CRANFIELD

Silsoe College

Soil Survey & Land Research Centre

ITONA TEA ESTATES:

IRRIGATION AND SOILS

Eur Ing E K Weatherhead
BA MA CEng MICE

R W Payton
BSc PhD

Professor M K V Carr
BSc PhD

Final Report
Reprinted July 1992

ITONA TEA ESTATES:

IRRIGATION AND SOILS

INDEX

APPENDICES

NOTES

Previous Reports

This final report combines the report issued in December 1990 with the Addendum issued in May 1991, including results of communications up to that date.

Base Maps

1. The base maps used in this report are photographically reproduced from local surveys. No responsibility is taken for their accuracy.

2. The contour levels shown appear to be from incorrect datums. For levels to the national datum (1:50000 maps):

Estate	Add
Itona	190 m
Stone Valley	335 m
Idetero	100 m
Maganga	10 m

3. The field names shown have been superseded. See Tables 5.1 to 5.4 and Figs. 7.1 to 7.4 for relationships to new field names. The report uses new field names except where prefixed by (old).

Acknowledgements

The reports authors wish to acknowledge the help provided by many Lonrho and Mufindi Tea Company staff in Tanzania, particularly Bimb Theobald, John Boyd-Moss and Peter Rowland. We are especially indebted to Anna Boyd-Moss and Coe Rowland for their kind hospitality.

PHOTOGRAPHS

EXECUTIVE SUMMARY

This report describes the soils and advises on irrigation development and soil management for the Itona, Stone Valley, Idetero and Maganga Tea estates of the Mufindi Tea Company, following a detailed study of the climatic, soil, water and tea resource base.

1:10000 scale soil maps of the four estates have been produced, together with descriptions and physical and chemical analyses of the main soils. Deep friable red clays predominate in existing tea areas; their chemical properties are unfavourable to many agricultural crops but their strong acidity and soil physical properties, including large water holding capacities, make them well suited to tea production. Areas of poorly suited soils are also shown.

Yield increases of up to 50% can be expected from a well designed and managed irrigation system, together with improved continuity of production.

The report supports the installation of a permanent irrigation system for 640 ha of the existing 746 ha, powered by electric pumps and developed in step with the electrification programme. In-field equipment should be a rotary impact sprinkler system on portable aluminium laterals supplied from buried mainlines, operated either conventionally or alternate set.

A system capacity of 4 mm/day net is proposed for existing tea areas, meeting 90% of seasonal water requirements. Irrigation would take place from June to November, applying typically 400 to 600 mm of water. The design is based on the less water-retentive soils, giving identical equipment and schedules across all four estates. Application depths and application rates are chosen to avoid night-time pipe moves with night-time sprinkler hops only on clonal tea under the alternate set option.

Water availability is a major uncertain limiting factor. The analysis is based on only two years flow data, which showed large variations in yield; continuing study and phased development is recommended. Two abstraction reservoirs and two storage reservoirs are recommended; topographic surveys of the latter are required before further design.

Recommendations are made for the siting of new tea areas from both soil suitability and water availability viewpoints. Both main areas are dependent on water from the new storage reservoirs.

The estimated marginal cost of the additional tea produced, considering irrigation costs only, are in the range of £0.17 - 0.45 and £0.25 - 0.68 per kg of made tea for clonal and seed tea respectively depending on assumptions made, calculated over a 10 year period at a 10% real interest rate.

It is intended that this report is passed to the equipment suppliers for detailed design and costing, before a final decision on investment and phasing is made.

CHAPTER 1

INTRODUCTION

Commercial irrigation of tea was first introduced into the Mufindi district of Southern Tanzania in 1970, following promising results from irrigation experiments at the Ngwazi Tea Research Unit from 1967 to 1970. Over the next decade the area of tea under irrigation was expanded, initially on the Brooke Bond group estates and later on the Lonrho estates. Preliminary feasibility studies identified the most suitable areas of tea and sources of water. A copy of the report prepared in 1970 for the Stone Valley Tea Company is attached as Appendix 1.

These irrigation schemes were based on self-contained, fully portable rotary impact sprinkler irrigation units designed to apply about 100 mm of water over a 20-22 hour period on an area of typically 2.5 ha. Water was stored behind small earth dams. Variously one, two or three rounds of irrigation might be applied over a season (from July to November) to unpruned tea, depending on the availability of water, equipment and at times fuel.

Commercial experience confirmed that irrigation was profitable and together with changes in fertiliser policy was a major reason why yields on some estates in the Mufindi district increased from around 1000 kg ha^{-1} of made tea in 1970 to about 2500 kg ha^{-1} by 1985. In the mid 1980s a new research programme began at the Ngwazi Tea Research Unit to identify new target yields, particularly for clonal tea, and to specify how these could be achieved through good irrigation, nutrition and harvesting management practices. This work, managed by Silsoe College, has continued into 1991.

In 1986 Lonrho plc regained management control of what is now the Mufindi Tea Company from the Tanzania Tea Authority, who retain a financial interest. Although some irrigation was still practiced, much of the equipment was old and needed replacement. Irrigation was recognized to be a key element for raising yields, improving continuity of production through the year and creating a profitable company. The opportunity existed to invest in a cost-effective irrigation scheme, and exploit the results of the research at Ngwazi. The decision was taken therefore to consider a major financial investment in irrigation equipment and water storage facilities.

Accordingly, Silsoe College and the Soil Survey and Land Research Centre were invited to undertake an irrigation needs assessment for Itona Tea estates, comprising Itona, Stone Valley, Idetero and Maganga estates in Mufindi. The principal objectives of this study were:

1. to describe and map the principal soils in the tea areas.

2. to assess the water requirements and water availability for irrigation, and identify suitable additional dam sites.

3. to estimate the likely yield and other benefits resulting from irrigation.

4. to specify design criteria for the irrigation schemes.

5. to undertake a preliminary cost-benefit analysis.

6. to suggest guidelines for operating the irrigation systems.

A team of three people, Professor M K V Carr, Silsoe College (tea irrigation specialist), Eur Ing E K Weatherhead, Silsoe College (irrigation engineer) and Dr R Payton, Soil Survey and Land Research Centre (soil scientist) visited Mufindi in June 1990. This report is based on observations made and data collected at that time, on measurements of the 1990 dry season streamflows from weirs installed during the visit, and on subsequent soil physical analysis carried out in the U.K.

The approach taken in our report is based on the discussions held at the beginning of and during our visit, identifying the need for an improved method of irrigation. The current method is adequate for the partial irrigation of tea near water sources, but is labour intensive, fuel inefficient, has excessive maintenance costs and does not achieve maximum potential benefits. The imminent prospect of electrification and the availability of finance give an opportunity now to move on to a more efficient and manageable system which can meet a higher proportion of the demand whilst giving smaller more frequent applications.

This change allows the switch from portable diesel to static electric pumps and the burial of those mains and submains which do not need to be portable. Portable sprinklers remain the only practical in-field option, but the specification should be optimised. Meanwhile, the existing diesel units, plus any bought for use during the changeover period, would be progressively moved to Idetero and then Maganga and/or become back-up units.

CHAPTER 2

RESOURCE BASE: CLIMATE

2.1 General

Itona Tea estates are situated around latitude 8° 30' S and longitude 35° 25' E at altitudes between 1780 m and 2050 m above sea level. The climate is characterised by relatively warm, wet weather from November to April, then cool drier or dry weather from May to August, and finally warm dry weather from September to the start of the rains in mid-November. The nearby 600 m deep Uzungwe escarpment gives the Mufindi district unique ecological conditions which allow tea to survive and grow even without irrigation, with misty conditions during July and August often mitigating the effects of the dry weather at that time.

The important variables which influence the yield of tea are mean air (or soil) temperatures, saturation deficit of the air (a measure of its dryness), water availability and total incoming solar radiation (sunshine) levels. Because of the high altitudes, temperatures are relatively close to the base temperature for the growth of tea shoots (ca. 12 to 13°C) even during the main growing season . They average 17 to 18°C from October to March, before declining to only 12 to 14°C during June, July and August, when rates of shoot extension become very slow. The saturation deficit of the air is always small (0.3 to 0.6 kPa), well below the critical value of about 2.3 kPa which can restrict the shoot growth rates in the hot dry season in Malawi. Potential evapotranspiration rates (ET) range from about 3 mm/d during June, July and August, to 5 mm/d during October and November. The annual ET total is about 1500 mm, which is close to the average annual rainfall. Rainfall is unevenly distributed, however, with the majority (over 80%) falling during the rainy season from November to May. During the dry season, potential evaporation rates exceed rainfall by 350 to 700 mm depending on the year and the distance of individual estates from the Uzungwe escarpment. The total incoming solar radiation over the year is very similar to that received in the other major tea growing areas in eastern Africa at 67 TJ/ha.

2.2 Weather records

Weather data recorded at the Ngwazi Tea Research Unit (alt. 1890 m) are available for the periods 1967 to 1970 and 1986 to the present. Some temperature data have been recorded at Stone Valley estate. Long-term rainfall records (from 20 to 40 years) are available from 12 tea estates within the Mufindi district.

Weather data are summarised below in Tables 2.1 to 2.5. These show the results of a detailed analysis by the Ngwazi Tea Research Unit of the long term rainfall records in Mufindi, and give a good indication of the year to year differences in the potential soil water deficit under a full cover of tea. This is a measure of by how much evaporation exceeds rainfall over the dry season and gives an indication of the maximum amount of irrigation water (net of losses) which might be required if the soil was to be kept close to field capacity (the maximum amount of water a soil can retain in the pores when free drainage has ceased). These values can also be used to predict the expected yield response to full irrigation.

Conditions at the Ngwazi site itself are marginally warmer than on the Itona Tea estates by up to 1°C in the dry season though evaporation rates during June, July and August are probably slightly lower. However, it has a lower total rainfall, a longer dry season, and a resulting higher potential soil water deficit.

Annual rainfall

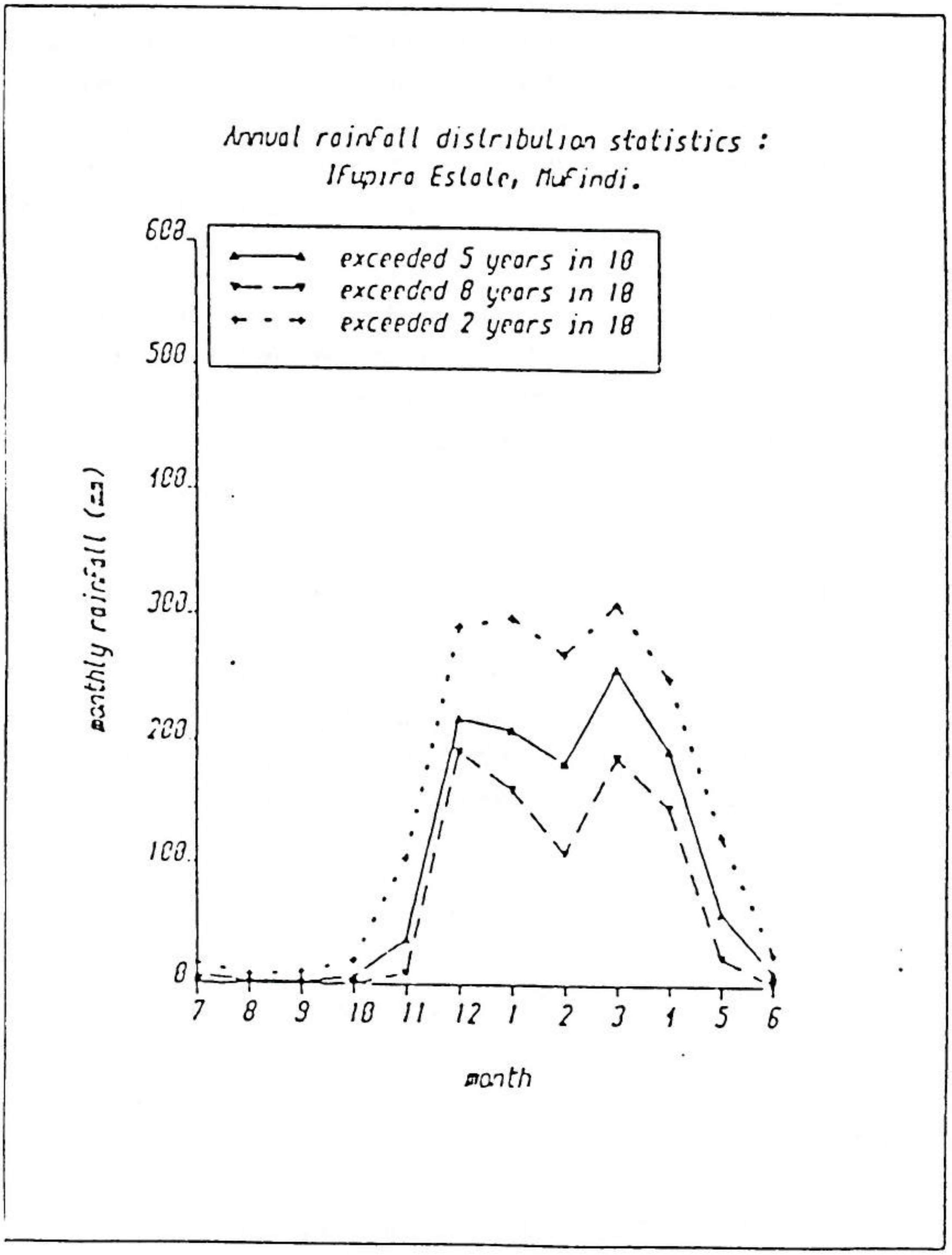
The average annual rainfall total on Stone Valley and Itona estates is between 1300 and 1400 mm. A similar total can be expected at Maganga estate and perhaps slightly less, 1200 to 1300 mm, at Idetero estate. There is a large year to year variation around these averages. A statistical analysis of the rainfall data on Stone Valley estate shows the range of expected rainfall totals (Table 2.1). The largest recorded value is 1698 mm and the lowest 963 mm; 8 years out of 10 more than 1084 mm can be expected.

Table 2.1. Annual rainfall (mm) at Stone Valley estate based on data from 1958 to 1980.

Probability of exceedance				
Highest	20%	50%	80%	Lowest
1678	1453	1310	1084	963

The monthly rainfall distribution at neighbouring Ifupira estate is shown in Figure 2.1. In 8 years out of 10 the monthly rainfall from December to April inclusive will exceed 120 mm, whereas in 2 years in 10 monthly totals will be greater than 300 mm over the same period. Very little rain can be expected after May and before November.

Figure 2.1 Monthly rainfall distribution at Ifupira estate at 20%, 50% and 80% probabilities of exceedance.



Start of the dry season

This has been defined as the first week in a 3-week spell when the mean potential rate of evaporation exceeds mean weekly rainfall. The median value across most of the tea areas in Mufindi is between the last week of May and the first week of June, with a range on two neighbouring estates (Table 2.2) from 30 April (earliest) to 2 July (latest).

Table 2.2. Start of the dry season (week beginning) on Lupeme and Ifupira estates.
Data for 1954 to 1986 (Lupeme) and 1959 to 1986 (Ifupira).

Rephrase ?

		Probability of exceedance			
Estate	Earliest	80%	50%	20%	Latest
Lupeme	30 April	7 May	21 May	4 June	2 July
Ifupira	30 April	7 May	21 May	4 June	2 July

Start of the wet season

A similar definition has been used to define the start of the wet season, namely the first week of a 3-week period when the mean weekly rainfall exceeds the mean weekly potential rate of evaporation. The wet season will normally have started by 3 December, but it can be as early as 5 November or as late as 17-24 December (Table 2.3).

Table 2.3. Start of the wet season (week beginning) on Lupeme and Ifupira estates.
Data for 1967 to 1985.

		Probability of exceedance			
Estate	Earliest	80%	50%	20%	Latest
Lupeme	5 Nov	19 Nov	3 Dec	17 Dec	24 Dec
Ifupira	5 Nov	26 Nov	3 Dec	10 Dec	17 Dec

Durations of the wet and dry seasons

The difference between the mean start and end dates of the wet season, as defined above, is 24 weeks, but with a range from 21 weeks to 28 or 30 weeks in extreme years, on Lupeme and Ifupira estates. On estates closer to the escarpment edge the wet season can be 3 or 4 weeks longer than this.

Similarly the average length of the dry season is about 27-28 weeks on Lupeme and Ifupira estates (extreme range 23 to 31 weeks).

Soil water deficits

Evaporation measurements are not as plentiful as rainfall, having only been recorded over limited periods of time at a few sites. During the rains and early dry season they average 80 to 100 mm/month, but rise to a peak of about 150 mm/month in October. The evaporation variability from year to year is likely to be small relative to rainfall variability. These evaporation figures are equated directly to water use by a full canopy of tea well supplied with water.

During the rainy season, rainfall will always exceed evaporation over any 3 week period. No irrigation of mature tea will therefore be needed. Over the dry season evaporation exceeds rainfall by an average of 550 to 600 mm, with a range from 400 to 450 mm in a 'wet' year up to 630 to 670 mm in a very 'dry' year. These potential soil water deficits are shown in Table 2.4.

Table 2.4. Potential soil water deficits (mm) at the end of the dry season at Lupeme and Ifupira estates.
Data for 1967 to 1985.

	Probability of exceedance				
Estate	Maximum	20%	50%	80%	Minimum
Lupeme	670	620	580	520	410
Ifupira	630	610	570	530	440

The original work at the Ngwazi Tea Research Unit suggested that the allowable soil water deficit at which irrigation of deep (4.3 m) rooting mature seedling tea should begin was about 100 mm. In Lupeme and Ifupira estates this critical value is normally first reached during the first half of July , and never before the middle of June or after the middle of August (Table 2.5).

Table 2.5. Date (week beginning) when soil water deficit first exceeds 100 mm at Lupeme and Ifupira estates.
Data for 1967 to 1985

		Probability of exceedance			
Estate	Earliest	75%	50%	25%	Latest
Lupeme	11 June	25 June	9 July	16 July	20 Aug
Ifupira	11 June	25 June	2 July	16 July	13 Aug

2.3 Effects of climate on irrigation response

Dry weather from May to November restricts the yield of tea grown without irrigation. Low temperatures during May to August limit the rates of shoot extension, even when tea is irrigated, but the tea continues to use water at this time. Any irrigation applied during these months which replenishes soil water deficits is like 'money in the bank' and will be converted into yield when temperatures rise in September and October.

With prevailing temperatures of 17 to 18 °C from October to April, the length of the shoot replacement cycle (the time taken for a bud released from apical dominance to grow into a shoot of 3 leaves and a bud ready for harvest) is about 70 to 80 days. Without irrigation only 2 or 3 major flushes will be completed before low temperatures restrict shoot growth in April/May. With irrigation there is an extra (very large) flush in October. Maximum temperatures at the time are only 25 to 26 °C and the saturation deficit of the air is only 0.6 to 0.9 kPa. Tea shoots are therefore able to grow rapidly if irrigated. (Note that this is not the case in Malawi where high maximum temperatures (> 30 °C) and dry air can sometime restrict shoot growth rates in September and October even when the tea is irrigated.)

CHAPTER 3

RESOURCE BASE: SOILS

3.1 Methods of assessment

The soils of the four tea estates were mapped using the free survey method described by Soil Survey Staff (1951). This involved prediction of the expected soil types according to changes in environmental factors such as landform, slope and geology under the prevailing climate of the region using accepted principles of soil genesis. Soil inspection points were then sited to test these predictions and to cover the area to be surveyed. Soils were examined to 3 m depth using a soil auger with extension rods and described according to the methods given in the FAO Guidelines for the Field Description of Soils (1977) and in Hodgson (1976). Areas of similar soil types were delineated as units on the 1:10,000 scale topographic maps of the four estates.

The main soils encountered on the four estates were described in more detail in soil profile pits excavated to 3 m depth and sited to characterize the most extensive map units. The soil layers or **horizons** encountered in these soil pits were sampled for chemical and physical analyses, including their moisture retention characteristics. Detailed soil profile descriptions and analytical results are given in Appendix II where methods of analyses are also described. The main soil types mapped have been classified according to the FAO-UNESCO (1988) system and subdivided into soil series according to soil texture, depth and other properties deemed to be of significance to soil management. The soil series have been given local place names following the convention used elsewhere in the world and their distribution is shown on the four soil maps which accompany this report (Appendix III). It should be noted that these names do not relate to nationally recognized soil series in Tanzania and have been defined for local correlation only.

3.2 Geology and landscape

This part of the Southern Highlands lies north east of the Mufindi Escarpment at elevations generally between 1700 to 2000 metres. The terrain is hilly and mainly strongly undulating, consisting of convex ridges falling away in long slopes of between 6 and 10° to narrow, steeper sided valleys which often remain in evergreen montane forest or secondary bush. The valley separating the Stone Valley and the Maganga estates is

1. Soil augering, Itona Estate (I1 towards W3)

2. Soil inspection, Itona Estate

particularly steep-sided and the tea plantings in the northern part of the Maganga Division occupy steep, often rocky, slopes of 20° or more.

The rock type of the area is of granitic composition but rarely outcrops at the surface and is covered by a deeply weathered mantle which attains depths of several metres on lower ridge flanks, often thinning to depths of little more than a metre on ridge crests. The steeper terrain of the Maganga Division forms the exception to this rule. Here outcrops of relatively fresh, hard, spheroidally weathered granite are common on summits and upper slopes.

The deeply weathered mantle which predominates on lower slopes has experienced strong weathering processes for a long period of time and gives rise to soil parent materials which are relatively high in clay minerals and oxides of iron and aluminium with few weatherable primary minerals which can release plant nutrients. On middle and lower slopes soil parent materials are rarely *in situ*, usually consisting of slope deposits or colluvium derived from deeply weathered granite by processes of soil creep and wash. The shallower depth to rock on ridge crests and upper slopes results in parent materials consisting of compact pinkish weathered granite which can be cut with a spade. These materials, known as granite saprolite, tend to have a greater reserve of silt-sized minerals that can weather to release plant nutrients such as potassium. Shallow gritty, coarse textured soil parent materials directly over hard granite only occur in patches close to rock outcrops on the steep terrain of the Maganga Division.

Other soil parent materials of restricted extent on the estates which are significant for soil development include massive veins of quartzite which outcrop on isolated hilltops and have in places been quarried for road material; silty and loamy river alluvium along the major streams; lacustrine alluvial clays of high base status in the Walihanga Basin on the Itona estate; and isolated pockets of peat or organic sediments found in concave depressions.

