrigated production of these crops ideally should be deep, medium textured and well drained. Table 4.3 summarises the criteria used in establishing the land classes and sub-classes.

TABLE 4.3

LAND CLASSIFICATION CRITERIA FOR GENERAL CROPS

Specifications for Lower Tana River Irrigation Project

Property Symbol	Class 1	Class 2	Class 3
Texture (s)	Fine sandy loam to friable clay loam, non compacted	Sandy loam to permeable or structured and self-mulching clay, non compacted	Loamy sand to permeable or structured and self-mulching clay, non compacted
Depth (s)	90 cm plus and >150 cm to impermeable horizon	60 cm plus and > 120 cm to impermeable horizon	45 cm plus and > 100 cm to impermeable horizon
Reaction (s)	pH < 9.0 unless soil is non sodic and calcareous	pH < 9 unless soil is non sodic and calcareous	pH < 9 unless soil is non sodic and calcareous
EC (1:2:5) (s)	< 1 mS/cm	< 2.5 mS/cm	< 2.5 mS/cm
Slope (t)	< 1%	< 3%	< 3%
Micro-Relief (t)	Smooth to very slightly undulating	Smooth to slightly undulating	Smooth to irregular
Vegetation (T)	Up to moderate bush	Up to moderate to thick bush with high palms	Up to dense bush and thicket, but excluding continuous high woodland forest
Drainage (d)	Well drained	Well to imperfectly drained, may have surface water for short periods	Well to imperfectly drained, may have surface water for several months
CLASS 6:	Land that does not meet the above criteria		