3.3 Soil characteristics and distribution

Itona series

Naturally well drained, very deep, clayey Humic Ferralsols developed from strongly weathered slope deposits derived from granite are classed as the Itona series and form the dominant soils of moderately sloping middle and lower slopes on the Itona and Idetero estates. They also occur in similar landscape positions in the south west sector of the Stone Valley estate. The Itona series is characterized by deep, strongly acid, dark-coloured, granular, friable clay topsoils of relatively high organic matter content which are extremely porous. Topsoil depth varies from 30 to 40 cm over most of the estates but in certain concave hollows of small extent on the Idetero estate topsoil thickness increases to 50 cm or more as a result of deposition. Topsoils overlie red friable clay subsoils which handle more like a loam in the field and have a well developed, stable granular or fine subangular blocky structure, remaining extremely porous to depths of 300 cm. Rooting is concentrated in the topsoil but the excellent subsoil structural conditions mean that roots are common throughout the soil profile, resulting in a very large profile available water content (measured values of water held between 0.1 and 15 bar tension range from 284 to 393 mm). A large proportion of this water is easily available for plant growth making these soils the most drought resistant on the estates. Infiltration rates are also high, and there is therefore a low risk of erosion despite the steep slopes. These soil physical properties make the Itona series well suited to tea production.

Soils of the Itona series are dominated by kaolinitic clay minerals with very low effective cation exchange capacities (ECEC) and they contain few silt or sand-sized minerals which can weather to release plant nutrients. They therefore have very low nutrient reserves, particularly in the subsoil where ECEC values fall to less than 3 millimoles (+) charge per 100 grams of soil. The greater organic matter content of the topsoils results in an increased capacity to hold nutrient cations but the soil reaction is strongly acid and there are high levels of exchangeable aluminium. Although not detrimental to tea, these levels of aluminium are toxic to many other crops such as maize. Measured values of exchangeable calcium and magnesium are low but are not likely to be limiting.

Exchangeable potassium levels are low or very low in topsoils and fall to below the absolute minimum requirement in the red subsoil layers. Available phosphorous is also low to very low and it will be important to maintain or increase the amounts of both these elements by regular fertiliser dressings. Profiles 1 and 7 represent Itona series soils under mature tea, whilst Profile 6 is from a recently planted area formerly under primary evergreen forest.

Idetero series

Naturally well drained Humic Ferralsols of the Idetero series are similar to those of the Itona series but are shallower, overlying compact pinkish decomposed granite at about 2 metres depth (see Soil Profile 4). They also have slightly less clayey topsoils and frequently have a clay-enriched subsoil horizon with blocky or prismatic structure at about 70 cm depth. They are found on hilltops, and moderately sloping convex upper and mid slopes of the Idetero and Itona estates where they merge into the Itona series on the long moderately to strongly sloping (6-9°) straight mid and lower slopes. They occur in similar landscape positions in the south of the Stone Valley estate but are replaced on hilltops in the northern sector by the shallower Stone Valley series which passes downslope into the Idetero series on midslope sites. They are also encountered in the southern part of the Maganga estate where they occur in both mid and lower slope sites in strongly sloping terrain, usually below Stone Valley series soils which occupy less steep upper slopes and ridge tops.

The red clay subsoil is more compact and slightly less porous than that of the Itona series but is still friable, usually breaking easily to a granular structure on manipulation and handing more like a clay loam than a clay. The strongly humic, moderately to strongly acid sandy clay topsoil is generally about 30 cm thick and is very friable with a granular, extremely porous structure. Rooting, although concentrated in the topsoil, is unimpeded to about 200 cm depth where root penetration is restricted by the firmer layer of weathered granite saprolite. Rooting may also be restricted in a few localities by a quartz stone line at shallower depths of 100 to 150 cm. The physical properties of Idetero series soils are still suited to tea production but the shallower soil depth and slightly denser subsoils reduce the amount of profile available water making them more droughty for tea than the deeper Itona series. Nevertheless, it remains relatively large (measured values between 0.1 and 15 bar are about 220 mm), and 75% of it is easily available for plant uptake.

The results of soil chemical analyses show that Idetero series soils are very similar to those of the Itona series with low nutrient reserves and low effective cation exchange capacities (ECEC), particularly in the red clay subsoils where potassium is usually strongly deficient. The relatively high levels of organic matter in the topsoil give an increased nutrient holding capacity but the acid topsoil reaction, combined with high levels of exchangeable aluminium tolerated by tea, is detrimental or even toxic to many crops such as maize. Available potassium and phosphorous levels are low and will require supplementing by regular fertiliser additions. Levels of exchangeable calcium and magnesium are also low but generally non-limiting for tea.

Stone Valley series

Gently to moderately sloping (1-5°) ridge tops and upper slopes, particularly on Stone Valley and Maganga estates, but also on parts of the Idetero estate, carry soils which show a distinct clay increase with depth, displaying a more compact clayey subsoil layer with coarse prismatic or blocky structure at about 70 cm depth. This passes into weathered but firm, massive decomposed granite at about 150 cm depth. A stone line consisting of angular quartz is often encountered at about 80 cm depth. Such soils are classified as Humic Acrisols and have been mapped as the Stone Valley series (see Profiles 2 and 5). Topsoils have a similar moist colour and structure to those of the Humic Ferralsols described above but they have a sandy clay loam texture and often appear greyer when dry. The yellowish brown subsoil between about 30 and 70 cm is a porous sandy clay with weak structure and low soil strength. It handles more like a loam in the field and has been depleted of clay by downward translocation. This overlies a yellowish red, moderately compact blocky or prismatic clay which becomes very sticky and plastic when wet. Deposition of clay translocated from above is apparent from prominent clay coatings on structural surfaces and in root channels (forming an Argillic horizon or an Argic B horizon of the FAO-UNESCO 1988 classification).

At depths of about 150 cm, the clay-enriched subsoil horizon passes into pinkish massive decomposed rock with abundant soft white specks which represent mineral (feldspar) crystals decomposed to secondary clay. This material can be cut with some difficulty by a spade but is dense and very firm when in place and restricts root penetration, so that roots are absent below about 150 cm depth. As in the Ferralsols, fine roots are concentrated in the topsoil to about 30 cm depth but roots are then only common to about 130 cm depth, and may only penetrate to 80 cm where there is a stone line. A sharp increase in bulk density and a parallel decrease in total porosity occurs on passing into the clay-enriched blocky subsoil horizon at about 70 cm depth. Initial infiltration rates will be rapid at the soil surface but water will be diverted laterally at the top of the denser subsoil horizon resulting in a major subsurface lateral flow component down the slope above the less permeable layer. There is only a moderate amount of profile available water (measured values range from 98 to 145 mm) and only about half of this is easily available for plant uptake. Available water is considerably less than in the deep Humic Ferralsols because roots only penetrate to about 100 cm or, in certain cases even less (see soil discussed below). Actual amounts of easily available water will be lower than measured values as roots only penetrate along fissures in the blocky structured subsoil and therefore exploit a smaller soil volume. This will lead to an earlier appearance of drought stress in tea crops growing on these soils and will require irrigation at an earlier stage in the dry season to offset adverse effects on growth and yields.

Some Humic Acrisols on ridge crests have particularly dense clay-enriched mottled subsoils (e.g. Soil Profile 3 in the Appendix) which are slowly permeable and result in slight seasonal waterlogging of the overlying soil horizon. This results in pale colours and bright yellowish brown mottles or iron oxide segregations in the weakly structured sandy clay loam below the topsoil. These soils form a gleyic variant of the Stone Valley series but have not been separated on the soil maps. Roots are rare below about 80 cm in such soils as penetration is impeded by high packing density and, during the wet season, by waterlogging of the subsoil. As root penetration is further restricted in such soils, they are the most likely to show drought stress symptoms early in the dry season.

The presence of weathering rock at shallower depth than in the Humic Ferralsols means that some weatherable minerals are still present mainly in the silt fraction, so that there is a potential for a slow release of nutrient elements as they decompose. This means that Humic Acrisols have a greater potential subsoil nutrient reserve than the more strongly weathered and leached Humic Ferralsols. Nevertheless, effective cation exchange capacities (ECEC) in the clayey subsoil remain low (measured values of 2.74 to 3.85 millimoles (+) per 100 grams soil) and saturation of the exchange complex with calcium, magnesium and potassium is less than 50% when measured at pH 7.0. The measured pH of the topsoil is generally strongly acid (pH 4.2 to 4.8) but in places increases to 5.6 probably in response to irregular fertiliser additions, past burning activities or local addition of faeces. Exchangeable aluminium levels are high in the more acid soils and reach levels which are toxic to maize and other arable crops. Levels of calcium, magnesium and potassium are adequate in most Stone Valley soils and therefore non-limiting. Available phosphorous is low and should be balanced by regular fertiliser additions. Organic matter levels are generally high in the topsoil but do not always attain levels required for Humic subgroup classification.

Walihanga series

A small proportion of all the tea estates are occupied by concave depressions between ridges and at the foot of long moderate slopes on ridge sides. Such land accounts for less than 5% of the estates and most of it is under forest. It is only extensive in the basin south west of Walihanga dam. New tea plantings have recently been extended onto this land at the southern side of the lake but establishment has been poor. The soils found in such sites are affected by often prolonged waterlogging due to a high groundwater table in the valley bottom and are classified as Mollic Gleysols. Most have clay at less than 50 cm depth and are grouped as the Walihanga series. Black, slightly acid organic sandy clay loam or wet peaty topsoils, which sometimes extend to 50 cm or more, overlie waterlogged, grey mottled sandy clay of high base status. This in turn passes into pale grey to white sticky, plastic waterlogged clay at about 1 metre depth.

Walihanga series soils have a higher nutrient status than the Humic Ferralsols and Acrisols of adjacent well drained slopes because they receive drainage water and leachates from higher ground. However, the performance of the tea is limited by very poor drainage which is difficult to improve in such low-lying situations. Land drainage is required on such sites. Soil pH levels of around 6.0 in the subsoil and a relatively high exchangeable calcium level in the topsoil could also adversely affect tea growth and, together with poor soil drainage, make the Walihanga series poorly suited to tea. The relatively good fertility status of these soils is confirmed by the soil analyses given under Profile 13 in Appendix II, and would allow successful cultivation for vegetables and other crops. Without drainage, cultivation by mechanical means should be avoided in the wet season and early in the dry season as these soils have poor trafficability. Relatively good yields of vegetables should however be possible with hand cultivation techniques.

Wanji series

Sandy gley

A few examples of fine loamy over sandy Mollic Gleysols with extremely deep, dark-coloured, granular, organic-rich topsoils over-deepened by deposition of soil eroded from upslope were encountered locally in sloping concave depressions on the Stone Valley and Itona estates where they are mapped as the Wanji series. On the Itona estate, these depressions are found mainly to the north of the Walihanga lake in Fields (old) Walihanga 5 (Profile 14) and the southern part of (old) Walihanga 6, but also in (old) Itona 3. On Stone Valley they occur in similar depressions in Fields (old) Wanji 4 and in the north east of (old) Kisima 2. A deep, slightly acid to neutral, black organic fine sandy clay loam topsoil up to 40 cm in thickness overlies up to 60 cm of black organic gritty sand which passes into grey wet reduced sand at about 1 metre from the soil surface. These highly permeable Wanji series soils are subjected to seasonally waterlogging of their subsoil layers by a fluctuating groundwater table controlled by seepage into the depressional sites. However, because of the coarse texture, permeability and the usually moderate slope, the topsoil and upper subsoil do not display signs of severe waterlogging. Such soils are predicted to have relatively large amounts of easily available water due to replenishment from shallow groundwater. Tea growing on such sites is less drought prone than on well drained soils of convex slopes.

Soil fertility is relatively high and pH values remain at about 6.0 throughout, suggesting that these soils are flushed with base-rich drainage water from upslope sites. The organic loamy topsoils have the highest measured effective cation exchange capacities of any soils on the tea estates (16.7 millimoles (+) per 100 grams soil) with high levels of exchangeable calcium (12.1 millimoles (+) per 100 grams soil). Despite these high soil pH and high exchangeable calcium values, the tea crop appears to be healthy. **The**

Wanji series is of extremely small extent so that separate soil management is not feasible.

Kidofi Complex

The strongly sloping terrain of the tea estates is dissected by narrow flat-bottomed stream valleys infilled with deposits of river alluvium of rapidly changing texture. The Mollic Fluvisols developed on these parent materials are consequently very variable in texture from silt loams to sands and are mapped as the Kidofi Complex on the Itona estate. All these alluvial soils are affected by permanent waterlogging of the subsoil layers due to a high groundwater table and are affected by the flushing of nutrients from soils on higher ground. Topsoils are generally black to very dark grey organic silt loams, silty clay loams or sandy loams with a neutral or slightly acid soil reaction and are waterlogged for much of the year. The degree of soil wetness is indicated by the predominance of marsh plants and the absence of high forest on these valley bottom soils. Subsoils are equally variable in texture. In addition, they are permanently waterlogged and anaerobic, as shown by their grey reduced soil colours. Sandy or gravelly deposits are often encountered at about 1 metre depth. As the silty subsoil layers are often semi-fluid, Kidofi Complex soils have a very low bearing capacity.

Soil fertility is likely to be moderate or high but land use is restricted by waterlogging and soil physical conditions. Kidofi Complex soils are unsuited for tea production or forestry and a high risk of flooding, even after land drainage measures, restricts the suitability of this land for other forms of cropping. Low stream terraces within the valley bottoms which lie a few metres above the level of the stream, sometimes carry more mature Mollic Gleysols of the Walihanga series or deep peaty organic soils known as Histosols.

Maganga Complex

Soils on slopes greater than 15 degrees occur on parts of the Stone Valley estate but are only common on the Maganga estate, particularly in the north. Here rock outcrops are common and soils are often shallow around the outcrops leading to low available water capacities. The physical limitations of such soils are obvious and no detailed sampling of them was undertaken. The shallow soils are classed as Ferralic Cambisols on the basis of field inspection and generally have relatively shallow dark greyish brown sandy loam topsoils containing common granite stones (see description of Profile 8). However, substantial parts of these steep slopes are still covered by somewhat deeper soils similar to the Humic Acrisols described from ridge tops on Stone Valley (e.g. Soil

Profile 2) or Humic Ferralsols which conform to a shallower variant of the Idetero series (Profile 4). Pinkish, decomposed granite is generally reached within a metre depth. The extreme variation in soil thickness and water holding capacity of soils on these steep slopes results in highly variable crop performance and tea yields locally within fields. These areas are mapped as the Maganga Complex on the Maganga estate soil map and are regarded as poorly suited or uneconomic for irrigation, as many limitations to achieving high yields would remain and water, in most cases, is difficult to lead to such areas. Soils of the Maganga Complex are also encountered to a small extent on steep slopes on the Stone Valley estate.

Valley Complex

Most of the existing areas of tea cultivation on the estates avoid strongly to steeply sloping convexo-concave lower valleyside slopes within about 100 metres of the flat valley bottoms and most of this land remains in forest. During reconnaissance surveys of potential new tea areas on the Itona estate, the soils of these lower slopes were examined. The soils were very variable but most showed signs of moister soil water regimes than soils higher up the slopes. Humic Ferralsols of the lower mid slopes (Itona series) pass first into more yellowish Xanthic Ferralsols with dark greyish brown sandy clay loam or sandy loam topsoils 20 to 25 cm thick over yellowish brown or strong brown, very porous sandy clay or sandy clay loam subsoils which extend to about 100 cm and may be slightly mottled. Below this depth the soil material changes to a pale yellow mottled sandy clay showing distinct signs of seasonal waterlogging by seepage water from upslope sites. Although not waterlogged for any substantial periods in the upper 50 cm, the deep subsoil layers below 100 cm are wet or very moist for much of the year and the soil profile as a whole is moister for longer periods than well drained slope soils. The moister conditions favour the formation of the iron oxides with yellowish rather than red colouration. The soil profile usually extends to more than 3 metres depth but often overlies sandy loam between 200 and 300 cm depth. This suggests that the soils are developed in highly weathered materials that have moved downslope over very long periods of time. These imperfectly drained soils are less suited to tea production than well drained Humic Ferralsols and are usually intimately mixed in a complex soil pattern with poorly drained soils of higher base status described below.

Closer to the valley floor on gentler concave slopes the soils become seasonally waterlogged nearer to the surface. This is reflected in the presence of greyish or pale yellow mottled horizons within 50 cm depth and indicates significant periods of wetness and the development of anaerobic conditions. Such soils are classed as types of Gleysol with various subtypes resulting from the highly variable soil texture and organic matter content in these lower slope positions. Organic matter contents usually increase in the topsoils, shown by their very dark greyish brown or black colour, and topsoil depth often increases to 26 or 35 cm. These soils lie in landscape situations which receive seepage water and leachates containing basic cations derived from soils higher up the slope. They are therefore seasonally waterlogged during the rains and are likely to have medium to high base status. Many are types of Mollic Gleysol similar to the Walihanga or the Wanji series, but where topsoils are thinner and organic matter contents decrease, Eutric Gleysols and more acid Dystric Gleysols are found. Soil textures include sandy loams, sandy clay loams and clays and often display abrupt changes with depth suggesting layered parent materials derived from materials moved from sites upslope.

This complex of Xanthic Ferralsols and undifferentiated Gleysols is mapped as the Valley Complex. In addition to the soil types mentioned, there are inclusions of waterlogged grey sands (Gleyic Arenosols) which overlie pale grey mottled moderately permeable sandy clay within 1 metre depth and are affected by a seasonally fluctuating watertable, and deep black humified organic soils or peats (Terric Histosols) more than 1 metre deep. These latter soil types are common in the large concave depression to the south west of the Itona factory.

Soils of the Valley Complex are poorly suited to tea cropping as well drained permeable soils are essential for satisfactory growth. Moreover, it has been shown that tea does not grow well on soils of high base status with negligible exchangeable aluminium and shows very distinctive pathological symptoms under such conditions. It is therefore recommended that areas mapped as the Valley Complex are avoided when extending tea onto new land.

3.4 Soil fertility and suitability for tea production

Humic Ferralsols of the Itona and Idetero series show many of the properties desirable for successful tea cropping. An acid soil reaction with a pH below 6.0 (preferably below 5.6), adequate levels of available aluminium, and relatively high organic matter contents in the topsoil are some of the most important soil chemical requirements for healthy growth. Both soil series satisfy these criteria. They have pH values between 4.6 and 5.2, with low but adequate levels of calcium and magnesium; exchangeable aluminium accounts for between 40 and 60% of the effective cation exchange capacity; and they have deep topsoils with organic matter contents of more than 5%. The soils are in addition physically well suited, being well drained with a very or extremely porous, granular structure stabilized by relatively large sesquioxide contents (high content of iron and aluminium oxides), a large or very large available water content, and unimpeded rooting to at least 200 cm depth and , in the case of the Itona series, to more than 300 cm depth. The main limitation to growth and yield under the seasonally dry climate is the tendency to soil droughtiness which, without irrigation, becomes apparent in the Idetero series after mid to late June and in the Itona series from mid to late July. Exchangeable potassium levels are low in topsoils and usually below the absolute minimum requirement in the red friable clay subsoils reflecting the very low natural mineral reserve of plant nutrients in these strongly weathered and leached soils. Available phosphorous is also present in low or extremely low amounts and will become limiting without phosphatic fertiliser additions.

Humic Acrisols of the Stone Valley series are less suited to tea cropping than the above mentioned soil series because of a less than ideal rooting depth, the presence of more compact blocky clay subsoils, and the common presence of stone lines at less than 1 metre depth. These adverse physical soil properties act to restrict the volume of the subsoil that can be exploited by roots and reduce the amount of water easily available for plant growth. Most examples of the Stone Valley series will show signs of drought stress by early to mid June in normal years and yields will be substantially reduced without irrigation. Soil chemical properties of the topsoil are similar to the Humic Ferralsols described above but, unlike the Ferralsols, exchangeable calcium and magnesium tend to increase in the clayey subsoil horizons. Available potassium is generally non-limiting and above the absolute minimum requirement in both topsoils and subsoils. The higher potassium levels reflect the greater natural reserve of potassium slowly released by the weathering of silt-sized micaceous minerals at depth.

Soils of the Maganga Complex are poorly suited to tea because of the complex soil pattern with highly variable soil depth, shallow topsoils and the presence of common rock outcrops. Moderate to small amounts of easily available water mean that drought stress shows up early in the dry season and, together with variable topsoil depth, accounts for the patchiness of crop performance on these soils. Subsoil layers are strongly deficient in available nutrients and, where topsoils are thin, deficiency symptoms show up in the crop and reduce yields. Irrigation is technically difficult on Maganga Complex soils due to the altitude to which water has to be led and the steep slopes. This land has a high risk of soil erosion, particularly where the red subsoil layers are exposed on pathways and along access lines bare of tea. Mulching will help to both reduce erosion hazard and build up nutrient levels.

Mollic Gleysols of the Walihanga series are poorly suited to tea due to impeded drainage, waterlogged sticky clay subsoils and relatively high pH values resulting from a dominance of calcium and magnesium on the exchange complex and negligible amounts of exchangeable aluminium. Tea is an aluminium accumulator, and it is widely held that adequate levels of exchangeable aluminium are necessary for healthy growth. This, rather than high calcium levels per se, combines with poor drainage to result in poor tea performance on these soils. These limitations are difficult to rectify due to the low lying landscape position and tea is not recommended. Food crops such as vegetables and maize will actually benefit from the higher nutrient status but land drainage would be necessary to achieve maximum productivity. Wanji series soils appear to be more suited to tea, probably because of their deep organic-rich loamy topsoils and permeable light textured subsoils which are waterlogged for only short periods after heavy rain. The presence of easily available water at shallow depth for much of the year in the Wanji series makes them less droughty than many soils on the estates and reduces the effects of drought stress on tea yields.

3.5 Soils of the proposed new tea areas

Soil survey procedures

Reconnaissance soil surveys of potential new tea areas along the Upangwa and on the valley sides to the north and south of the Walihanga were undertaken during the fieldwork in June and October. Soil transects were made through the Eucalyptus plantations north of the Walihanga and aligned from the ridge top down towards the stream in the valley bottom. North to south traces were cut through the forest and secondary bush covering the interfluve ridge between the Walihanga and the Kidofi to the south. Similar traces were cut in roughly north to south directions across the Upangwa valley from the abandoned staff quarters and from the Itona Factory, both ending up in the vicinity of the murram pit near the ridge top to the south of the stream. A further easterly trace was cut from the murram pit to the junction of the Upangwa and the Kidofi.

Trace intervals

Soils were inspected with a soil auger at 200 metre intervals along the traces and observations were recorded to 3 metres depth. The soils were classified and placed into soil series on the basis of these field observations. More detailed descriptions of soil pits excavated to 3 metres were made of the principal soil types encountered. As dense forest restricted the view, and as neither contoured topographic maps nor aerial photographs were available for these areas, soil boundaries had to be interpolated between auger points and are therefore only very approximate.

Vegetation

Eucalyptus plantations cover the valley side slopes north of the Walihanga, north of the Upangwa up to the abandoned staff quarters, and again on the ridge top south of the Upangwa valley. The rest of the proposed extension area is covered either by primary evergreen forest, or by secondary forest or thicket, most of which is at least 25 years old. Tall primary forest occurs around the Itona guest house and staff quarters extending eastwards either side of the road to Stone Valley almost as far as the path to the pumphouse, and extending as a tongue into the Kidofi valley. The approximate extent of this primary forest, which has considerable intrinsic conservation interest, is marked on the soil map. A small outlier of primary forest surrounded by secondary thicket was also encountered just to the east of the pumphouse path. The full extent of this was difficult to ascertain on the ground but its approximate position is marked on the map. It is recommended that these areas are left uncleared as forest reserves and windbreaks.

Much of the secondary forest consists of thicket about 10 metres high made up of small trees (generally less than 20 cm diameter at breast height) and shrubs but usually containing a few larger trees (up to 15 metres high and around 30 cm diameter at breast height). Isolated and much larger trees, a relic from the primary forest, also occur in places. Small areas of stunted bush, where regrowth is restricted to low bushes less than 3 metres in height, are found at the nose of the interfluve close to the bridge across the Kidofi to Stone Valley, and north of the Uanji dam lake.

Soil characteristics and suitability for tea

The approximate distribution of the principal soils of the proposed extension areas on the Itona estate are depicted as broken lines on the soil map which accompanies this report. This shows that the most extensive soils of the moderately to strongly sloping (6 to 9 degrees) ground either side of the Upangwa valley are naturally well drained deep Humic Ferralsols of the Itona series (similar to Profile 6). Similar soils occupy midslope to lower slope positions in both the Kidofi valley and to the north of the Walihanga stream but pass upslope into the Idetero series which occupy upper slopes and the broad convex ridge tops. Idetero series soils occupy most of the strongly sloping valley side south of the Walihanga almost to the valley floor. Both these soil types have unrestricted rooting depth to at least 2 metres and very large or large profile available water capacities. Organic-rich topsoils, which tend to be slightly less deep than under mature tea, are acid or very acid (soil pH about 4.5) with appreciable amounts of exchangeable aluminium. Effective cation exchange capacity is likely to be very low, but should increase in surface horizons due to the relatively high organic matter levels that are indicated by the dark topsoil colours. This facilitates retention of nutrients in the topsoil added in the form of fertiliser.

Such soils are regarded, on the evidence of the field observations, as suitable for tea planting and should respond well to irrigation. Those mapped as the Itona series are likely to be equivalent to some of the better yielding tea soils on the estate. However, the reconnaissance survey did not include chemical soil analyses so that residual effects of former pyrethrum cultivation or burning effects could not be investigated. More obvious soil problems help to account for the two areas of stunted bush mentioned in section 3.5 b above. These have less dark coloured shallow topsoils with evidence of admixture of red friable clay subsoil material and have been mapped as shallow topsoil phases, forming non-humic variants of the Itona and Idetero series. The loss of topsoil, possibly during dam construction, or in the process of original primary forest clearance, or perhaps due to past land use practices, has severe consequences for the nutrient holding capacity of the soil. It results in a very low effective cation exchange capacity in both topsoil and subsoil horizons and, consequently, to very low levels of essential plant nutrients. This helps to explain the very poor regrowth of forest on these areas even after 25 years, despite good water holding properties and free drainage. Such areas are unsuitable for tea plantings, as is the area scraped for construction of the Uanji Dam and currently under cypress plantation.

Itona series soils continue onto some upper slope sites south of the Upangwa but thin out to depths of less than a metre over very hard quartzite in the vicinity of the murram pit. These soils are unsuited to tea as they have moderate to small amounts of available water and shallow rooting depth. Their distribution along the ridge top to the west is uncertain but it is recommended that a zone of at least 100 metres from the edge of disturbed ground around the murram pit be left in forest or eucalyptus plantation.

Seasonally waterlogged Gleysols of the Valley Complex, affected by lateral seepage of water on lower slopes transitional to the valley bottom, were of only local extent in the Walihanga valley. These are poorly suited to tea planting but would largely be inundated by the effects of the dam. It is recommended that a 50 metre wide zone immediately around the proposed lake should not be planted so as to avoid any adverse effects on the newly established tea. Rooting depth would be restricted by waterlogged anaerobic subsoils in these soils. Valley Complex soils are more widespread along parts of the Upangwa valley, particularly in the bowl-like depression south west of the Itona Factory where soil texture is particularly variable (see under Valley Complex in section 3.3). Tea plantings are not recommended on these poorly drained lower slope sites where growth of the tea bushes will be retarded by waterlogging, high calcium and magnesium levels and low exchangeable aluminium. It is recommended that a wider zone of about 100 metres either side of the Upangwa stream should be left as forest or cleared for forestry plantation.

Waterlogged alluvial soils (Fluvisols) of the Kidofi Complex which occur along the flat valley bottoms are unsuited to tea production. Land drainage is difficult without pumped schemes and the land would remain liable to flooding, making it poorly suited to alternative crops. The severe waterlogging also precludes successful tree growth and limits forestry potential.

Recommendations

Deep Itona series soils on mid slopes of 6 to 9 degrees to the north of the Walihanga, on both sides of the lower Upangwa and north west of the Kidofi are well suited to irrigated tea production, although areas under primary evergreen forest should be left intact. Idetero series soils present on the interfluve south of the Walihanga and on the ridge top north of the Walihanga are more drought prone but, with irrigation, can be viewed as good tea soils without severe chemical or physical limitations. Shallow phases of both these soil series are unsuited to tea and should be avoided. Waterlogged Kidofi Complex soils in valley bottoms and seasonally waterlogged soils of the Valley Complex occupying seepage sites on lowermost slopes should also be avoided. It is recommended that a strip of land about 100 metres wide either side of the Upangwa stream be left free of tea. A similar strip of about 50 metres wide is recommended along the Kidofi and the Walihanga streams. Wider areas of unsuitable land occur at the confluence of the Upangwa and the Kidofi, and in the bowl-shaped depression south west of Itona Factory.

3.6 Effects of forest clearance methods on soil fertility

On two recently cleared areas on the Itona estate, one immediately north of the Factory Dam and the other north west of (old) Walihanga 3, the young tea has not performed well. The soil survey revealed that topsoils were thinner than in normal examples of the Itona and Idetero series, generally being less than 20 cm deep and having a strong admixture of red clay subsoil material. This can only be attributed to the method of forest clearance in which a bulldozer was used to push trees over and downslope towards the valley bottom. Examination of soils on the lower slope near the fall into the valley bottom confirmed this assumption as more than a metre of topsoil mixed with tree roots was encountered under rough ground at the margins of the tea plantings. The consequences of this treatment are severe because most of the nutrient holding capacity of these Humic Ferralsols is contained in the organic-rich topsoil. The very low effective cation exchange capacity and small amounts of nutrient cations held in the subsoil mean that deficiencies of potassium and phosphorous are likely to be the cause of poor tea growth. The slow regrowth of forest on Itona and Idetero series soils which have lost much of their topsoil was mentioned in section 3.5 and points to the long term effects of such land management practices. An alternative method of clearance is recommended.

The actual failure of tea bushes in the north west area cannot be attributed to these soil conditions and must have an alternative explanation which is beyond the scope of the present study.

CHAPTER 4

RESOURCE BASE: WATER

4.1 Catchments

Stone Valley and Itona

Hydrologically, Stone Valley and Itona estates should be considered as one unit, since they share common catchments and could utilise the same water resources. There are four main streams to consider.

The Kidofi is the main stream on Stone Valley. It rises in forest reserve and flows along the north-west Stone Valley boundary and between the estates. It flows through two large reservoirs, the Ubena and Uanji Dams, and there are a number of minor ponds on the smaller tributaries. There is a good storage site below Uhehe village.

The Upangwa flows through the southern half of Itona estate. It is unregulated but flows into the Kidofi upstream of Uhehe site and Uanji Dam. Two potential dam sites were considered on the Upangwa. The Upper (rock) Site is at the lower edge of the existing tea, the Lower (sand) Site is in a natural bowl downstream below the factory.

As the Kidofi leaves the estates, it is joined first by the Ifupira. This flows along the north-eastern boundary of Stone Valley. It is regulated by the small Ifupira Dam in its upper reaches, but the lower reaches are unregulated and the water unused. There are several possible sites for a lower dam, the best being where a large tributary joins it from the adjoining shambas.

Just beyond the Stone Valley boundary the Kidofi is also joined by the Walihanga. This rises in a small area of shamba and flows through the northern half of Itona estate before entering the Kidofi. The Walihanga is regulated by several reservoirs. The largest, Walihanga Dam, is used for irrigation, while the Factory Dam downstream provides water for the factory and the housing. The lower half of the catchment is again unregulated and the water unused. Again there are several potential sites for a lower dam.

The Kidofi and Upangwa catchments are entirely on well protected forest reserve or estate lands. The Ifupira particularly has a large part of its catchment in shamba and may have a sediment problem.

The Kidofi is also used further downstream as a source for Ifupira estate; in 1990 some water was released from Uanji Dam for their use.

Idetero

There are three main catchments supplying Idetero estate.

The Fikiri flows along the north-eastern boundary through three reservoirs (herein referred to as the top, middle and lower Fikiri dams). The catchment is shared with Lupeme estate, and the lower dam has a large part of its catchment regulated by another dam on a tributary in Lupeme estate. There is a potential storage site straddling the estates alongside the proposed new development Id12.

The "House Stream" runs through the centre of Idetero estate. It rises mostly in estate tea and woodland, and its numerous tributaries are regulated by a large number of mostly small dams, the latest being at the downstream estate boundary. The best dam sites have already been used. A site just upstream of the House was surveyed but rejected.

The Kilima stream runs along the south-west boundary, beyond the new road. There are two smallish reservoirs shared with Kilima estate, but no good storage sites.

Maganga

Maganga estate is located on a high ridge between two valleys. A small river, the Msiwasi, flows to the north, but is 200 m lower than most of the tea on that side. A substantial stream, the Nyamalongolo, runs to the south about 30 m higher and nearer to the tea. It is not regulated but is used upstream to irrigate a small area of tea on Lupeme estate.

Any dam across either stream would be a major structure. There are remains of a small dam on a minor tributary along the eastern Maganga estate boundary.

General

The catchment areas, vegetation and slopes above likely abstraction points in the above catchments are summarised in Table 4.1

Table 4.1 Catchment areas, vegetation and slope above likely abstraction points.

Stream	Site	Catchment Total ha	Vegetation forest %	Vegetation tea %	Vegetation shamba %	Slope %
Stone Valley/Itona:						
Upangwa	Rock site	140	50	50	0	4
	Upangwa site	220	50	50	0	4
Kidofi	Ubena Dam	380	75	25	0	4
	Uhehe site	840	80	20	0	3
	Uanji Dam	985	70	30	0	3
	+W5 (new)					
Ifupira	Ifupira Dam	80	0	50	50	6
	New lower site	150	0	25	75	4
Walihanga	Walihanga Dam	155	20	40	40	7
	Factory Dam	240	20	50	30	6
	Lower site +W4	345	70	30	20	4
Combined	Ex. W5					
	Inc. W5					
Idetero:		1480				
Fikiri	Top Dam	105	30	20	50	6
	Middle site	130	30	30	40	4
	Lower Dam	430	40	30	30	4
(+Id12)	Top Dam					
	Middle site					
	Lower dam					
House	Factory Dam	295	20	30	50	8
	House Dams	430	40	30	30	6
	Lower Dam	515	40	30	30	5
(+trans.)	Factory Dam					
	House Dams					
	Lower Dam					
Kilima	Lower Dam	60	50	50	0	9
Combined	Lower dams	1005				
	+Id12 & trans.	1005				
Maganga:						
Msiwasi	At Maganga	2100	30	20	50	3
Nyamalango	At Maganga	455	60	20	20	3

As noted above, many of the streams are on the boundaries of the estates. At present there seem to be no clear legal agreements for specifying the division of flow with neighbouring estates or protecting supplies from upstream or to downstream users. On shared streams, the estates agree pumping schedules jointly.

All the catchments overlie deep granite. It is considered unlikely that any significant inter-catchment groundwater movement occurs.

4.2 Existing flow data

There is very little data available on stream flows in the area. Standard yield formulae could be used with rainfall data to obtain wet season runoff, but this is not critical unless very large reservoirs are contemplated. Without detailed hydrogeological data it is not possible to generate the more important dry season base flows this way.

Preliminary base flow figures were calculated using records of flows gauged weekly from July to November 1988 on six catchments on the Brooke Bond estates (data provided courtesy of Colin Congdon). One set was rejected as unsatisfactory. For the other five, the recorded flows show a steady decline once the large recording irregularities have been smoothed out, though there is considerable variation between catchments. The figures were standardised for catchment area and then both linear and exponential decay curves fitted; these give very similar results. Mean yields decreased by 1.10 $m^3/h.km^2$ per week, from 44 $m^3/h.km^2$ at the start of July 1988 to 25 $m^3/h.km^2$ by the start of November 1988 (Table 4.2). In view of the suspected low accuracy of readings and the very large variation between catchments, a more sophisticated analysis is not justifiable.

4.3 Gauged Flows

Temporary gauging stations were established at twelve sites (A to L) for the 1990 dry season (Table 4.3). Data from weir M, added later, have been ignored (see below). These sharp-crested rectangular weirs, initially of 0.3 m to 0.8 m width, were sized to measure dry-season baseflows. Five weirs were sited across streams, the others were incorporated into dam spillways. Water levels and upstream abstractions were recorded daily through the dry season by estate managers and checked periodically by the company engineer. Many of the weirs were narrowed in September as flows reduced.

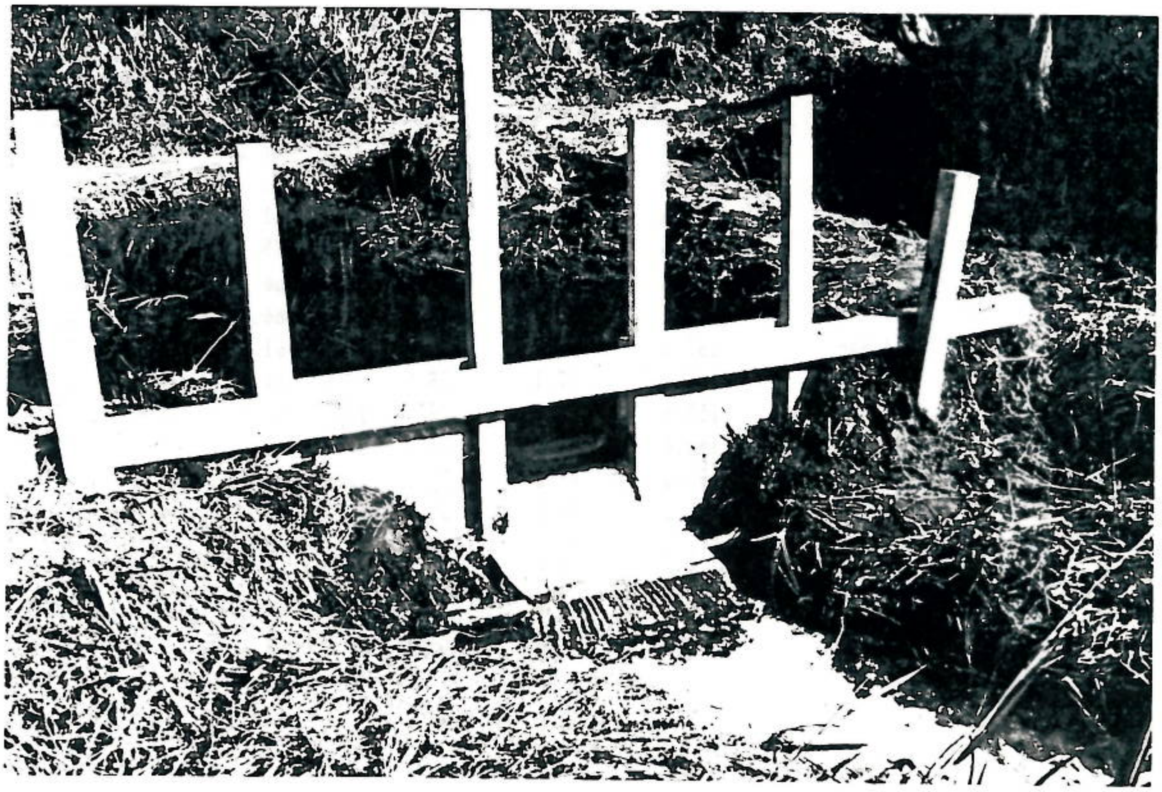
The discrepancy between gauged flows from weirs G and M is still unexplained. Both were installed after our departure; G following our discussions with John Boyd-Moss

Table 4.2 Flows and yields recorded on Brooke Bond estates in 1988, together with the best linear fit values.

Catchment:	Nyalawa	Mkalala	Kidspelo	Luiga	S. Vall	Lufuna	
Area (km2):	0.3	6.1	0.4	4.6	1.5	1.4	
Date		Streamflows (m3/h)					
9 Jul	NA	421.0	NA	NA	106.0	32.0	
16	NA	439.0	NA	139.0	92.0	28.0	
23	NA	333.0	NA	92.0	92.0	25.0	
30	NA	320.0	15.0	92.0	92.0	32.0	
6 Aug	NA	333.0	8.0	88.0	92.0	23.0	
13	57.0	323.0	8.0	144.0	113.0	23.0	
20	57.0	322.0	11.0	143.0	99.0	21.0	
27	62.0	323.0	13.0	144.0	99.0	21.0	
3 Sep	57.0	319.0	13.0	128.0	92.0	15.0	
10	57.0	318.0	11.0	90.0	92.0	15.0	
17	54.0	317.0	11.0	53.0	99.0	19.0	
24	51.0	315.0	11.0	99.0	57.0	19.0	
10 Oct	51.0	301.0	12.0	48.0	69.0	13.0	
8	48.0	287.0	12.0	51.0	66.0	13.0	
15	48.0	246.0	12.0	54.0	69.0	10.0	
22	40.0	231.0	11.0	66.0	66.0	21.0	
29	NA	219.0	11.0	54.0	66.0	10.0	
5 Nov	NA	NA	11.0	54.0	60.0	10.0	
		Catchment Yield (m3/h/km2)					Fitted Value
9 Jul	NA	69.0	NA	NA	70.7	22.9	43.9
16	NA	72.0	NA	30.2	61.3	20.0	42.8
23	NA	54.6	NA	20.0	61.3	17.9	41.7
30	NA	52.5	39.5	20.0	61.3	22.9	40.6
6 Aug	NA	54.6	21.1	19.1	61.3	16.4	39.5
13	167.6	53.0	21.1	31.3	75.3	16.4	38.4
20	167.6	52.8	28.9	31.1	66.0	15.0	37.3
27	182.4	53.0	34.2	31.3	66.0	15.0	36.2
3 Sep	167.6	52.3	34.2	27.8	61.3	10.7	35.1
10	167.6	52.1	28.9	19.6	61.3	10.7	34.0
17	158.8	52.0	28.9	11.5	66.0	13.6	32.9
24	150.0	51.6	28.9	21.5	38.0	13.6	31.7
10 Oct	150.0	49.3	31.6	10.4	46.0	9.3	30.6
8	141.2	47.0	31.6	11.1	44.0	9.3	29.5
15	141.2	40.3	31.6	11.7	46.0	7.1	28.4
22	117.6	37.9	28.9	14.3	44.0	15.0	27.3
29	NA	35.9	28.9	11.7	44.0	7.1	26.2
5 Nov	NA	NA	28.9	11.7	40.0	7.1	25.1

3. Installation of weir in Uanji Dam spillway

4. Weir installed across Ifupira stream



and M subsequently for unknown reasons. Peter Rowland believes both were installed satisfactorily. However both sets of results cannot be correct. Weir M readings appear suspect and have been ignored in the analysis.

The average flows were calculated on a weekly basis (Table 4.4), the yields normalised for catchment area (Table 4.5) and corrected for the upstream abstractions (Table 4.6). Some data were not available (NA) due variously to gaps in the readings, theft or damage to weirs, changes in reservoir stoplog levels and readings being discontinued when flow ceased.

These data, even (particularly) the corrected yields, need to be interpreted with careful consideration of the effects of reservoir storage between abstraction and gauging points. Initially the reservoirs buffer the abstraction, but eventually flow from that part of the catchment ceases altogether, and both that catchment area and the abstraction correction must be disregarded for downstream analysis. Flows may restart gradually once the reservoir has refilled.

Table 4.3 Gauging sites

Weir	Stream	Site	Details
A	Walihanga	Confluence	Across stream below roadbridge
B	Kidofi	Confluence	Across stream below roadbridge
C	Ifupira	Confluence	Across stream below footbridge
D	Kidofi	Uanji Dam	In south spillway
E	Kidofi	Uanji Dam	In north spillway
F	Kidofi	Ubena Dam	In spillway
G	Upangwa	Upangwa Site	Across stream
H	Kilima	Lower Dam	In spillway
I	House	Lower Dam	In spillway
J	Fikiri	Lower Dam	In spillway
K	Fikiri	Lower Dam	In spillway
L	Nyamalongola	By Maganga	Across stream
M	Upangwa	Upangwa Site	Across stream above G (disregarded)

Table 4.4 Flows (l/s) recorded during 1990 and catchment areas (ha)

Flows, l/s

Weir	A	B	C	D+E	F	G	M	A+B+C	H	I	J	K	H+I+J	L
Catchment	372.0	980.0	185.0	960.0	400.0	220.0	200.0	1537.0	117.0	500.0	880.0	327.0	1497.0	820.0
	Flow	Flow	Flow	Flow	Flow	Flow	Flow	Flow	Flow	Flow	Flow	Flow	Flow	Flow
June 25	15.1	59.1	42.6	87.6	20.9	NA	NA	116.8	31.3	73.2	147.6	61.1	252.2	73.6
July 2	15.2	42.9	31.6	61.6	29.7	35.8	NA	89.8	0.0	65.0	114.4	23.6	179.4	98.9
9	11.0	78.3	26.2	56.8	36.1	39.2	NA	115.5	0.0	56.1	140.5	21.2	196.6	91.7
16	14.4	75.5	18.8	67.9	13.6	32.1	NA	108.7	15.7	43.6	100.0	18.8	159.3	NA
23	12.3	69.7	18.8	67.9	4.8	30.6	NA	100.8	19.3	56.1	100.0	21.2	175.5	NA
30	12.3	69.7	18.8	67.9	2.6	32.3	12.6	100.8	25.1	60.5	119.7	39.7	205.4	75.8
Aug 6	10.3	69.7	21.2	67.9	0.9	26.9	9.0	101.2	10.7	60.5	119.7	51.6	190.9	75.8
13	10.3	99.5	21.2	64.2	0.9	27.2	9.1	131.1	0.0	51.9	113.0	54.7	164.9	96.6
20	10.3	38.9	18.8	64.2	NA	26.9	9.1	68.0	0.0	65.0	69.7	42.6	134.7	93.6
27	1.4	14.3	7.4	16.6	1.0	26.4	9.0	23.1	0.0	1.4	38.2	34.0	39.6	89.1
Sept 3	5.6	17.1	23.6	16.6	1.5	16.7	7.7	46.3	NA	0.7	38.2	54.7	NA	87.3
10	3.7	24.3	16.0	18.4	0.0	11.4	5.9	44.0	11.4	0.3	3.7	31.2	15.4	86.4
17	NA	29.6	18.0	22.8	0.0	11.4	5.9	NA	9.1	1.0	39.7	NA	49.8	83.7
24	2.7	40.9	16.6	NA	0.0	11.4	5.9	60.2	7.0	3.8	0.5	11.7	11.3	75.8
Oct 1	4.1	38.0	16.6	NA	0.0	9.1	3.7	58.7	0.0	0.0	NA	25.5	NA	69.7
8	4.1	40.9	10.1	53.0	0.0	9.1	3.7	55.1	0.0	NA	38.9	17.1	NA	62.9
15	2.6	44.1	12.6	53.0	0.0	6.0	2.5	59.2	0.0	NA	NA	NA	NA	62.9
22	2.6	26.2	12.6	22.9	0.0	5.1	3.7	41.4	0.0	NA	NA	7.4	NA	56.4
29	2.0	44.1	13.4	19.4	0.0	6.3	3.7	59.4	0.0	0.3	NA	15.0	NA	53.2
Nov 5	0.0	16.0	10.8	5.6	0.0	5.3	3.1	26.8	0.0	0.0	10.3	6.7	10.3	53.2

Table 4.5 Yields ($m^3/h.km^2$) normalised for catchment area (ha) recorded during 1990, before correction

Flow Yields, m3/h.km2

Weir	A	B	C	D+E	F	G	M	A+B+C	H	I	J	K	H+I+J	L
Catchment	372.0	980.0	165.0	960.0	400.0	220.0	200.0	1537.0	117.0	500.0	880.0	327.0	1497.0	820.0
	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield	Flow Yield
June 25	14.7	21.7	82.8	32.9	18.8	NA	NA	27.4	96.4	52.7	60.4	67.2	60.6	32.3
July 2	14.7	15.8	61.5	23.1	26.8	58.7	NA	21.0	0.0	46.8	46.8	26.0	43.1	43.4
9	10.7	28.8	51.0	21.3	32.5	64.1	NA	27.1	0.0	40.4	57.5	23.3	47.3	40.3
16	13.9	27.7	36.6	25.5	12.3	52.6	NA	25.5	48.3	31.4	40.9	20.7	38.3	NA
23	11.9	25.6	36.6	25.5	4.3	50.1	NA	23.6	59.4	40.4	40.9	23.3	42.2	NA
30	11.9	25.6	36.6	25.5	2.4	52.8	22.7	23.6	77.3	43.6	49.0	43.7	49.4	33.3
Aug 6	10.0	25.6	41.2	25.5	0.8	44.0	16.2	23.7	32.9	43.6	49.0	56.8	45.9	33.3
13	10.0	36.6	41.2	24.1	0.8	44.5	16.3	30.7	0.0	37.3	46.2	60.2	39.7	42.4
20	10.0	14.3	36.6	24.1	NA	44.0	16.3	15.9	0.0	46.8	28.5	46.8	32.4	41.1
27	1.3	5.3	14.3	6.2	0.9	43.1	16.2	5.4	0.0	1.0	15.6	37.5	9.5	39.1
Sept 3	5.5	6.3	46.0	6.2	1.3	27.4	13.9	10.9	NA	0.5	15.6	60.2	NA	38.3
10	3.6	8.9	31.1	6.9	0.0	18.6	10.6	10.3	35.0	0.3	1.5	34.3	3.7	37.9
17	NA	10.9	35.1	8.5	0.0	18.6	10.6	NA	28.1	0.7	16.2	NA	12.0	36.7
24	2.6	15.0	32.4	NA	0.0	18.6	10.6	14.1	21.6	2.8	0.2	12.9	2.7	33.3
Oct 1	4.0	13.9	32.4	NA	0.0	14.9	6.7	13.7	0.0	0.0	NA	28.1	NA	30.6
8	4.0	15.0	19.7	19.9	0.0	14.9	6.7	12.9	0.0	NA	15.9	18.8	NA	27.6
15	2.5	16.2	24.6	19.9	0.0	9.8	4.4	13.9	0.0	NA	NA	NA	NA	27.6
22	2.5	9.6	24.6	8.6	0.0	8.3	6.7	9.7	0.0	NA	NA	8.1	NA	24.8
29	1.9	16.2	26.0	7.3	0.0	10.4	6.7	13.9	0.0	0.3	NA	16.5	NA	23.3
Nov 5	0.0	5.9	20.9	2.1	0.0	8.7	5.6	6.3	0.0	0.0	4.2	7.4	2.5	23.3
12	0.0	2.8	34.9	0.0	0.0	8.7	4.4	6.0	0.0	NA	5.0	17.9	NA	NA
19	0.0	NA	NA	0.0	0.0	7.2	1.6	NA	0.0	NA	9.7	17.9	NA	NA
26	0.0	NA	NA	0.0	0.0	6.8	2.5	NA	0.0	NA	15.1	20.7	NA	NA

Table 4.6 Yields ($m^3/h.km^2$) normalised for catchment area (ha) recorded during 1990, following correction for upstream abstraction.

Total Yields, m3/h.km2

Weir	A	B	C	D+E	F	G	M	A+B+C	H	I	J	K	H+I+J	L
Catchment	372.0	980.0	185.0	960.0	400.0	220.0	200.0	1537.0	117.0	500.0	880.0	327.0	1497.0	820.0
	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield	Total Yield
June 25	51.4	27.0	82.8	38.3	28.7	NA	NA	39.7	96.4	52.7	60.4	67.2	60.6	32.3
July 2	48.6	21.7	61.5	29.1	26.8	58.7	NA	33.0	58.5	46.8	46.8	35.3	47.7	43.4
9	42.6	33.7	51.0	26.4	32.5	64.1	NA	37.9	0.0	40.4	57.5	32.7	47.3	40.3
16	43.0	38.0	36.6	36.0	37.5	52.6	NA	39.0	48.3	31.4	44.4	30.1	40.4	NA
23	41.0	36.4	36.6	36.5	30.9	50.1	NA	37.5	59.4	40.4	44.0	31.6	44.0	NA
30	41.0	36.4	36.6	36.5	28.9	52.8	22.7	37.5	77.3	43.6	51.4	50.3	50.8	33.3
Aug 6	39.0	35.9	41.2	36.0	26.0	44.0	16.2	37.3	125.2	43.6	51.2	62.8	54.5	33.3
13	39.0	45.4	41.2	32.7	24.2	44.5	16.3	43.3	127.7	37.3	46.2	60.2	49.6	42.4
20	31.8	25.3	36.6	33.5	NA	44.0	16.3	28.2	152.3	46.8	31.6	55.1	46.1	41.1
27	23.1	13.5	14.3	14.7	13.0	43.1	16.2	15.9	0.0	44.2	15.6	37.5	24.0	39.1
Sept 3	34.5	14.9	46.0	15.0	11.7	27.4	13.9	23.4	NA	25.7	27.5	60.2	NA	38.3
10	-30.2	13.2	62.2	11.2	NA	18.6	10.6	23.2	35.0	25.5	8.9	34.3	16.5	37.9
17	NA	21.1	58.4	19.0	NA	18.6	10.6	NA	28.1	18.7	38.5	NA	31.1	36.7
24	22.0	18.1	32.4	NA	NA	18.6	10.6	20.8	52.3	28.0	13.7	28.3	21.5	33.3
Oct 1	23.3	20.4	32.4	NA	NA	14.9	6.7	22.5	46.2	21.2	NA	28.1	NA	30.6
8	25.7	18.3	19.7	23.3	NA	14.9	6.7	20.3	0.0	NA	25.1	43.6	NA	27.6
15	24.2	23.0	24.6	26.8	NA	9.8	4.4	23.5	0.0	NA	NA	NA	NA	27.6
22	28.6	20.8	24.6	20.0	NA	8.3	6.7	23.2	0.0	NA	NA	33.4	NA	24.8
29	30.9	29.4	26.0	NA	NA	10.4	6.7	29.4	0.0	14.3	NA	41.8	NA	23.3
Nov 5	33.9	10.5	20.9	NA	NA	8.7	5.6	17.4	46.2	0.0	4.2	7.4	6.1	23.3
12	NA	7.9	34.9	NA	NA	8.7	4.4	NA	61.5	NA	9.5	30.0	NA	NA
19	NA	NA	NA	NA	NA	7.2	1.6	NA	0.0	NA	17.2	38.2	NA	NA
26	NA	NA	NA	NA	NA	6.8	2.5	NA	0.0	NA	15.1	20.7	NA	NA

On the Kidofi, flows out of Ubena Dam (F) were initially low as the reservoir filled following the placing of stoplogs across the spillway in June, and subsequently virtually stopped after heavy pumping. This depressed flows further downstream (B,D,E). Pumping from the Uanji Dam further distorted flows (B,D,E) after mid-August. Some later high readings represent the release of water to Ifupira estate. Flows from the Walihanga (A) were similarly distorted by reservoir drawdown after mid-August. The Ifupira (C) and Upangwa (G) catchments were much less affected, though the flows in the latter declined markedly after September

On Idetero estates reasonably consistent results were obtained from the House (I) and Fikiri (J,K) streams, showing a steady decline until September when pumping stopped flows. The smaller Kilima (H) stream was too affected by pumping to analyse. The Nyamalongolo stream at Maganga (L) showed a steady decline throughout and gave the most consistent record.

Generally the undistorted sections of the recordings support the Brooke Bond fitted values but with slightly lower yields. There is still a great deal of scatter. Computer fitted standardised yield curves for the major catchments showed that the Kidofi and Nyamalongolo started with slightly lower yields, although the latter then declined more slowly, while the Idetero streams started with higher yields but declined more rapidly. Overall, a weighted average shows yields decreasing by 1.28 $m^3/h.km^2$ per week from 43.2 $m^3/h.km^2$ at the start of July to 20.2 $m^3/h.km^2$ by the start of November 1990. However, it is noted that the accuracy of the recorded flows becomes progressively worse towards the end of the dry season, as the proportion of flow abstracted increases.

It is reasonable to assume that the proportional rate of decrease will be similar from year to year, but the initial flow will depend on the preceding wet season rainfall pattern. Rainfall at Stone Valley in 1989/90 from October to May was 1200 mm, below the twelve year average of 1294 mm and being the tenth lowest of those twelve. The flows recorded therefore represent a dry year. The Brooke Bond flows were recorded in 1988 after the 1987/88 wet season rainfall of 1269 mm, only slightly lower than average.

The 1988 Brooke Bond figures have been retained in the analysis to represent an average year, and results checked against the 1990 values to represent a dry year.

The data obtained are for the 1990 season only, though selected weirs could be replaced or rebuilt for 1991. (The weirs across the spillways had to be removed at the start of the wet season). It is strongly recommended that a small permanent gauging network should be set up to help manage the irrigation and obtain longer term data. Where possible, streams should be gauged upstream of abstraction points and reservoirs.

4.4 Existing reservoirs

There are 20 large existing reservoirs, listed in Table 4.7, and many minor ponds, which have been ignored. The gross storage capacities shown have been estimated by a combination of survey, pacing, aerial photography and calculation of valley slope. It was not possible to take depth soundings, and some siltation may have occurred. It is recommended that more accurate figures be obtained for the larger dams, particularly Ubena Dam, which is calculated to contain 40% of the existing storage.

The calculated relative sizes of Ubena and Uanji Dams were subsequently queried from site, but agree with the limited measurements made. It is recommended again that more accurate data should be obtained for Ubena Dam for operational purposes.

Only a few of the existing reservoirs have sufficient capacity to provide significant seasonal storage. A typical small irrigation unit, with say 30 sprinklers, uses over 1000 m^3/day. The smaller reservoirs nevertheless provide useful abstraction points and act as balancing ponds for portable equipment, being emptied and then left to refill slowly from baseflow. Continuous abstraction would not be possible from them once the streamflow fell below demand unless water could be released from a storage reservoir upstream.

The existing storage represents only about 14 days of gross requirements and 30 days of streamflow in November on Stone Valley/Itona, and 11 days and 27 days respectively on Idetero. Not all is usable, and some on Idetero is shared with neighbouring estates.

Attention is drawn to the poor state of maintenance of many of the existing dams. Trees and bushes have grown on several, risking cracking and failure. Most of the spillways are being undercut by erosion at the outlet, and need extending or providing with plunge pools. Several show signs of erosion alongside the spillways, perhaps due to the lack of cutoffs to resist the head occurring when spillways are stoplogged.

Note: subsequent to the preparation of this report, the Walihanga Dam failed leading also to the destruction of Factory Dam. It is understood that the replacement of one or both dams is proposed by site staff. No considerations arising from these failures have been included in this report.

5. Itona Estate (I1 across Walihanga Dam to W2)

6. Walihanga Dam (W2 behind)

Table 4.7 Existing Storage (minor ponds omitted).

Stream	Site	Estimated storage (000 m3)
Kidofi	Ubena Dam	190
	Ubena Pool	3
	Factory dam	6
	Uanji Dam	24
Ifupira	Ifupira Dam	8
Walihanga	Secret dam	1
	Walihanga Dam	30
	Factory Dam	21
Total on Stone Valley/Itona		283
Fikiri	Top Dam	47
	Middle Dam	13
	Lower dam	35
House stream	Upper Dams	7
	Factory Dam	20
	House Dams	12
	Lower Dam	21
Kilima	Upper Dam	6
	Lower dam	5
Total on Idetero		166
Total on Maganga		0

CHAPTER 5

RESOURCE BASE: TEA.

5.1 Introduction

Each of the four estates was visited and the areas of tea reconciled with the new field maps. It was also necessary to relate the new field numbering system with the previous field names. Yield data were abstracted from various record books for the previous pruning cycle, and for the current cropping year (1989/90) to give relative yields from individual fields and estates. Irrigation records were also inspected. Not all the historical data were complete.

Each of the four estates is considered in turn in relation to actual and potential yields with and without irrigation.

Itona Estate

Tea was first planted on this estate in 1957 and development continued for the next eight years to 1965. Much of this land has had a history of previous cultivation, particularly pyrethrum. By 1970 60 ha had been planted with tea but it was described at that time as "in such poor condition that irrigation was out of the question. The only tea which looked healthy was that which had recently been pruned and given remedial application of potassium and phosphate" (Carr, 1970, Appendix 1).

In the early 1970s other poor areas (formerly fields I_3 and I_4) were rehabilitated in this way, and the couch grass eradicated. New planting began again in 1982 and is continuing to the present, all with clonal tea, mainly clone 207. Table 5.1 summarises field areas, dates of planting, type of tea and recent yields, including the current year.

Apart from a small area in Itona 3 which is being rehabilitated, most of the tea now looks very healthy, with few vacancies. Yields in the current year (1989/90) are good, averaging 2227 kg/ha from Oct 1 to May 31. In Walihanga 2 they are exceptionally good, almost to the point of disbelief: if these yields are confirmed as being in excess of 6000 kg/ha for the year this will be a record for Mufindi. All the clonal tea in Walihanga division looks in excellent condition, and 6000 kg/ha is theoretically possible for clone 207. Walihanga 2 is reported to have had 3 rounds of irrigation in 1989 (up to 300 mm?), other areas had 1 or 2 rounds, and the pruned fields were not irrigated.

TABLE 5.1 ITONA ESTATE

Field name: Now	Field name: previous	Area (ha)	Year of planting	Type of tea	Average yield for last complete pruning cycle (kg/ha/y)	Yields 1989/90: Oct-Dec	Yields 1989/90: Oct-May
Itona 1	I1 I2	8.4 3.4 4.4 16.2*	58/59 57/58 61/62	seed seed seed + clone	1985-89 1600 800	1650	3250
Itona 2	I3 I4	8.3 12.8 21.1	63/64;82/83 63/64	seed plus clone (1 ha)	1200 800	950	2400
Itona 3	I5	10.4 2.5 12.9	64/65 83/84	mainly seed clone	1982-86 1200	300	1850
Itona 4	I6 I7 I8	10.3 10.1 7.5 27.9	64/65 82/83 64/65	seed clone seed	1050(?)	1400	2450
Total Itona Divison	88.1*plus about 10 ha planted in 1990, all clone						
Walihanga 1	W1	1.2 5.7	56/57 83/84	seed clone	400 1984-88		
	W2	2.8 1.5 11.2	63/64 82/83	seed clone	1300	1550	3300
Walihanga 2	W3 W4 W5 W6	9.3 5.7 12.9 6.8 34.7	58/59;81/82,86/87 82/83 81/82 81/82;82/83	seed (5 ha) clone clone clone	1982-86 1100 (from 29 ha) 1300 (from 5.7 ha)	3950	6250
Walihanga 3	W7	5.0 6.8 11.8	86/87 88/89	clone clone (some imported clone 1)	-	100	250
Total Walihange Div.		57.7					
Total Itona Estate	135.8				1050	2250	

Footnote: These are the best estimates of field yields obtainable from the records, and may be subject to error. Yields have been rounded to nearest 50 kg. Nearly all the clonal tea is clone 207. There is an old (1960s) clonal field trial in Itona 3 (12 clones selected by L. Napier-Ford).

It is not certain though how much water each irrigation round actually represented or the area covered. During the 1989 dry season (Oct-December) yields averaged about 1040 kg/ha but Walihanga 2 was again exceptional with nearly 4000 kg/ha.

The total area of tea on this estate is now about 146 ha including about 10 ha planted in 1990 in Itona 1. Of this total about 51 ha is clonal tea (nearly all clone 207) which is in production, 24 ha is very young tea and the balance of 71 ha is mature tea derived from seed. Another 250-300 ha of development are planned, some (about 10 ha) adjacent to W3, but the majority below the factory area and I4: these plans should be revised as a result of this study.

With such a large proportion of high yielding clonal tea already in production and with new areas being planted or planned for development, this is the estate where irrigation would be developed first if water could be made available. It is also close to the factory and good management supervision is possible . Target yields, averaged over a pruning cycle, with 'full' irrigation should be 5000 kg/ha for clone 207 and 3000-3500 kg/ha for seeding tea.

Stone Valley Estate

Development of tea on this estate began in 1944, and continued to 1947; further expansion occurred from 1961 to 1967, by which time most of the estate had been planted to tea (Table 5.2). The total area of tea is now about 242 ha. It is virtually all seedling tea, but with small areas of clone 207 and some clone 1 in Field 3 (formerly Wanji 1). Parts of this estate, particularly the old factory division, have a history of previous cultivation, mainly pyrethrum.

Yields over the last complete (4-year) pruning cycle ranged from 1250 kg/ha (Field 9) to 1950 kg/ha (Field 3); because the pruning dates were different, direct yield comparisons are difficult. In the current year (1989/90) the yields (from Oct 1 to May 31) range from 1910 kg/ha (Field 9) to 2740 kg/ha (Field 2). The highest dry season yield in 1989 was 750 kg/ha (Fields 3 and 8) and the average was 530 kg/ha.

The highest yielding fields in general appear to be the (old) Wanji division fields 1, 2 and 3 (now parts of Fields 2 & 3); the lowest yielding fields are Field 4 (old pyrethrum shambas) and Field 9 (couch grass?). Yields from Field 6 are remarkably good considering the large number of vacancies (despite infilling) which exist, particularly in (old) Kisima 6, where there are many rocky outcrops.

7. Stone Valley Estate (Field 6, (old) Kisima 6)

8. Stone Valley Estate (Field 6 to Field 8)

TABLE 5.2 STONE VALLEY ESTATE

Field name Now	Field name previous	Area (ha)	Year of planting	Type of tea	Average yield for last completed pruning cycle (kg/ha/y)	Yields 1989/90 (kg/ha) Oct-Dec	Yields 1989/90 (kg/ha) Oct-May
Field 1	Wanji 5 Wanji 6	15.9	1947 1967	)seed)	1985-89 1850	480	2390
Field 2	Wanji 3 Wanji 4	18.6	1947 1945	)seed)	1983-87 & 1984-88 1750	690	2740
various Field 3	Wanji 1 Wanji 2 Wanji 7	22.6	1964 1947 1965	clone 1)seed)	1950	750	2650
Field 4	Factory 1 Factory 2 Factory 7	29.1	1964 1962 1961	))seed)	1982-86 & 1983-87 1400	290	1950
Field 5	Factory 3 Factory 4 Factory 5 Factory 6 Kisima 7	36.1	1962 1962 1962 1961 1962	)))seed))	1982-86 1800	430	2080
Field 6	Kisima 3 Kisima 4 Kisima 5 Kisima 6	37.7	1944 1944 1947 1962	))seed))	1985-89 1600	410	2180
Field 7	Kisima 1 Kisima 2 Kinga 2 Kinga 3	36.9	1944 1944 1945 1945	))seed))	various 1700	650	2430
Field 8	Kinga 1 Kinga 4 Kinga 5	23.4	1945 1944 1944	))seed)	1983-87 & 1984-88 1750	760	2450
Field 9	Kinga 6 Kinga 7	21.7	1963 1944/64	)seed +)some clone)207	1984-88 1250	480	1910
Total		242				530	2280

Most of the unpruned tea in this estate was irrigated in 1989, but with only one round. (Old) Wanji 2 and 4, Factory 7 and Kisima 1 had two rounds.

Target yields across the whole of this estate with full irrigation are probably similar at 3000-3500 kg/ha, but perhaps rather less, at least initially, in Fields 4 and 9.

Idetero Estate

The earliest tea was planted on this estate in 1954, but it was developed mainly during the 1960s with the addition of small area of clonal tea in 1981 and 1982 (Table 5.3). This is a relatively compact estate presently totalling about 277 ha of mature tea, with a planned development of about 40 ha below Field 9. Average yields during the 2 or 3 year period to 1989/90 ranged from 1230 kg/ha (Field 9) and 1550 kg/ha (Field 7) up to 2760 kg/ha (Field 1) and even 2970 kg/ha (Field 6). In the current year (1989/90) Field 1 had yielded 3650 kg/ha by 31 May, compared with only 1600 kg/ha for Field 9 (pruned 1989). The estate average in 1989/90 was already 2450 kg/ha by May 31, of which the dry season contribution was only 650 kg/ha. All the unpruned tea is reported to have had one round of irrigation in 1989, and a small area had two rounds.

This is a good, potentially very high yielding compact estate, capable of yielding about 2500 kg/ha without irrigation and perhaps as much as 4000 kg/ha with full irrigation. There is only a very small area of clonal tea, but the planned development area could probably yield 5000-6000 kg/ha when in full production.

Maganga Estate

Most of the estate was planted in the period 1963 to 1966, mainly with seedling tea, but with some clones in Section 4 (Table 5.4). There was some infilling with clones during the 1980s. Section 1 is very steep and stony, with rocky outcrops. Section 4 is the best area with a yield of 2600 kg/ha in 1989/90 (to 31 May) even without irrigation. The 1989 dry season yield for this section was 480 kg/ha.

This is a difficult estate to contemplate irrigating except for Section 4 and parts of Sections 2 and 3. Section 4 in particular is potentially high yielding, possibly 4000-4500 kg/ha. Without irrigation yields will continue to average from 1500 kg/ha (Section 1) to 2500 kg/ha (Section 4).

9. Kilima Upper Dam, Idetero Estate (Id1 towards Id2)

10. Idetero Estate (Id9 and, across track, Id8)

TABLE 5.3 IDETERO ESTATE

Field name Now	previous	Area (ha)	Year of planting	Type of tea	Average yield for previous 2 or 3 years (kg/ha/y)	Yields 1989/90 (kg/ha) Oct-Dec 1989	Oct-May 89 90
South Division							
Field 1	A3 A4 A5	23	1954-1960 1954-1960 1981	Mainly seed + some clone 207 (20%)	2760(3)	700	3650
Field 2	B1 B2	22	1954-1968 1954-1969	seed	1720(3)	575	2300
Field 3	A1 A2 C	18	1954-1966 1954-1962 1960-1968	seed	2330(2)	200	2500
Field 4	D1 D2 D3	40	1960 1960 1954-1968	seed (some clones)	(?)	550	2300
Field 5	E3 E4	15	1961 1961-1962	seed	2280(3)	475	2400
Field 6	E1 E2	13	1964 1964	seed	2970(3)	800	2950
Total		135					
North Division							
Field 7	F1 F2 F3	30	1964 1964 1982	seed + some clone 1 + 207	1550(2)	300	1800
Field 8	G3 G4	22	1963 1963	seed	(?)	650	2900
Field 9	G1 G2	25	1963 1963	seed	1230(2)	50	1600
Field 10	H1 H5 H6	29	1962 1962 1962	seed	(?)	700	2500
Field 11	H2 H3 H4	35 142	1962 1962 1962	seed	(?)	400	2450
Total/mean		277			-	650	2450

TABLE 5.4 MAGANGA ESTATE

Field name	Area (ha)	Year of planting	Type of tea	Average yield (kg/ha) 1988/89 only	Yields 1989/90 (kg/ha) Oct-Dec 1989	Yields 1989/90 (kg/ha) Oct-May 1989-90
Section 1	27	1963-66	seed	2000	220	1550
Section 2	21	1963-66	seed	1600	270	2000
Section 3	21	1963-66	seed	1650	480	1950
Section 4	23	1963-66	mainly clonal	2450	480	2600
Total	92				358	2005

11. Maganga Estate (Section 4)

12. Maganga Estate (Section 1)

5.2 Yield potential

There is a considerable range in yields, from 1500 kg/ha on Section 1, Maganga estate, the worst yielding field on all four estates in the current year, and an apparent yield in excess of 6000 kg/ha on Walihanga 2, Itona estate. Average estate yields this year are all in excess of 2000 kg/ha, ranging from 2005 at Maganga to 2450 on Idetero (at 31 May), averaged over the four year pruning cycle.

Although there is some influence from favourable weather conditions this year, there is evidence that the benefits of improved nutrition and bush husbandry over the past few years are beginning to be reflected in larger yields. Only a limited amount of irrigation has been practised recently, with currently only one round on Stone Valley and Idetero estates, but two and occasionally three rounds on some fields on Itona estate following the purchase of the new irrigation unit. There has been no irrigation on Maganga estate in recent years. These differences are reflected in the averaged dry season yields in 1989 (October to December) which ranged from 360 kg/ha at Maganga, 530 kg/ha at Stone Valley, 660 kg/ha at Idetero and 1040 kg/ha at Itona for all tea.

Large yields are clearly possible, 5000 kg/ha from fully irrigated clonal tea and 3000-3500 kg/ha from the best seedling tea. The obvious order of priority for development of irrigation is Itona, Stone Valley, Idetero and Maganga estates for logistical and technical reasons.

At these altitudes averaged yields of at least 3000 kg/ha should be obtainable from well irrigated and fertilised seeding tea, perhaps up to 4000 kg/ha for the best areas in good years. The corresponding yields from high yielding clones (like 207) should be 5000-6000 kg/ha. Without irrigation yields will be about 1/3 less. Taking the more conservative of these values to predict responses to different levels of irrigation gives an indication of yield response to different levels of irrigation (Table 5.5).

Table 5.5. Forecast annual yields of made tea (kg/ha) for different levels of effective irrigation, for seedling and clonal tea, averaged over four year pruning cycle

	Effective Irrigation (mm)						
	0	100	200	300	400	500	600
Clone (207)	3200	3500	3800	4100	4400	4700	5000
Seed	1800	2000	2200	2400	2600	2800	3000

These estimates are the approximate yields averaged over a 4-year pruning cycle with no irrigation in the year of prune and assume that 300-350 kg N/ha is applied as NPK with up to half applied in July/August and the balance in December/January. For fully irrigated tea, 40-50% of the total annual yield can be expected in the period July to December inclusive.

To clarify subsequent correspondence, it is re-emphasised that the linear yield response of forecast annual yields given in table 5.5 is against levels of effective irrigation, ie. the increased transpiration resulting from irrigation. Even under perfect irrigation this is limited to the seasonal soil moisture deficits listed in table 2.4; in practice system capacity limitations and water shortages will also restrict effective irrigation. The irrigation efficiency declines as larger seasonal depths are applied, resulting in the normal curvi-linear response to gross application depth. This decline in efficiency is more marked with low uniformity, poor scheduling and large application depths. Efficiencies of 80 and 90% have been assumed in the report for the system recommended; these will not necessarily apply to other systems.

CHAPTER 6

IRRIGATION CRITERIA

6.1 Irrigation water requirement

Mature tea

The water requirements of tea which is completely covering the ground is close to that for evaporation from an open water surface. In round figures this corresponds to 3 mm/day during June, July and August, 4 mm/day in September and 5 mm/day in October and November. On this basis, and assuming an irrigation efficiency of 90 per cent, the irrigation water requirements for mature tea are given in Table 6.1, together with the monthly rainfall range. The high efficiency used (90%) assumes an increasing water deficit, minimising deep percolation losses due to non-uniformity. A lower figure should be used if full irrigation is achieved, e.g. in months of lower demand (see section 6.5).

Table 6.1. Daily and monthly water requirements (mm) of mature tea with complete ground cover on Itona Tea Estates, together with the monthly rainfall total range for 1978-1989.

	J	J	A	S	O	N
Daily E_T (net)	3	3	3	4	5	5
Daily ET (gross)	3.3	3.3	3.3	4.4	5.5	5.5
Monthly E_T (net)	90	93	93	120	155	150
Monthly E_T (gross)	100	103	103	133	172	167
Monthly Rain	0-60	0-20	0-13	0-10	0-46	7-218

Rainfall over this six month period is very variable and for the purpose of irrigation design is ignored. Any rain falling during this period is therefore a bonus.

The dates for the expected start, end and duration of the dry season, the week when the soil water deficit first reaches 100 mm and the potential soil water deficit at the end of the dry season, all as defined in Chapter 2, are summarised for different probabilities in Table 6.2.

Table 6.2 Summary table showing expected start, end and duration of the dry season, the week when the potential soil water deficit first exceeds 100 mm, and the total potential soil water deficit, all at different levels of probability

	Probability of exceedance				
	Extreme	80%	50%	20%	Extreme
Start	30 Apr	7 May	21 May	4 June	2 Jul
End	5 Nov	19 Nov	3 Dec	17 Dec	24 Dec
Duration (weeks)	23	25	27	29	31
Date when 100 mm SWD is reached	11 June	25 June	9 July	16 Jul	20 Aug
Potential total SWD	650	615	575	525	425

Irrigation should begin before the SWD reaches the allowable soil water deficit (see below) for that field, and continue to as near the end of the dry season as possible. The latter date is particularly critical for irrigation planning, since streamflows are then at their lowest and reservoirs are emptying. For calculating the water balance, irrigation is assumed to end at the end of November in an average year, and mid-December in a 1 in 5 dry year.

Currently 25% of the command area of mature tea is pruned each year and not irrigated. It is assumed that pruning cycles will be adjusted so that this proportion applies to each irrigation unit each year.

Three irrigation plans have been considered, A providing up to 5 mm/d net, B providing up to 3 mm/d net and C providing up to 4 mm/d net, all for the unpruned tea only. Plan A meets full demand in the October peak, but leaves equipment underused for much of the season. Plan B gives maximum equipment utilisation throughout the dry season. It meets full demand until the beginning of September, and then the soil moisture deficit grows at 1 mm/d through September and 2 mm/d thereafter. Plan C is an intermediate option which provides some spare capacity and flexibility from June to August, meets full demand in September and leaves a deficit growing at 1 mm/d through October and November.

Following the water resource balance below and an analysis of marginal costs and benefits, it was recommended that the permanent systems be designed to supply plan C, 4 mm/d net. This can meet over 90% of the seasonal water requirements, particularly if a small build-up in deficit is allowable at the end of the season. It gives more flexibility than plan B whilst avoiding the very high marginal cost of meeting the peak demand of plan A. It also limits water resource problems and reservoir storage needs. However, it was noted the client might wish to propose the higher figure, particularly on clonal tea and new developments, depending on company objectives.

Following discussions, Plan C remains the recommended plan. Plan C requires a system capacity of 4 mm/day net (4.4 mm/day gross) for the unpruned tea, normally 75% of the gross area. In an average year this will apply 3 mm/day net (3.75 mm/day gross) from June to August and 4 mm/day net (4.4 mm/day gross) from September to November. Allowing for non-uniformity, variable starting dates, late rains and an allowable end-of-season deficit, it is estimated that this could provide up to 500 mm of effective irrigation in an average year (see Table 5.5 above) if sufficient water is available. This would of course be reduced if water shortages resulted in irrigation restriction.

Young tea

For young tea, the crop water requirements can be reduced roughly in relation to the percentage leaf cover over the ground. However, efficiencies will be lower and total water requirements are unlikely to be significantly different after the first year.

6.2 Water resource balance methodology

The water resource balance is based on the irrigation water requirements given in section 6.1 and the flows predicted in section 4.4.

It is assumed that the required water will be used at each abstraction point if available, and any excess passed downstream to the next point. The abstraction points are limited to existing or potential dam sites and grouped to simplify future electrification. The command areas were allocated considering proximity and topography, and then adjusted iteratively to optimise water resources.

The extraction points and command areas used in the water balance are listed in Table 6.3, together with catchment areas. The ratio of total catchment area to total command area at each point is a useful initial indicator of water availability.

6.3 Water resource balance results

The local inflows and gross water requirements at each point are shown in Tables 6.4 and 6.5, for the 1988 (Brooke Bond) yields and 1990 (measured) yields, representing average and dry years respectively.

For this analysis, it is assumed that the water in shared catchments is evenly split; inflows have been reduced accordingly.

Tables 6.6 to 6.11 show the water balance results for plans A, B and C for the average and dry years respectively. The left-hand columns (residuals) show the flow still passing each point after abstraction; negative numbers indicate water required from storage. The right-hand columns (deficit) show the running total of storage required.

Itona/Stone Valley Estates

There is clearly a serious water shortage in Itona estate. A new abstraction point at the rock site on the Upangwa is recommended to supply I3 and I4. This will meet most of the requirements for plan B in normal years, though not full irrigation in dry years.

Despite this the Walihanga Dam would still be empty by the end of August. Raising the level of this dam is not recommended for safety reasons. Some improvement can be made by supplying one third of the area from Factory Dam downstream. A new and safer water source for the factory and housing will be required. With priority for the limited storage given to the clonal tea on W1 to W3, areas I1 and I2 will receive little water after August; it is suggested areas I1 and I2 are not included in the permanent irrigation system. There should be no further development in the upper part of Itona estate.

A new balancing pond/abstraction point is proposed on the lower Walihanga to supply the first stages of a new development there (W4: 25 ha). A supply from Uanji Dam and/or Uhehe Dam is proposed for later stages along the Kidofi (W5: 80 ha).

On the Kidofi, the large storage in Ubena Dam (if accurate) is adequate to meet full supply for S6 to S9 in average years. Another excellent storage site exists at Uhehe site, below Uhehe Camp. This should be used in later stages to secure full supply for the rest of Stone Valley, including S3 (see below), and to meet the requirements of the new W5 development. A major new storage reservoir is therefore proposed at Uhehe site.

Ifupira Dam is able to supply S3 fully until September. After that, about half of S3 should be supplied from Uanji Dam to eliminate the additional storage need shown for Ifupira Dam. This will be cheaper than constructing a new dam on the lower Ifupira site. It is suggested that for simplicity the system be able to irrigate all S3 from Uhehe or Uanji Dam after electrification and the construction of Uhehe Dam.

Table 6.3 Extraction points and command areas used in the water balance.

Stream	Site	Catchment Local ha	Catchment Total ha	Command Area Local Fields	Command Area Local ha	Total ha
Stone Valley/Itona:						
Upangwa	Rock site	140	140	I3-4	41	41
	Upangwa site	80	220		0	41
Kidofi	Ubena Dam	380	380	S6-9	120	120
	Uhehe site	240	840	S4-5	65	226
	Uanji Dam	145	985	S1-2	35	261
	+W5 (new)		985	+W5(new)	80	341
Ifupira	Ifupira Dam	80	80	S3	23	23
	New lower site	70	150		0	23
Walihanga	Walihanga Dam	155	155	I1-2,W1	49	49
	Factory Dam	85	240	W2-3	46	95
	Lower site +W4	105	345	W4(new)	25	120
Combined	Ex. W5		1480			445
	Inc. W5		1480			525
Idetero:						
Fikiri	Top Dam	105	105 *	Id 8-9	47	47
	Middle site	25	130 *		0	47
	Lower Dam	300	430 *	Id 10-11	[illegible]	110
(+Id12)	Top Dam	105	105 *	Id 8-9	47	47
	Middle site	25	130 *	Id 12(new)	40	87
	Lower dam	300	430 *	Id.10-11	63	150
House	Factory Dam	295	295	Id 3,4p,5-7	101	101
	House Dams	135	430		[illegible]	101
	Lower Dam	85	515	Id 4p	[illegible]	121
(+trans.)	Factory Dam	295	295	Id 3,4p,5-6	71	71
	House Dams	135	430	Id 7	[illegible]	101
	Lower Dam	85	515	Id 4p	[illegible]	121
Kilima	Lower Dam	60	60 *	Id 1-2	[illegible]	[illegible]
Combined	Lower dams		1005	Id 1-11		[illegible]
	+Id12 & trans.		1005	Id 1-12		[illegible]
Maganga:						
Msiwasi	At Maganga	2100	2100 *	M1	[illegible]	[illegible]
Nyamalango	At Maganga	455	455 *	M2-4	64	64

*Water in shared catchments assumed to be evenly split.

Table 6.4 Local inflows and water requirements, based on 1988 (Brooke Bond) yield figures, representing an average year.

Stream	Site	Local inflows mid-month, 88 data (m3/h) June	July	Aug	Sep	Oct	Nov	Dec	Local gross water requirements (m3/h) June	July	Aug	Sep	Oct	Nov	Dec
		m3/h.km2:							m3/h.ha:						
		47.6	42.8	38.0	33.2	28.4	23.6	18.8	1.38	1.38	1.38	1.85	2.31	2.31	2.31
Stone Valley/Itona:															
Upangwa	Rock site	67	60	53	46	40	33	26	42	42	42	57	71	71	71
	Upangwa site	38	34	30	27	23	19	15	0	0	0	0	0	0	0
Kidofi	Ubena Dam	181	163	144	126	108	90	71	124	124	124	167	208	208	208
	Uhene site	114	103	91	80	68	57	45	67	67	67	90	113	113	113
	Uanji Dam	69	62	55	48	41	34	27	36	36	36	49	61	61	61
	+W5 (new)	0	0	0	0	0	0	0	83	83	83	111	139	139	139
Ifupira	Ifupira Dam	38	34	30	27	23	19	15	24	24	24	32	40	40	40
	New lower site	33	30	27	23	20	17	13	0	0	0	0	0	0	0
Walihanga	Walihanga Dam	74	66	59	51	44	37	29	51	51	51	68	85	85	85
	Factory Dam	40	36	32	28	24	20	16	48	48	48	64	80	80	80
	Lower site +W4	50	45	40	35	30	25	20	26	26	26	35	43	43	43
Combined	Ex. W5	704	633	562	491	420	349	278	461	461	461	617	771	771	771
	Inc. W5	704	633	562	491	420	349	278	543	543	543	725	910	910	910
Idetero:															
Fikiri	Top Dam	50	45	40	35	30	25	20	49	49	49	65	81	81	81
	Middle site	12	11	10	8	7	6	5	0	0	0	0	0	0	0
	Lower Dam	143	128	114	100	85	71	56	65	65	65	87	109	109	109
(+Id12)	Top Dam	50	45	40	35	30	25	20	49	49	49	65	81	81	81
	Middle site	12	11	10	8	7	6	5	41	41	41	56	69	69	69
	Lower dam	143	128	114	100	85	71	56	65	65	65	87	109	109	109
House	Factory Dam	140	126	112	98	84	70	55	105	105	105	140	175	175	175
	House Dams	64	58	51	45	38	32	25	0	0	0	0	0	0	0
	Lower Dam	40	36	32	28	24	20	16	21	21	21	28	35	35	35
(+trans.)	Factory Dam	140	126	112	98	84	70	55	73	73	73	98	123	123	123
	House Dams	64	58	51	45	38	32	25	31	31	31	42	52	52	52
	Lower Dam	40	36	32	28	24	20	16	21	21	21	28	35	35	35
Kilima	Lower Dam	29	26	23	20	17	14	11	48	48	48	64	80	80	80
Combined	Lower dams	478	430	382	334	285	237	189	287	287	287	384	480	480	480
	+Id12 & trans.	478	430	382	334	285	237	189	328	328	328	440	549	549	549
Maganga:															
Msiwasi	At Maganga	1000	899	798	697	596	496	395	27	27	27	36	45	45	45
Nyamalango	At Maganga	217	195	173	151	129	107	86	66	66	66	89	111	111	111

Table 6.5 Local inflows and water requirements, based on 1990 measured yield figures, representing a dry year.

Stream	Site	Local inflows mid-month, 1990 data (m3/h)							Local gross water requirements (m3/h)						
		June	July	Aug	Sep	Oct	Nov	Dec	June	July	Aug	Sep	Oct	Nov	Dec
		m3/h.km2:							m3/h.ha:						
		46.2	40.6	35.0	29.4	23.9	18.3	12.7	1.38	1.38	1.38	1.85	2.31	2.31	2.31
Stone Valley/Itona:															
Upangwa	Rock site	65	57	49	41	33	26	18	42	42	42	57	71	71	71
	Upangwa site	37	32	28	24	19	15	10	0	0	0	0	0	0	0
Kidofi	Ubena Dam	176	154	133	112	91	70	48	124	124	124	167	208	208	208
	Uhehe site	111	97	84	71	57	44	30	67	67	67	90	113	113	113
	Uanji Dam	67	59	51	43	35	27	18	36	36	36	49	61	61	61
	+W5 (new)	0	0	0	0	0	0	0	83	83	83	111	139	139	139
Ifupira	Ifupira Dam	37	32	28	24	19	15	10	24	24	24	32	40	40	40
	New lower site	32	28	25	21	17	13	9	0	0	0	0	0	0	0
Walihanga	Walihanga Dam	72	63	54	46	37	28	20	51	51	51	68	85	85	85
	Factory Dam	39	35	30	25	20	16	11	48	48	48	64	80	80	80
	Lower site +W4	49	43	37	31	25	19	13	26	26	26	35	43	43	43
Combined	Ex. W5	684	601	518	435	354	271	188	461	461	461	617	771	771	771
	Inc. W5	684	601	518	435	354	271	188	543	543	543	728	910	910	910
Idetero:															
Fikiri	Top Dam	49	43	37	31	25	19	13	49	49	49	65	81	81	81
	Middle site	12	10	9	7	6	5	3	0	0	0	0	0	0	0
	Lower Dam	139	122	105	88	72	55	38	65	65	65	87	109	109	109
(+Idi2)	Top Dam	49	43	37	31	25	19	13	49	49	49	65	81	81	81
	Middle site	12	10	9	7	6	5	3	41	41	41	56	69	69	69
	Lower dam	139	122	105	88	72	55	38	65	65	65	87	109	109	109
House	Factory Dam	136	120	103	87	71	54	37	105	105	105	140	175	175	175
	House Dams	62	55	47	40	32	25	17	0	0	0	0	0	0	0
	Lower Dam	39	35	30	25	20	16	11	21	21	21	29	35	35	35
(+trans.)	Factory Dam	136	120	103	87	71	54	37	73	73	73	98	123	123	123
	House Dams	62	55	47	40	32	25	17	31	31	31	42	52	52	52
	Lower Dam	39	35	30	25	20	16	11	21	21	21	28	35	35	35
Kilima	Lower Dam	28	24	21	18	14	11	8	48	48	48	64	80	80	80
Combined	Lower dams	464	408	352	295	240	184	128	287	287	287	384	480	480	480
	+Idi2 & trans.	464	408	352	295	240	184	128	328	328	329	440	549	549	549
Maganga:															
Msiwasi	At Maganga	970	853	735	617	502	384	267	27	27	27	36	45	45	45
Nyamalango	At Maganga	210	185	159	134	109	83	58	66	66	66	89	111	111	111

Table 6.6 Water balance results for plan A in average year.

Stream	Site	Residuals mid-month at full supply (m3/h) June	July	Aug	Sep	Oct	Nov	Dec	Deficit at end-month, full supply (000m3) June	July	Aug	Sep	Oct	Nov	Dec
Stone Valley/Itona:															
Upangwa	Rock site	24	17	11	-10	-31	-38	-45	0	0	0	-8	-31	-59	-93
	Upangwa site	62	52	41	27	23	19	15	0	0	0	0	0	0	0
Kidofi	Ubena Dam	57	38	20	-40	-100	-118	-136	0	0	0	-30	-104	-192	-294
	Uhehe site	166	126	85	16	-22	-37	-52	0	0	0	0	-16	-44	-83
	Uanji Dam	199	151	104	16	-19	-26	-33	0	0	0	0	-14	-34	-59
	+W5 (new)	116	69	21	-95	-139	-139	-139	0	0	0	-71	-174	-277	-380
Ifupira	Ifupira Dam	14	10	7	-5	-17	-21	-25	0	0	0	-4	-17	-32	-51
	New lower site	48	40	33	23	20	17	13	0	0	0	0	0	0	0
Walihanga	Walihanga Dam	23	16	8	-17	-41	-48	-56	0	0	0	-12	-43	-79	-120
	Factory Dam	16	4	-7	-36	-56	-60	-64	0	0	-5	-32	-73	-117	-165
	Lower site +W4	40	23	14	0	-13	-19	-24	0	0	0	0	-10	-24	-41
Combined	Ex. W5								0	0	-5	-86	-309	-582	-905
	Inc. W5								0	0	-5	-157	-483	-859	-1286
Idetero:															
Fikiri	Top Dam	1	-4	-9	-30	-52	-57	-62	0	-3	-9	-32	-70	-112	-158
	Middle site	13	11	10	8	7	6	5	0	0	0	0	0	0	0
	Lower Dam	91	74	58	20	-17	-32	-48	0	0	0	0	-13	-37	-72
(+Id12)	Top Dam	1	-4	-9	-30	-52	-57	-62	0	-3	-9	-32	-70	-112	-158
	Middle site	-28	-31	-32	-47	-62	-63	-65	-20	-43	-67	-102	-148	-195	-243
	Lower dam	78	63	49	12	-24	-38	-53	0	0	0	0	-18	-46	-86
House	Factory Dam	36	22	8	-42	-91	-105	-120	0	0	0	-31	[illegible]	-178	-247
	House Dams	100	80	59	45	38	32	25	0	0	0	0	0	0	0
	Lower Dam	120	95	70	45	28	17	7	0	0	0	0	0	0	0
(+trans.)	Factory Dam	67	53	39	-1	-39	-53	-68	0	0	0	0	-20	-69	-120
	House Dams	100	80	59	3	-14	-20	-27	0	0	0	0	-10	-25	-45
	Lower Dam	120	95	70	4	-11	-15	-19	0	0	0	0	-8	-19	-33
Kilima	Lower Dam	-19	-22	-25	-44	-63	-66	-68	-14	-30	-48	-81	-128	-177	-227
Combined	Lower dams								-14	-33	-58	-144	-310	-503	-725
	+Id12 & trans.								-34	-76	-125	-215	-412	-644	-912
Maganga:															
Msiwasi	At Maganga	973	872	771	661	551	451	350	0	0	0	0	0	0	0
Nyamalango	At Maganga	150	129	107	62	18	-4	-25	0	0	0	0	0	-3	-21

Table 6.7 Water balance results for plan A in dry year.

Stream	Site	Residuals mid-month at full supply (m3/h)							Deficit at end-month, full supply (000m3)						
		June	July	Aug	Sep	Oct	Nov	Dec	June	July	Aug	Sep	Oct	Nov	Dec
Stone Valley/Itona:															
Upangwa	Rock site	22	14	7	-16	-38	-45	-53	0	0	0	-12	-40	-73	-113
	Upangwa site	59	47	35	24	19	15	10	0	0	0	0	0	0	0
Kidofi	Ubena Dam	51	30	9	-55	-117	-138	-160	0	0	0	-41	-128	-231	-350
	Uhehe site	154	107	60	4	-36	-54	-72	0	0	0	0	-27	-67	-121
	Uanji Dam	185	130	75	-2	-26	-34	-42	0	0	0	-2	-21	-46	-78
	+W5 (new)	102	47	-8	-111	-139	-139	-139	0	0	-6	-89	-192	-295	-396
Ifupira	Ifupira Dam	13	9	4	-8	-21	-25	-30	0	0	0	-6	-22	-40	-63
	New lower site	45	37	29	21	17	13	9	0	0	0	0	0	0	0
Walihanga	Walihanga Dam	21	12	4	-22	-48	-57	-65	0	0	0	-17	-52	-94	-143
	Factory Dam	13	-1	-14	-39	-59	-64	-69	0	-1	-11	-40	-84	-132	-183
	Lower site +W4	35	17	11	-4	-18	-24	-30	0	0	0	-3	-16	-34	-57
Combined	Ex. W5								0	-1	-11	-120	-390	-719	-1106
	Inc. W5								0	-1	-17	-209	-582	-1014	-1504
Idetero:															
Fikiri	Top Dam	0	-6	-12	-34	-56	-62	-68	0	-5	-13	-39	-91	-127	-178
	Middle site	12	10	9	7	6	5	3	0	0	0	0	0	0	0
	Lower Dam	85	67	49	8	-31	-50	-68	0	0	0	0	-23	-60	-111
(+Id12)	Top Dam	0	-6	-12	-34	-56	-62	-68	0	-5	-13	-39	-81	-127	-178
	Middle site	-30	-31	-33	-48	-63	-65	-66	-21	-45	-69	-105	-152	-200	-249
	Lower dam	73	57	40	1	-37	-54	-71	0	0	0	0	-29	-68	-121
House	Factory Dam	32	15	-1	-53	-104	-121	-138	0	0	-1	-41	-118	-208	-311
	House Dams	94	70	47	40	32	25	17	0	0	0	0	0	0	0
	Lower Dam	113	84	56	37	18	6	-7	0	0	0	0	0	0	-5
(+trans.)	Factory Dam	63	46	30	-12	-53	-69	-86	0	0	0	-7	-48	-99	-163
	House Dams	94	70	46	-2	-20	-27	-35	0	0	0	-1	-16	-36	-62
	Lower Dam	113	84	55	-3	-14	-19	-24	0	0	0	-2	-13	-27	-45
Kilima	Lower Dam	-20	-23	-27	-46	-65	-69	-72	-14	-32	-51	-86	-134	-186	-239
Combined	Lower dams								-14	-36	-66	-165	-357	-582	-844
	+Id12 & trans.								-36	-81	-134	-242	-472	-744	-1057
Maganga:															
Msiwasi	At Maganga	943	826	708	581	457	339	222	0	0	0	0	0	0	0
Nyamalango	At Maganga	144	118	93	45	-2	-28	-53	0	0	0	0	-2	-22	-62

Table 6.8 Water balance results for plan B in average year.

Stream	Site	Residuals mid-month at 3mm/d net (m^3/h)							Deficit at end-month at 3mm/d net ($000m^3$)						
		June	July	Aug	Sep	Oct	Nov	Dec	June	July	Aug	Sep	Oct	Nov	Dec
Stone Valley/Itona:															
Upangwa	Rock site	24	17	11	4	-3	-9	-16	0	0	0	0	-2	-9	-21
	Upangwa site	62	52	41	31	23	19	15	0	0	0	0	0	0	0
Kidofi	Ubena Dam	57	38	20	2	-16	-35	-53	0	0	0	0	-12	-38	-77
	Uhene site	166	126	85	45	24	8	-22	0	0	0	0	0	0	-16
	Uanji Dam	199	151	104	57	29	6	-9	0	0	0	0	0	0	-7
	+W5 (new)	116	69	21	-26	-54	-77	-83	0	0	0	-19	-60	-117	-178
Ifupira	Ifupira Dam	14	10	7	3	-1	-5	-9	0	0	0	0	-1	-4	-11
	New lower site	48	40	33	26	20	17	13	0	0	0	0	0	0	0
Walihanga	Walihanga Dam	23	16	8	1	-7	-14	-22	0	0	0	0	-5	-15	-32
	Factory Dam	16	4	-7	-19	-23	-28	-32	0	0	-5	-19	-37	-57	-81
	Lower site +W4	40	23	14	9	4	-1	-6	0	0	0	0	0	-1	-5
Combined	Ex. W5								0	0	-5	-19	-57	-125	-250
	Inc. W5								0	0	-5	-38	-116	-241	-428
Idetero:															
Fikiri	Top Dam	1	-4	-9	-14	-19	-24	-29	0	-3	-9	-20	-34	-51	-73
	Middle site	13	11	10	8	7	6	5	0	0	0	0	0	0	0
	Lower Dam	91	74	58	43	27	11	-4	0	0	0	0	0	0	-3
(+Id12)	Top Dam	1	-4	-9	-14	-19	-24	-29	0	-3	-9	-20	-34	-51	-73
	Middle site	-28	-31	-32	-33	-34	-36	-37	-20	-43	-67	-91	-117	-143	-171
	Lower dam	78	63	49	34	20	6	-9	0	0	0	0	0	0	-7
House	Factory Dam	36	22	8	-7	-21	-35	-49	0	0	0	-5	-20	-46	-83
	House Dams	100	80	59	45	38	32	25	0	0	0	0	0	0	0
	Lower Dam	120	95	70	52	42	31	21	0	0	0	0	0	0	0
(+trans.)	Factory Dam	67	53	39	24	10	-4	-18	0	0	0	0	0	-3	-16
	House Dams	100	80	59	38	19	1	-6	0	0	0	0	0	0	-4
	Lower Dam	120	95	70	46	21	0	-5	0	0	0	0	0	0	-4
Kilima	Lower Dam	-19	-22	-25	-28	-31	-33	-36	-14	-30	-48	-69	-92	-117	-144
Combined	Lower dams								-14	-33	-58	-94	-146	-214	-302
	+Id12 & trans.								-34	-76	-125	-180	-242	-314	-418
Maganga:															
Msiwasi	At Maganga	973	872	771	670	569	469	368	0	0	0	0	0	0	0
Nyamalango	At Maganga	150	129	107	85	63	41	19	0	0	0	0	0	0	0

Table 6.9 Water balance results for plan B in dry year.

Stream	Site	Residuals mid-month at 3mm/d net (m3/h) June	July	Aug	Sep	Oct	Nov	Dec	Deficit at end-month at 3mm/d net (000m3) June	July	Aug	Sep	Oct	Nov	Dec
Stone Valley/Itona:															
Upangwa	Rock site	22	14	7	-1	-9	-17	-25	0	0	0	-1	-8	-20	-38
	Upangwa site	59	47	35	24	19	15	10	0	0	0	0	0	0	0
Kidofi	Ubena Dam	51	30	9	-12	-33	-55	-76	0	0	0	-9	-34	-75	-131
	Uhehe site	154	107	60	27	9	-9	-37	0	0	0	0	0	-6	-34
	Uanji Dam	185	130	75	33	8	-10	-18	0	0	0	0	0	-7	-20
	+W5 (new)	102	47	-8	-50	-75	-83	-83	0	0	-6	-43	-99	-161	-222
Ifupira	Ifupira Dam	13	9	4	0	-5	-9	-14	0	0	0	0	-4	-11	-21
	New lower site	45	37	29	21	17	13	9	0	0	0	0	0	0	0
Walihanga	Walihanga Dam	21	12	4	-5	-14	-22	-31	0	0	0	-4	-14	-31	-54
	Factory Dam	13	-1	-14	-23	-27	-32	-37	0	-1	-11	-28	-48	-72	-100
	Lower site +W4	35	17	11	5	-1	-7	-13	0	0	0	0	-1	-6	-15
Combined	Ex. W5								0	-1	-11	-42	-109	-228	-413
	Inc. W5								0	-1	-17	-95	-207	-388	-635
Idetero:															
Fikiri	Top Dam	0	-6	-12	-18	-24	-29	-35	0	-5	-13	-27	-44	-66	-92
	Middle site	12	10	9	7	6	5	3	0	0	0	0	0	0	0
	Lower Dam	85	67	49	30	12	-6	-24	0	0	0	0	0	-4	-22
(+Id12)	Top Dam	0	-6	-12	-18	-24	-29	-35	0	-5	-13	-27	-44	-66	-92
	Middle site	-30	-31	-33	-34	-35	-37	-38	-21	-45	-69	-94	-121	-149	-177
	Lower dam	73	57	40	23	6	-10	-27	0	0	0	0	0	-8	-28
House	Factory Dam	32	15	-1	-18	-34	-51	-67	0	0	-1	-14	-40	-77	-127
	House Dams	94	70	47	40	32	25	17	0	0	0	0	0	0	0
	Lower Dam	113	84	56	44	32	20	7	0	0	0	0	0	0	0
(+trans.)	Factory Dam	63	46	30	13	-3	-20	-36	0	0	0	0	-2	-17	-44
	House Dams	94	70	46	22	1	-6	-14	0	0	0	0	0	-5	-15
	Lower Dam	113	84	55	26	1	-5	-10	0	0	0	0	0	-4	-11
Kilima	Lower Dam	-20	-23	-27	-30	-33	-37	-40	-14	-32	-51	-74	-98	-126	-155
Combined	Lower dams								-14	-36	-66	-115	-182	-273	-397
	+Id12 & trans.								-36	-81	-134	-195	-266	-373	-522
Maganga:															
Msiwasi	At Maganga	943	826	708	590	475	357	240	0	0	0	0	0	0	0
Nyamalango	At Maganga	144	118	93	68	43	17	-8	0	0	0	0	0	0	-6

Table 6.10 Water balance results for plan C in average year.

Stream	Site	Residuals mid-month at plan C (m3/h) June	July	Aug	Sep	Oct	Nov	Dec	Deficit at end-month, plan C (000m3) June	July	Aug	Sep	Oct	Nov	Dec
Stone Valley/Itona:															
Upangwa	Rock site	24	17	11	-10	-17	-24	-31	0	0	0	-8	-20	-38	-61
	Upangwa site	62	52	41	27	23	19	15	0	0	0	0	0	0	0
Kisofi	Ubena Dam	57	38	20	-40	-59	-77	-95	0	0	0	-30	-74	-131	-201
	Ubebe site	166	126	85	16	1	-15	-30	0	0	0	0	0	-11	[illegible]
	Uanji Dam	199	151	104	16	-7	-14	-21	0	0	0	0	-5	-16	[illegible]
	+W5 (new)	116	69	21	-95	-111	-111	-111	0	0	0	-71	-154	-236	[illegible]
Ifupira	Ifupira Dam	14	10	7	-5	-9	-13	-17	0	0	0	-4	-11	-21	[illegible]
	New lower site	48	40	33	23	20	17	13	0	0	0	0	0	0	0
Walihanga	Walihanga Dam	23	16	8	-17	-24	-31	-39	0	0	0	-12	-30	-53	-82
	Factory Dam	16	4	-7	-36	-40	-44	-48	0	0	-5	-32	-61	-94	-129
	Lower site +W4	40	23	14	0	-5	-10	-15	0	0	0	0	-4	-11	-22
Combined	Ex. W5								0	0	-5	-86	-205	-374	-594
	Inc. W5								0	0	-5	-157	-358	-611	-91[illegible]
Idetero:															
Fisiri	Top Dam	1	-4	-9	-30	-35	-40	-45	0	-3	-9	-32	-58	-88	-122
	Middle site	13	11	10	8	7	6	5	0	0	0	0	0	0	0
	Lower Dam	91	74	58	20	5	-11	-26	0	0	0	0	0	-8	-23
+Idi2	Top Dam	1	-4	-9	-30	-35	-40	-45	0	-3	-9	-32	-58	-88	-122
	Middle site	-29	-31	-32	-47	-48	-50	-51	-20	-43	-67	-102	-138	-175	-213
	Lower Dam	79	63	49	12	-2	-17	-31	0	0	0	0	-2	-14	-37
House	Factory Dam	36	22	8	-42	-56	-71	-85	0	0	0	-31	-73	-126	-189
	House Dams	100	80	59	45	38	32	25	0	0	0	0	0	0	0
	Lower Dam	120	95	70	45	35	24	14	0	0	0	0	0	0	0
+trans.	Factory Dam	67	53	39	-1	-15	-29	-43	0	0	0	0	-11	-33	-65
	House Dams	100	80	59	3	-3	-10	-16	0	0	0	0	-2	-10	-22
	Lower Dam	120	95	70	4	-4	-8	-12	0	0	0	0	-3	-8	-17
Kilima	Lower Dam	-19	-22	-25	-44	-47	-50	-53	-14	-30	-48	-81	-116	-153	-192
Combined	Lower Dams								-14	-32	-56	-144	-247	-375	-530
	+Idi2 & trans.								-34	-76	-125	-215	-330	-461	-665
Maganga:															
Msiwasi	At Maganga	370	372	371	661	560	460	359	0	0	0	0	0	0	0
Nyamalango	At Maganga	150	129	107	62	40	19	-3	0	0	0	0	0	[illegible]	-2

Table 6.11 Water balance results for plan C in dry year.

Stream	Site	Residuals mid-month, plan C (m3/h) June	July	Aug	Sep	Oct	Nov	Dec	Deficit at end-month, plan C (oocm3) June	July	Aug	Sep	Oct	Nov	Dec
Stone Valley/Itona:															
Upangwa	Rock site	22	14	7	-16	-23	-31	-39	0	0	0	-12	-29	-53	-81
	Upangwa site	59	47	35	24	19	15	10	0	0	0	0	0	0	[illegible]
[illegible]	Ubena Dam	[illegible]	30	3	-55	-76	-97	-113	0	0	0	-41	-97	-159	-257
	Ubehe site	154	[illegible]	[illegible]	4	-14	-32	-50	0	0	0	0	-10	-34	-71
	Uanji Dam	[illegible]	[illegible]	75	-2	-14	-22	-30	0	0	0	-2	-12	-28	-51
	-W5 new	[illegible]	47	-3	-111	-111	-111	-111	0	0	-6	-89	-171	-254	-336
Ifupira	Ifupira Dam	[illegible]	3	4	-8	-13	-17	-22	0	0	0	-6	-16	-29	-45
	New lower site	45	[illegible]	23	21	17	13	9	0	0	0	0	0	0	[illegible]
Wallhanga	Wallhanga Dam	[illegible]	12	4	-22	-31	-40	-48	0	0	0	-17	-40	-69	-105
	Factory Dam	[illegible]	-1	-14	-39	-44	-48	-53	0	-1	-11	-40	-73	-108	-148
	Lower site -W4	[illegible]	17	11	-4	-10	-15	-21	0	0	0	-3	-10	-21	-37
Combined	Ex. W5								0	-1	-11	-120	-286	-511	-786
	Inc. W5								0	-1	-17	-209	-453	-765	-1123
[illegible]:															
[illegible]	Top Dam	—	-6	-12	-34	-40	-46	-52	0	-5	-13	-39	-69	-103	-142
	Middle site	12	[illegible]	3	7	6	5	3	0	0	0	0	0	0	0
	Lower Dam	[illegible]	[illegible]	49	8	-10	-28	-46	0	0	0	0	-7	-28	-62
+[illegible]	Top Dam	[illegible]	-6	-12	-34	-40	-46	-52	0	-5	-13	-39	-69	-103	-142
	Middle site	[illegible]	[illegible]	-30	-48	-50	-51	-52	-21	-45	-69	-105	-142	-180	-213
	Lower dam	[illegible]	[illegible]	40	1	-16	-33	-49	0	0	0	0	-12	-36	-72
House	Factory Dam	[illegible]	15	-1	-63	-70	-86	-103	0	0	-1	-41	-92	-157	-233
	House Dams	94	70	47	40	32	25	17	0	0	0	0	0	0	0
	Lower Dam	[illegible]	94	56	37	25	13	0	0	0	0	0	0	0	0
+trans.	Factory Dam	[illegible]	46	30	-12	-28	-45	-61	0	0	0	-9	-30	-63	-108
	House Dams	34	70	46	-2	-9	-17	-24	0	0	0	-1	-8	-21	-39
	Lower Dam	[illegible]	94	55	-3	-7	-12	[illegible]	0	0	0	-2	-8	-17	-29
[illegible]	Lower Dam	[illegible]	[illegible]	-27	-46	-49	-53	-56	-14	-32	-51	-86	-123	-162	-204
Combined	Lower dams								-14	-36	-66	-165	-291	-450	-641
	+[illegible] & trans.								-36	-81	-134	-242	-390	-581	-813
Maganga:															
Msiwasi	At Maganga	[illegible]	[illegible]	708	581	466	349	231	0	0	0	0	0	0	0
Nyamalango	At Maganga	144	[illegible]	[illegible]	45	20	-6	-31	0	0	0	0	0	-4	-27

Idetero estate

There is presently a water shortage on the House stream around Factory Dam. Id8 and Id9 are therefore supplied from the Fikiri. A pumped transfer back from the north House Dam to the Factory Dam is also suggested for the future after electrification, rather than a major new storage reservoir or pumping direct from the House Dam to Id7. The water balance has been repeated with and without this transfer.

The water balance for the Fikiri has been repeated with and without the new development Id12, which would require a major new storage dam at or above the Middle site. The water balance depends critically on the split of water with Lupeme estate, which needs negotiating. It would be advantageous to take more of the Idetero share at the top dam.

There is a large shortage on the Kilima stream, but no suitable site for the required storage. Id1 and Id2 should have a low priority for irrigation development, despite the location of clonal tea there.

Maganga estate

The water balance confirms that a storage reservoir is not required at Maganga, even if fields M2, M3 and M4 were all irrigated. It is proposed however that only M4, with clonal tea and near the Nyamalongolo, is irrigated.

6.4 Allowable soil water deficit

For irrigation design and day-to-day management, it is important to identify the allowable soil water deficit. This value should not be exceeded if yields are not to be depressed by water stress. It varies with the water retention properties of the soil and the effective rooting depth. The rooting depths and total and easily available water in the root zones for the main soil series are summarised (from chapter 3) in Table 6.12.

Table 6.12. Representative rooting depths, total and easily available water in the root zones for individual soil series.

Soil Series	Rooting Depth	Total A.W.	Easily A.W.
Ngwazi	5.0	520	430
Itona	3.0	340	300
Idetero	2.0	220	150
Stone Valley	1.1	125	90

Mature Tea

At Ngwazi the results of experiments suggest that the allowable SWD is between 50 and 150 mm, depending on the clone, season and the stage of growth (i.e. the proportion of actively growing shoots in the bush).

At Ngwazi roots extend to depths of about 5 m; by comparison on the mid-slope Itona series soils, the maximum observed depth of rooting is about 3 m. The total available water in the respective root zones at these two sites is 520 and 340 mm respectively. Within the top 3 m of the soil, the total available water capacity of the two soils is similar at 300-350 mm. Despite the difference in rooting depth, it has been assumed that the allowable soil water deficit is similar to Ngwazi on the Itona Series soils. It is rather less however on Idetero and Stone Valley Series soils where the rooting depths are only 2 m and 1.1 m respectively. The effective rooting depths to be used for planning full irrigation will be less than these maximum root depths.

Evidence (limited) from Ngwazi also suggests that the allowable soil water deficit for high yielding clonal tea is less than that for seedling tea.

The allowable soil water deficits proposed (Table 6.13) have been selected to take these factors into account.

Table 6.13 Allowable soil water deficits (mm).

	Idetero/Stone Valley Series	Itona Series
Seed	80	120
Clones	40	60

There is probably a tolerance of ± 20 per cent in each of these values. Yields will be influenced more by the total depth of effective irrigation water applied over the season as a whole, then by two or three days delay in irrigation.

Young tea

For young clonal tea during the first few years after planting, the allowable water deficits increase from 20 mm in the first year to 40 mm in the second year and, on Itona series soil only, to 60 mm in the third year. Irrigation intervals increase correspondingly.

6.5 Irrigation application depths

The depth of water applied per application, net of losses, should be less than or equal to the allowable soil water deficit. For simplicity of operation, the number of different irrigation plans in any one area should be kept to a minimum. It is clear from the soil maps that the Itona series soils are so interspersed with the Idetero and Stone Valley series that separate units are rarely feasible, with the possible exception of the south-west corner of Stone Valley estate. It is proposed, therefore, to use standard irrigation plans based on the Idetero/Stone Valley soils for design purposes. The soils will however be irrigated differently at the end of the dry season, if water is limited, giving priority to the droughtier soils.

Recommended irrigation application depths are given in Table 6.14. The smaller applications in the first half of the season allow shorter sets when daylight is shorter and equipment less intensively used. A lower efficiency 80% has also been assumed for this period, when deficits are low.

The irrigation interval to meet full demand can then be calculated by dividing the net application depth by the crop water requirements (Table 6.15).

Under the recommended Plan C, the system capacity is limited to 4 mm/d net. This gives constant irrigation intervals throughout the year, Table 6.16.

In the event of significant rainfall at the start of the season, the cycle should be delayed for one day per 3 mm of effective rainfall, rather than altering the application depth. At the end of the season, rainfall will help offset the growing deficit, and should be ignored until the soil returns to field capacity.

Table 6.14 Irrigation application depths (mm)

	June-August (efficiency = 80%)		Sept-Nov (efficiency - 90%)	
	Net	Gross	Net	Gross
Seed	60	75	80	90
Clones	30	37	40	45

Table 6.15 Irrigation intervals (days), to meet full demand

	June	July	August	Sept	Oct	Nov
ET (mm/d)	3	3	3	4	5	5
Intervals (days):						
Seed	20	20	20	20	14	14
Clones	10	10	10	10	7	7

Table 6.16 Recommended irrigation interval (days), to meet Plan C

	June	July	August	Sept	Oct	Nov
ET (mm/d)	3	3	3	4	4	4
Intervals (days):						
Seed	20	20	20	20	20	20
Clones	10	10	10	10	10	10

CHAPTER 7

OUTLINE SYSTEM DESIGN

7.1 Introduction

This chapter gives an outline design of the proposed final irrigation system. It does not constitute a complete or legal contract specification and nothing in it shall detract from the supplier(s) obligation to design and provide a high quality system fit for its intended purpose. Because of the complex layout and topography of the sites, it may be necessary or sensible to work outside these guidelines in particular areas; where this occurs the supplier should be requested to bring it to the clients attention.

7.2 Command area and abstraction points

The design is to cover existing tea and the proposed new areas W4, W5 and Id12. (Typical designs only are possible for new areas until topographic surveys are complete).

Abstraction points and command areas are to be generally as shown in Table 7.1 and Figures 7.1 to 7.4. Minor changes may be made to suit the pipe layout.

The commands shall be subdivided into roughly similar sized units supplied independently. On steep commands, these divisions should separate high lift from low lift areas, to minimise unnecessary pumping costs, and pressure variation.

Each unit shall be designed and quoted for separately, to allow phased development.

7.3 Design system capacity

All permanent equipment (pumps and mainlines) shall be designed to be capable of supplying both a peak rate of 4.4 mm/day (gross) to any 75% of the area commanded by that unit and a peak rate of 5.5 mm/day (gross) to any 60% of the area commanded, over a 20 hour pumping day.

Table 7.1 Abstraction Points

Field	Stream	Abstraction point
Itona		
I1-2		No permanent system (water limitation)
I3-4	Upangwa	New rock site
W1, W2 west	Walihanga	Walihanga dam
W2 east, W3	Walihanga	Factory dam
W4 (new)	Walihanga	Lower Walihanga dam (new)
W5 (new)	Kidofi	Uanji dam and new Uhehe dam
Stone Valley		
S1-1	Kidofi	Uanji dam
S3-4	Kidofi	New Uhehe dam (S3 temporarily supplied from Ifupira dam) (S4,5 temporarily supplied from Uanji dam)
S6-9	Kidofi	Ubena dam
Idetero		
Id1	Kilima	Upper or lower dam (limited water)
Id2	Kilima	Lower dam (limited water)
Id3,4 west,5-7	House	Factory dam
Id4 east	House	Lower dam
Id8-9	Fikiri	Top dam (NB: not shown on base map)
Id10-11	Fikiri	Lower dam
Id12 (new)	Fikiri	New Fikiri dam
Maganga		
M1-3	-	Not irrigated (cost limitation)
M4	Nyamalongolo	Direct abstraction (diesel pump)

7.4 Pumps and mainline

The pumps at each abstraction point are to be sited together near the dams.

The system is to be designed for permanent electric pumps, although initially the system will use portable diesel powered pumps. Details of the power supply should be obtained from the client. Provision should remain for the diesel pumps to be reconnected as back-ups in case of breakdown or power failure. A minimum number of different pump models should be used with common components and easy interchangeability. Suitable protection against water hammer, backflow, low flow, pipe bursts and electricity supply failure must be provided.

Figure 7.1

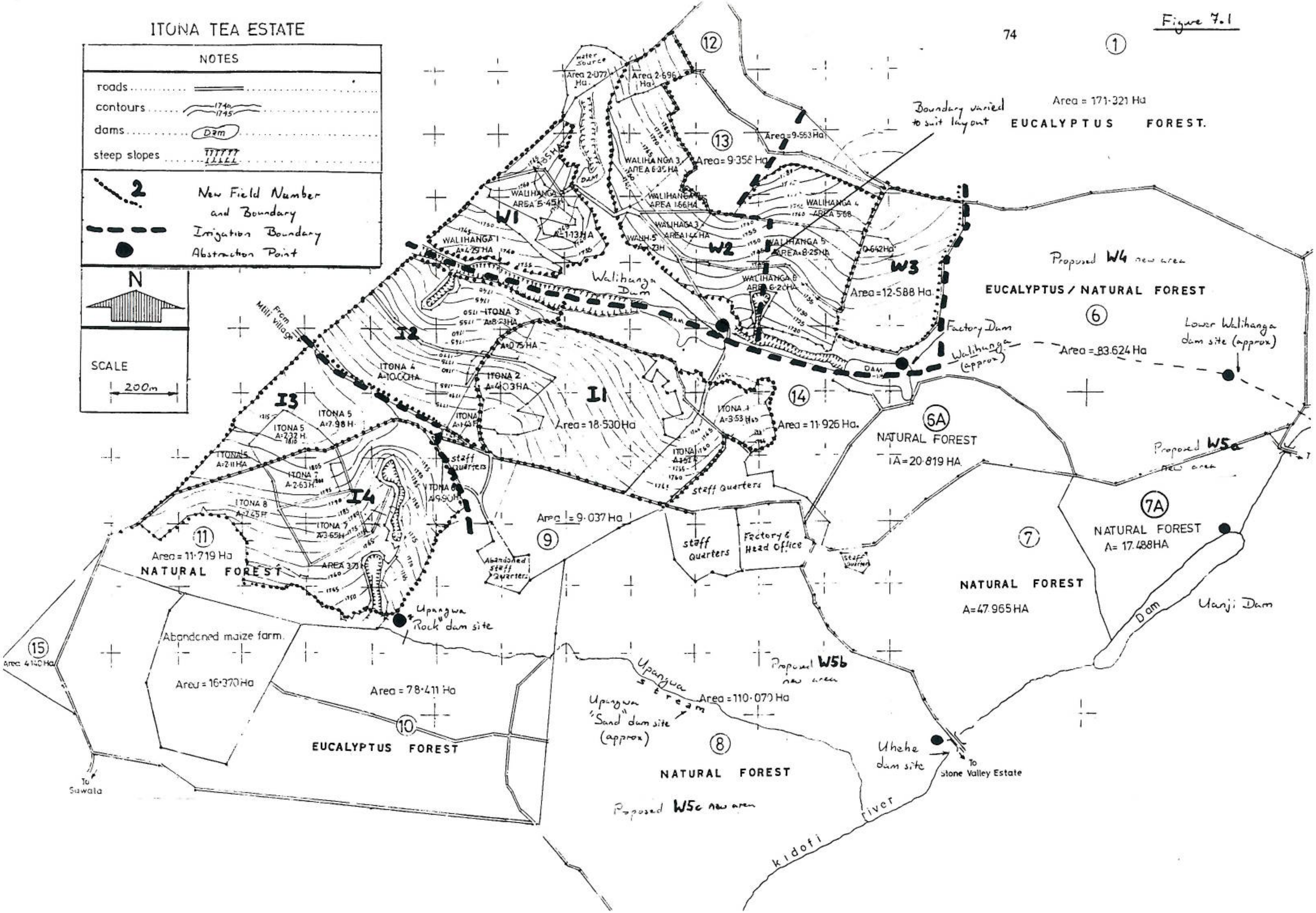

ITONA TEA ESTATE
NOTES
roads
contours
dams
Dam
steep slopes
New Field Number and Boundary
Irrigation Boundary
Abstraction Point
N
SCALE
200m
Area = 171·321 Ha
EUCALYPTUS FOREST.
Boundary varied to suit layout
Proposed W4 new area
EUCALYPTUS / NATURAL FOREST
Area = 83.624 Ha
Lower Walihanga dam site (approx)
Factory Dam
Walihanga (approx)
Walihanga Dam
Area = 12·588 Ha.
Area = 9·553 Ha
Area = 9·356 Ha
Area 2·077 Ha.
Area 2·696 Ha.
water source
WALIHANGA 1 A=4·29 HA
WALIHANGA AREA 5·45H
WALIHANGA 3 AREA 6·35 HA
WALIHANGA AREA 1·66HA
WALIHANGA 3 AREA 1·44 HA
WALIHANGA 4 AREA 5·68
WALIHANGA 5 AREA 8·25HA
WALIHANGA 6 AREA 6·2·CHA
W1
W2
W3
I1
I2
I3
I4
ITONA 2 A=4·03HA
ITONA 3 A=8·23HA
ITONA 4 A=10·CCHA
ITONA 5 A=7·98 H
ITONA 5 A=2·32 H.
ITONA 5 A=2·11 HA
ITONA 7 A=2·63 H
ITONA 7 A=3·65H
ITONA 8 A=2·45 H
AREA 3·71
ITONA 4 A=3·53 Ha
Area = 18·530 Ha
Area = 11·926 Ha.
NATURAL FOREST
A = 20·819 HA
Proposed W5a new area
NATURAL FOREST
A = 17.488HA
Uanji Dam
Dam
NATURAL FOREST
A=47.965 HA
staff quarters
Factory & Head Office
Abandoned staff quarters
Area = 9·037 Ha
Area = 11·719 Ha
NATURAL FOREST
Upangwa Rock dam site
Abandoned maize farm.
Area = 16·370 Ha
Area = 78·411 Ha
EUCALYPTUS FOREST
Area 4·140 Ha
To Sawala
From Mill village
Upangwa stream
Area = 110·070 Ha
Proposed W5b new area
Upangwa "Sand" dam site (approx)
NATURAL FOREST
Proposed W5c new area
Uhehe dam site
To Stone Valley Estate
kidofi river

Figure 7.2

STONE VALLEY ESTATE

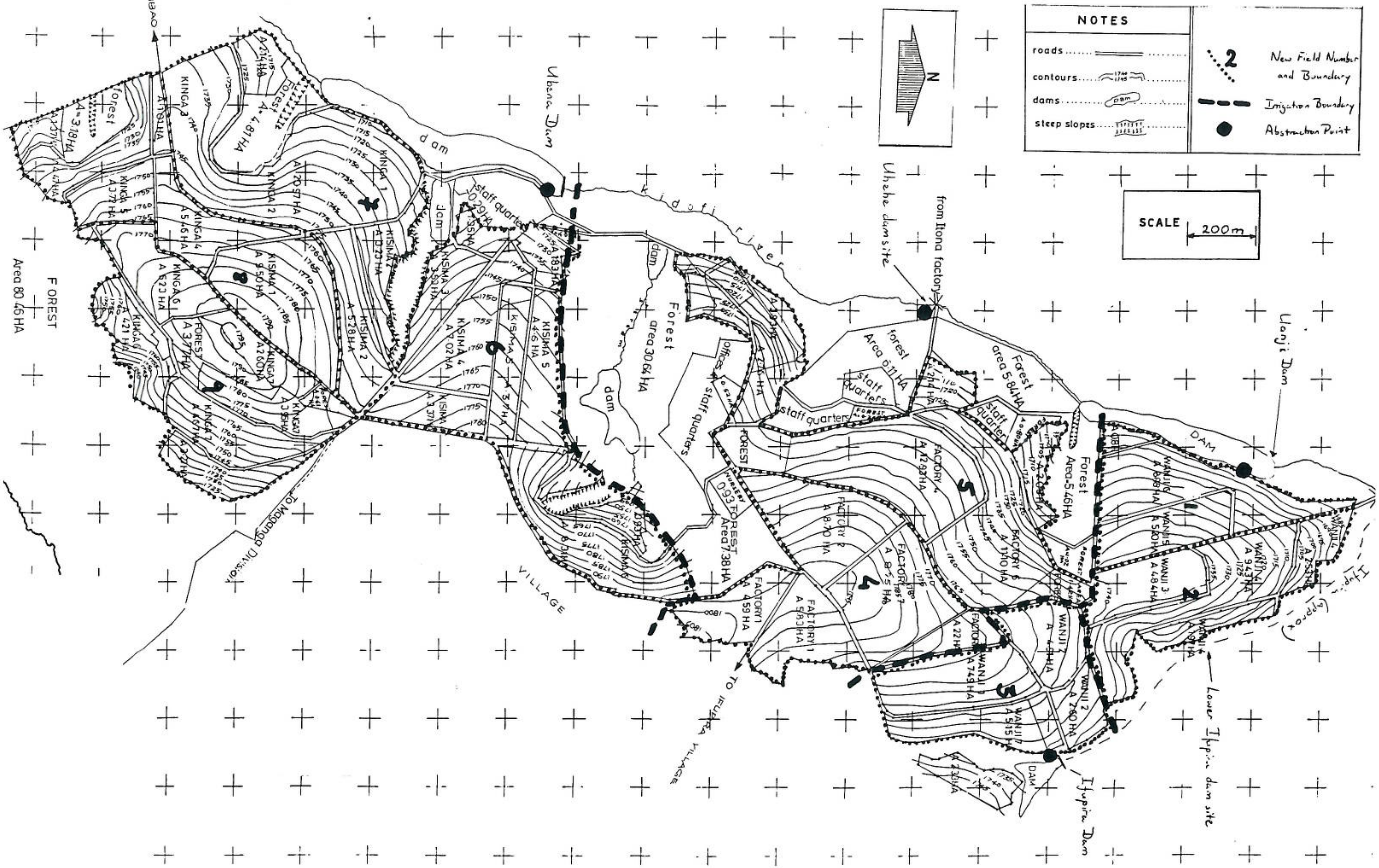


Figure 7.3

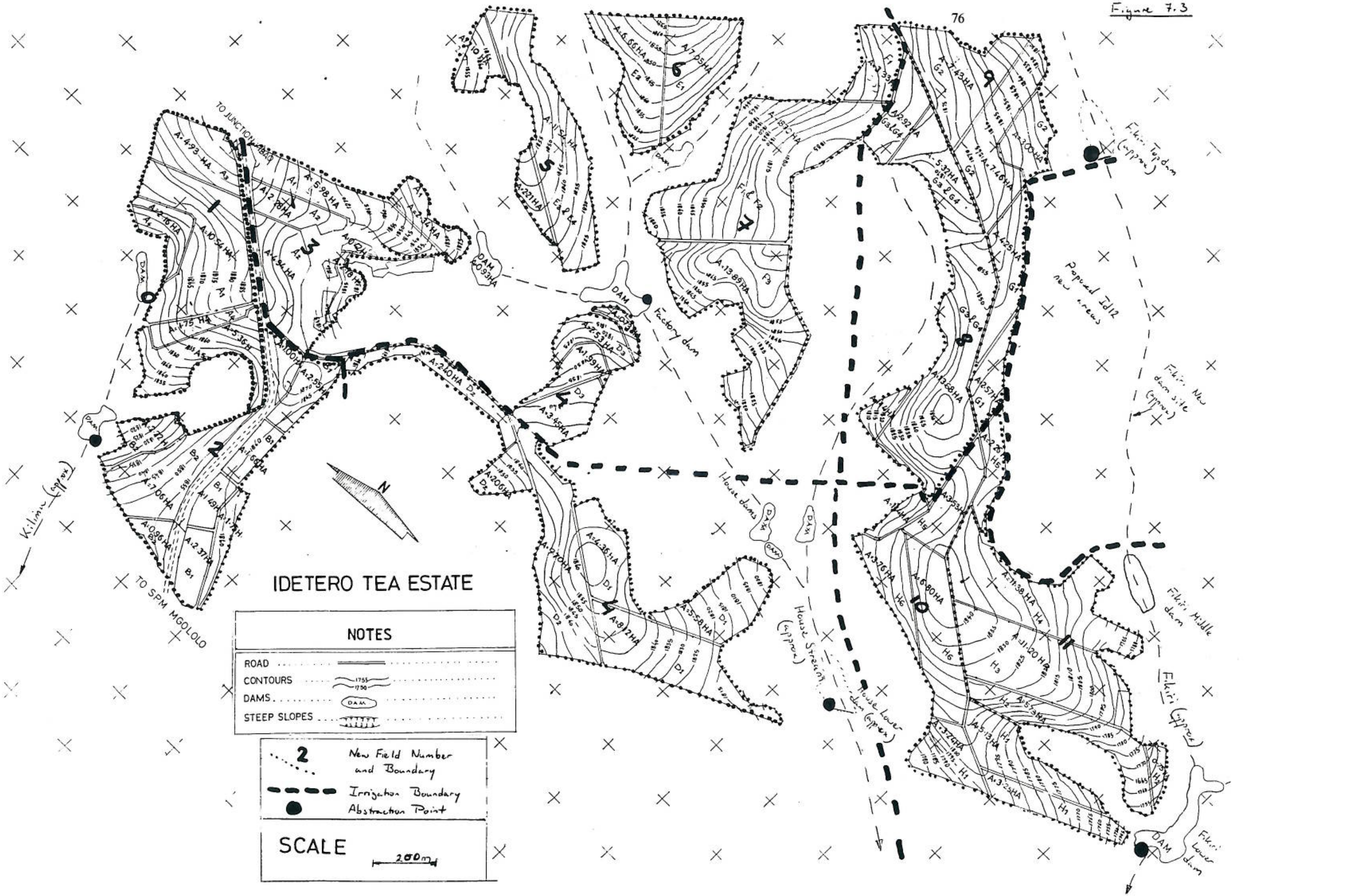
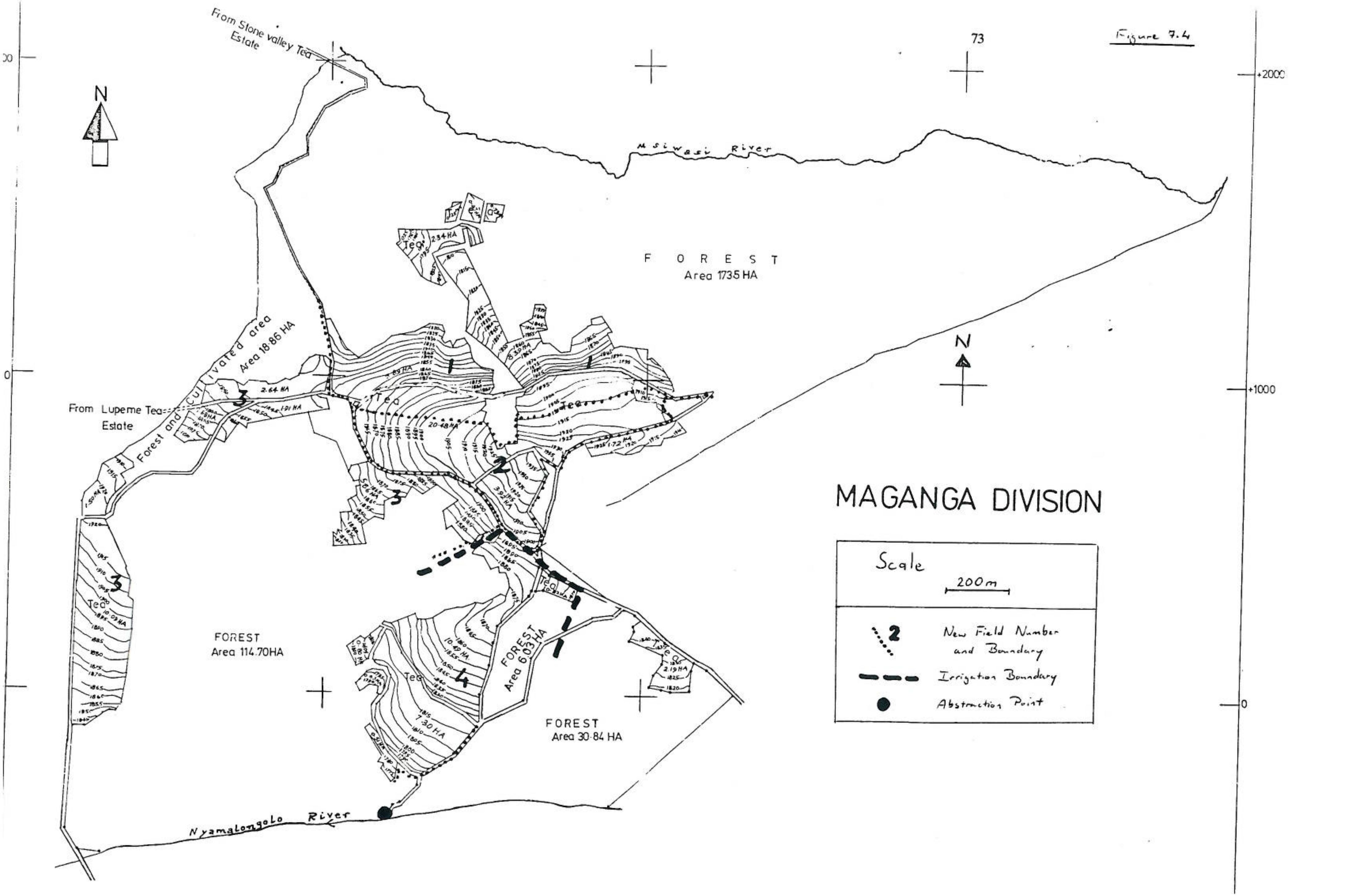

IDETERO TEA ESTATE
NOTES
ROAD
CONTOURS
DAMS
STEEP SLOPES
New Field Number and Boundary
Irrigation Boundary
Abstraction Point
SCALE
200m
N
TO JUNCTION
TO SPM MGOLOLO
Fikiri Top dam (approx)
Proposed Idl2 new areas
Fikiri New dam site (approx)
Fikiri Middle dam
Fikiri (approx)
Fikiri Lower dam
House Stream (approx)
House Lower dam (approx)
House dams
Factory dam
Kilimia (approx)

Figure 7.4


MAGANGA DIVISION
Scale
200m
New Field Number and Boundary
Irrigation Boundary
Abstraction Point
N
FOREST
Area 1735 HA
Msiwasi River
From Stone valley Tea Estate
From Lupeme Tea Estate
Forest and Cultivated area
Area 18.86 HA
FOREST
Area 114.70HA
FOREST
Area 6.03HA
FOREST
Area 30.84 HA
Nyamalongolo River
Tea
2.34 HA
2.64 HA
1.91 HA
20.48 HA
3.92 HA
10.40 HA
7.30 HA
1.72 HA
10.03 HA
2.19 HA
+2000
+1000
0

Pump performance must be derated for local temperatures and altitude. (Note that contour levels shown on the base maps and hence soil maps are not correct or consistent between estates. For correction to the national datum on 1:50000 maps, add 190, 335, 100 and 10 m to the Itona, Stone Valley, Idetero and Maganga contour levels respectively).

Mainlines shall be buried plastic pipes of suitable diameter and pressure class to allow conversion to a gun system at a later date if required. Sufficient hydrants should be included to allow efficient operation with the proposed irrigation intervals and set times.

7.5 In-field system

The in-field system recommended is a hand-move rotary impact sprinkler system, operated either alternate set or conventionally as discussed below. The steep and varied topography and the field shapes make any of the self-move alternatives difficult and expensive to operate effectively other than on selected sites. A mixed system would be unnecessarily complicated. Though trickle irrigation is attractive for tree crops, it is very capital intensive for tea and liable to damage during pruning. The relatively low wage levels also support a hand-move system.

The recently purchased Wright Rain systems use Lancer rotary impact sprinklers with a single 13/64 " nozzle on an 18 x 18 m spacing. This produces a 5.37 mm/hr application rate, which was seen to be acceptable on the tea and produces only limited run-off on roadways.

All sprinklers should be fitted with a pressure compensator. These are particularly useful on the uneven shapes in Mufindi, where it is impossible to align all laterals horizontally whilst maintaining the required spacing. Modern compensators can be reasonably cheap and introduce little pressure loss. They simplify lateral alignment, allow longer laterals in difficult locations and reduce the importance of accurately re-adjusting lateral pressure after each move. The improved uniformity resulting will help achieve the high efficiency sought.

The laterals should be aluminium, for lightness. There is some preference on site for the "Bauer" type connectors, but this seems to relate to problems experienced on mainline pipes at high pressure. A proportion of 'short lengths' of submain should be supplied to allow alignment of submain valves with the cutlines through the tea. Sufficient 'extra' lengths of lateral should be supplied to allow field operators to adjust the layout to suit non-standard field lengths without greatly varying the number of sprinklers in operation.

(a) *Alternate set option*

Alternate set operation involves the use of only every second (or even third) sprinkler position at each set. The outlets along the lateral pipe contain simple automatic valves so that flow only occurs when the riser and sprinkler are inserted. After irrigating one set of positions, the sprinklers can be hopped to the other positions. Once all the sprinkler positions have been irrigated, the lateral is moved to the next lateral position as in a conventional system. A sequence of hop-move-hop-move etc. is used.

Alternate set systems give greater flexibility for uneven shaped fields, allow longer laterals which reduce mainline costs, and reduce application rates since sprinklers hardly overlap during operation. The system can still be used conventionally where more convenient. Furthermore, the easy removal of sprinklers encourages dismantling before pipe movement and hence reduces damage.

A slightly higher application rate is preferable to suit the recommended application depths whilst avoiding night-time pipe moves. These are difficult in tea and can lead to damage, besides being unpopular with staff. Sprinkler hops, in contrast, can be simply performed with the aid of a suitable lamp, and are needed to provide the smaller applications needed on clonal tea. An application rate of 9 to 10 mm/h will apply the 90 mm gross application in September to November for seed tea in 9-10 hours, allowing a morning pipe-move and early evening 'hop' before dark, as favoured by the site management. On the clonal tea, the 45 mm gross application is applied in 4½-5 hours, allowing a pipe move, hop and pipe move during daylight followed by one hop only in the dark. The smaller applications in June to August require shorter set times.

A typical unit design using an alternate set is given as an example in Table 7.2; there will obviously be variation around these values depending on individual unit areas and field layouts.

(b) *Conventional system option*

Itona Tea Estate management have expressed reservations over the practicality of using night-time 'hops' in the alternate set system discussed above, and have suggested continued conventional use of the existing sprinkler specification. The best arrangement using this is shown in Table 7.3. Two moves per day are suggested. A single move per day, applying 108 mm gross, would only be feasible for seed tea on Itona soils and would require careful scheduling, and is not recommended.

Table 7.2 Typical unit design using an alternate set system

Equipment

Command area:	40 ha
Irrigated area:	30 ha
Pump(s):	electric centrifugal
Discharge:	70 m^3/h
Pressure:	depends on pipe layout and static lift
Mainline:	150 mm (decreasing) diameter pvc buried pipe
Laterals:	80 mm diameter portable aluminium pipe
Sprinkler:	rotary impact
Discharge:	2.91 m^3/h
	18 x 18 m
Application rate:	9 mm/h
No. of sprinklers:	24 (average)
No. of laterals:	4 (depending on field shape)
Sprinklers/laterals:	6 (depending on field shape)
Lateral length:	216 m (depending on field shape)
Unit length	720 m (depending on field shape)

Operation:

	June-August		Sept-Nov	
	seed	clones	seed	clones
Irrigation demand (mm/d)	3	3	4	4
Irrigation interval (days)	20	10	20	10
Net application (mm)	60	30	80	40
Efficiency (%)	80	80	90	90
Gross application (mm)	75	37	90	45
Set time (hr)	8.3	4.1	10	5
Lateral moves/day	1	2	1	2
Sprinkler hops/day	1	2	1	2
Pumping hours/day	16.6	16.6	20	20
Irrigation cycle (days)	20	10	20	10
Days off per interval	0	0	0	0

Table 7.3 Typical unit design using existing equipment in a conventional system

Equipment

Command area:	40 ha
Irrigated area:	30 ha
Pump(s):	electric centrifugal
Discharge:	70 m^3/h
Pressure:	depends on pipe layout and static lift
Mainline:	150 mm (decreasing) diameter pvc buried pipe
Laterals:	100 mm diameter portable aluminium pipe
Sprinkler:	rotary impact, 13/64" nozzle
Discharge:	1.74 m^3/h
	18 x 18 m
Application rate:	5.37 mm/h
No. of sprinklers:	40 (average)
No. of laterals:	2 (depending on field shape)
Sprinklers/laterals:	20 (depending on field shape)
Lateral length:	360 m (depending on field shape)
Unit length	432 m (depending on field shape)

Operation:

	June-August seed and clones	Sept-Nov seed and clones
Irrigation demand (mm/d)	3	4
Irrigation interval (days)	14	12
Net application (mm)	42	48
Efficiency (%)	80	90
Gross application (mm)	55	53
Set time (hr)	10	10
Lateral moves/day	2	2
Sprinkler hops/day	0	0
Pumping hours/day	20	20
Irrigation cycle (days)	12	12
Days off per interval	2	0

The existing equipment could in fact be used in either conventional (2 moves per day) or alternate set (1 move and 1 hop per day) operation. A full alternate set uses twice as much in-field pipework and is probably not worthwhile with this sprinkler size except where odd field shapes or long lateral lengths create problems with the conventional system. It is recommended however that all riser outlets be valved, allowing the removal of sprinklers for moving and for alternate set operation where required.

7.6 Mainlines and Pump Sites

(i) Permanent systems

In a permanent/electric system, it is sensible to bury the mainlines, connecting to the laterals with portable submains from hydrants. The optimum arrangement of pumps, mains, hydrants and sub-mains needs careful design for each irrigation unit.

Buried mainlines will require much less maintenance and replacement than portable pipes, reduce friction losses (if correctly sized) and simplify access. They will be a particular improvement where high lifts require high pump pressures. Electric pumps similarly have advantages of lower maintenance, simplicity and reliability.

It should be noted that the optimum layouts and pipe sizes for permanent systems are not the same as those for portable systems. It would be a mistake to simply replace portable pipes with buried lines of the same size and location. Permanent systems are worth designing and optimising.

The relative advantages of permanent and portable systems should be compared for each area. It may well be better to remain with portable systems in parts of Idetero where water is stored in many small reservoirs which must be allowed to replenish after use.

(ii) Interim systems

Until electrification, which may be delayed for some years at Idetero, it is sensible to retain the full advantages of the portability of diesel units and portable pipes.

CHAPTER 8

NEW DAMS AND RESERVOIRS

8.1 Recommended sites

Four new dams were proposed in section 6.3:

a) a balancing pond at the Upangwa rock site
b) a balancing pond at the Walihanga lower site
c) a seasonal storage reservoir at the Kidofi Uhehe site
d) a seasonal storage reservoir at the Fikiri middle site

8.2 Upangwa rock site

This site is below and slightly downsteam of the lower corner of I4, marked by survey pegs and two large exposed rocks in the stream bed.

Soil suitability

Unstable, permeable and waterlogged silty Kidofi Complex soils affected by a high groundwater table form only a very narrow strip here and overlay hard rock at about 60 cm to 1 m depth. The rock is exposed as two large flat boulders in the stream bed itself. These permeable alluvial soil materials are unsuitable for dam foundations and must be removed before dam construction. A narrow strip of sandy clay loams and sandy clays of the Valley Complex about 30 metres wide occurs on the lowermost slopes and, although subject to seepage from upslope, will provide a relatively stable foundation for the dam.

On the north valley side, grey mottled very plastic clay affected by seasonal waterlogging was encountered at 1.8 metres depth 14 metres from the break of slope into the valley floor. This would provide useful material for the clay core of the dam.

Gleysols of the Valley Complex on the south side of the valley show layers of coarser textured, permeable sandy loams affected by lateral seepage to 1.2 metres depth and overlie grey mottled sandy clay. These permeable coarse textured materials could be problematical. Deep, well drained friable red clays of the Itona series stretch to within about 30 m of the break of slope in the valley bottom and form a useful source of stable structured material for dam construction. This material, when puddled wet, will become plastic and with suitable puddling treatment would form an impermeable layer. As these soils are dominated by kaolintic clays, cracking on drying out will be minimized. In the moist friable state they can be handled easily and form a stable but permeable building material which resists dispersion by raindrop impact when uncompacted.

Outline design

A clay core earth dam 4 m high is proposed, to provide an abstraction point and limited storage.

The exact siting of the centreline will depend on the extent of the rock boulders upstream, since a good seal is essential for the cut-off key. This must extend down either well into the clay or into a key cut into unweathered rock. The key must extend well into the banks, particularly on the south side.

A zoned construction is proposed, with puddled clays in the central core and unworked friable clays for the shells. Suggested cross-section dimensions are:

Height	4 m
Freeboard	1 m
Core width	4 m reducing to 3 m at top
Base width	23 m reducing to 3 m at top (sideslopes 2.5:1)

Only a small spillway is required, of similar design to those used elsewhere on the estate, of a nominal 1.0 m width and 0.6 m depth. This should be constructed on undisturbed soil on the north bank, with a 2 m wide grass spillway outside it, and extend downstream to rock foundations or well below existing bed level, to avoid undermining.

8.3 Walihanga lower site

This site is in the lower reaches of the Walihanga, just downstream of a natural widening, and marked by survey pegs.

Soil suitability

Waterlogged fine silty soils of the Kidofi Complex saturated by groundwater at 25 cm depth occupy the flat valley floor at this proposed dam site. These permeable unstable soils overlie gravel at 90 cm depth. Both silty and gravelly materials are unsuitable as dam foundations and should be removed prior to construction. They will overlie weathered granite at some depth below 1 metre which could not be ascertained during the survey.

Lower slopes to the north of the dam site are occupied by soils of the Valley Complex up to 50 m from the flat valley floor. They are predominantly deep Xanthic Ferralsols with yellowish plastic clay at about 50 cm depth which becomes affected by seasonal waterlogging at depths of about 1 metre. Clay continues to 2 metres depth where a stone line is encountered. These soils should form relatively stable, impermeable foundation material. The plastic clay is of a non-swelling type and can be used to construct the clay core.

Stable friable red clays of the Itona series are found upslope. These soils, similar to those described under 7.2 above, are about 3 metres deep and form a non-cracking soil material suitable for construction of dam walls, but note that in their uncompacted state they are very permeable. More compact, pink, weathered disintegrated granite is found at about 3 m depth and may continue for a considerable depth before hard unweathered granite is reached.

Land rises more steeply from the valley floor on the south side of the Walihanga stream and carries Humic Ferralsols of the Idetero series. These have properties similar to the Itona series but pink weathered granite is encountered at about 2 metres depth. Soils of the Valley Complex form only a very narrow strip on this side of the valley restricted to concave slopes.

Outline design

The dimension of this dam will be similar to the rock site dam described above. The main construction difficulty will be in excavating the cut-off trench down to unweathered granite, which could be quite deep.

A much larger spillway is required at this site; the catchment area is similar to those of Ubena Dam and the lower Fikiri dam. A 1.0 m wide spillway on each bank is suggested.

8.4 Uhehe site

The dam would be sited across the Kidofi at the narrow section where the Itona to Stone Valley footpath now crosses. The valley widens suddenly upstream, and storage would extend well back up the Kidofi and a short way back into the Upanga tributary.

A detailed survey of the reservoir area proved impossible to obtain during the visit because of the high vegetation and swampy conditions but a longitudinal levelling survey confirmed the valley is very flat at this point.

Soil suitability

The flat valley floor is occupied by unstable waterlogged alluvial soils of the Kidofi Complex which here consist of silty clay loams or silt loams interlayered with saturated sands. These are unsuitable for dam foundations and must be removed prior to dam construction. This material is semi-fluid and continues down to at least 2 metres. In some places on the western side of the valley bottom, more compact, pale yellowish mottled sandy clay loam derived directly from weathered granite was reached at about 2.2 metres depth suggesting that weathered granite will be encountered below the alluvial deposits. Greyish mottled Mollic Gleysols of the Valley Complex occupy the lowermost slopes to a point about 20 metres from the break of slope into the flat valley floor. These consist predominantly of very sticky and very plastic slowly permeable sandy clay loam or clay suitable for the clay core of the dam. These lower slope sites have poor to imperfect natural drainage and soils are affected by slow lateral seepage from upslope sites but are not affected by the groundwater table in the alluvial deposits of the valley bottom.

Beyond a distance of about 20 metres from the valley floor, both sides of the valley are occupied by Humic Ferralsols with properties similar to those described in sections 7.2 and 7.3 above. These stable friable red clays are well suited to dam construction but need to be puddled where impermeable materials are required. At a point 30 metres from the flat valley floor on the eastern side of the valley, compact pinkish weathered granite was reached at 240 cm (giving Idetero series soils). The latter material contains common silt-sized mica and is a less stable construction material than the red friable clay above.

Outline design

This dam will be a major structure, with a storage of 300,000 m^3 plus. It will be another zoned dam, perhaps similar in dimensions to Ubena Dam. To fix crest level, a topographic survey of the valley upstream is required, up to say 10 m above the valley bed level at the dam site. Again, construction of the cut-off will be difficult, and a temporary dam upstream may have to be constructed first to allow dewatering. Earth volumes will be substantial, and specialist equipment may be required for moving and compacting the earth.

The large storage will significantly attenuate any flood discharges, and overflow weirs will therefore be similar to or smaller than those on Uanji dam downstream.

In view of the size of this structure, a full topographic survey and engineering design is strongly recommended: this will be a major structure if built to full height.

The level of the base of Ubena Dam needs checking during the survey to ensure it is above the backwater from Uhehe.

8.5 Fikiri middle site

This site is located across a narrow section of the Fikiri alongside the proposed Id12 (for which it is required), downstream of a wide grassy bowl. It is marked by a peg on the west bank. The dam and reservoir would be partly on land in the adjoining estate. The location and water rights need agreeing before construction.

The site was located relatively late in the study and a soil survey has not been carried out. From the soil maps, however, it appears that suitable material for construction exists on either bank, and that the design would be similar to the adjacent dams on the Fikiri, though possibly higher.

Again a topographic survey of the potential reservoir area is required to optimise storage characteristics. A soil survey of the dam centreline is also required for final design.

8.6 Other sites

Four other sites were surveyed as discussed below.

Other sites for storage were inspected visually, but none appeared to give storage/earthwork ratios comparable to those recommended. It would be worth reviewing this when a full contoured survey of the estate valleys is available.

Upangwa site

The Upangwa "sand" site is topographically attractive, but was rejected as a storage reservoir after the soil survey.

Parts of the lower valley sides at the site are covered by deep waterlogged grey sandy soils (Gleyic Arenosols) affected by seepage from upslope, including critical areas on the proposed dam site for irrigation works in this valley. The depth of the sandy deposits on which these soils have developed were not investigated in detail but preliminary observations suggest that they are up to 1.6 metres deep over moderately permeable waterlogged white mottled silty clay loam and are widespread on the south lower valley side at the narrowest part of the valley where the configuration of the land is otherwise most suited to dam construction. Observations in late June and mid October 1990 demonstrated that there is a free groundwater table in these soils which fluctuated from 1.2 metres from the surface in June to 2 metres in October. This shows that the silty clay loams are indeed permeable and probably contain sandy layers at greater depth. As permeable sandy materials such as these form unsuitable foundations, and as observations of the watertable indicate that they may occur again at depth, damming the valley at this point is not recommended.

The sandy materials tend to be relatively dirty loamy sands intermixed with sandy loams and are therefore not well suited as a source of building sand unless washing facilities are available.

Lower Ifupira site

This site is alongside Stone Valley Field 2, immediately below where a tributary joins the Ifupira from the shambas. The site is technically feasible and would increase the useful catchment area by 70 ha, supplying an additional streamflow in the water short September-November period. This would provide an alternative to part of the Uhehe storage. A low dam similar to Ifupira dam and with a balancing storage of say 3000 m^3 would be required.

House Stream

On Idetero estate, a site between the House dams and Factory dam was surveyed, but rejected because of the restricted storage capacity and the construction and design difficulties that would be caused by the backwater from the House Dam, which would flood the foundations.

Nyamalongolo

A site on the Nyamalongolo by Maganga estate was surveyed, but would only be sensible for a large storage, whereas the water balance shows only a small storage, if any, is required. A temporary weir and direct abstraction should be used instead.

CHAPTER 9

COSTS AND BENEFITS

9.1 General

This chapter seeks only to establish rough estimates of the likely costs and benefits of irrigating tea on the Itona Tea estates. A full cost-benefit analysis is not attempted because of the sensitivity to market prices and downstream production and delivery costs. All values are in 1990 pounds sterling.

This cost data is intended for initial guidance only and is based on very limited work. It is included under the understanding that the proposals will be submitted to manufacturers to obtain detailed designs and costing, and these quotations will then be used for system evaluation and selection. The commercial quotations obtained by R Ghaui for portable systems should clearly be compared with similar commercial quotations for permanent systems.

For comparison with other estimates, it must be noted that the benefits and costs given in this report are all stated in terms of gross area averaged over the four years pruning cycle (ie. including the 25% pruned areas) rather than in terms of net irrigated areas (ie. excluding pruned areas), and that this report considers replacement costs to be a capital cost, writing the system off over ten years, rather than as a running cost.

9.2 Irrigation costs

The capital cost of the irrigation equipment is mainly a function of the area commanded and peak capacity. Equipment quotations for Itona Tea estates made by Wright Rain Ltd. in 1989, for sprinkler systems with diesel pumps, range from £1200/ha to £1800/ha (FOB UK Port). These were to supply 3.7 mm/day gross over a 20 hour pumping day, but appear to have been overdesigned. Allowing conservatively for the increased system capacities, longer mainlines from the corrected abstraction points, the switch to electric pumps with back-up diesel facilities, transport, installation, inflation and construction of the two extra balancing reservoirs proposed, then the total capital costs would to be in the range £2000 - £3000/ha. Converting this to an annuity over 10 years at a real interest rate of 10%, this equates to £325-487/ha per annum. Running costs are dominated by maintenance and fuel. Allowing an arbitrary 1% of capital cost per annum for maintenance will cost £20-£30/ha p.a. Electricity to apply 400 mm net would cost £10-£20/ha p.a. In contrast, labour costs for moving pipes etc. are very small at under £1/ha p.a. due to the low wage rates. Total running costs would therefore be in the region of £30-£50/ha p.a., giving a total annual cost of £355-537/ha.

R Ghaui subsequently obtained quotations of £750-£1000/ha for portable systems. He has also mentioned a quote of £1050/ha for Ngwazi, though this is for a low-lying area and fairly near the water source. As these systems are for similar in-field equipment, it suggests the capital costs may be lower than estimated above. Conversely running costs may be higher than estimated. R Ghaui estimates a running cost of £200/ha irrespective of whether using diesel or electric. The figures for the portable diesel system are based on existing practice and presumably are correct. The maintenance and replacement costs should be substantially lower for a permanent electric system with buried mains. Labour and transport for moving mainlines and pumps and the need for pump attendants, should similarly be reduced. Fuel costs depend on the eventual price of the electricity - R Ghaui's figures of 3p-5p per kw/hr are very much higher than figures previously quoted, and may question the whole basis of electrification.

Revising capital costs to £1000-2000/ha depending on location, and running costs to £100-200/ha pa gives an amortised capital cost of £160-320/ha pa (over 10 years at 10% interest), and hence total annual costs of £260-520/ha (cf £355-537/ha above).

9.3 Irrigation benefits

Benefits will include extra yield and improved continuity of production from September to May, allowing more efficient use of the factory, transport, management and labour. Only the extra yield is quantified here, with the others regarded as ancillary though nevertheless important benefits.

Assuming an average effective application of 400 mm (ie. allowing for some restrictions due to water shortage), the average yield increase will be about 1200 kg and 800 kg of made tea per hectare for the clonal and seed tea respectively (Table 5.5). Using the total irrigation costs estimated above from the Wright Rain quotations, this corresponds to an irrigation cost of £0.30-0.45 and £0.44-0.68 per kg of made tea for clonal and seed tea respectively.

Where sufficient water is available to supply 500 mm of effective irrigation, yield increases of 1500 kg and 1000 kg of made tea for the clonal and seed tea respectively can be expected (Table 5.5).

Using the lower cost figure from R Ghaui's estimates (£260/ha pa) and the higher yields, the irrigation cost for the additional tea is £0.17 to £0.26 per kg of made tea for clonal and seed tea respectively.

Note these costs exclude all planting, processing, shipping and marketing costs, and any contribution to the electrical supply capital costs. Non-yield benefits of irrigation have been ignored. Benefit-cost ratios, internal rates of return and net present values can be calculated from these figures if the value of an additional kg of tea and the production costs excluding irrigation can be supplied by Itona Tea Estates.

9.4 Value of seasonal reservoir storage

Where adequate water is not available from existing sources, irrigation benefits are reduced pro-rata. Most of the proposed seasonal reservoir storage is intended to supply additional water at the end of the irrigation season, rather than meet the full requirements. The £2000-3000/ha Wright Rain capital equipment cost corresponds to a capital cost of £4.50-6.80 per ha mm gross applied (£0.45-0.68 per m^3) at 400 mm application depth . This gives an indication of the comparable acceptable capital cost of seasonal storage for water used to apply more than 400 mm per annum, assuming irrigation capital costs have already been recovered.

9.5 Summary

The figures in this chapter give an indication of likely costs and benefits. The major cost is clearly the capital cost; this should be revised when new quotations are received. The costs are highly sensitive to data sources and assumptions made on equipment life and discount rate. The spread in total irrigation costs of £0.17-0.68 per kg of made tea ranges from very reasonable to very marginal, again emphasising the importance of concentrating irrigation development on the lower cost sites and clonal tea. It is re-emphasised however that these figures are based on cost extrapolations and it is urged that quotations for alternative systems for at least one area are obtained with proposed designs and prices Bills of Quantities for comparison.

CHAPTER 10

OPERATION GUIDELINES

10.1 Weather data

It is recommended that in each of the four estates there should be one well sited and maintained standard rain-gauge. Rainfall should be recorded on a daily basis. The rain-gauge should be sited away from obstructions (such as buildings or trees), and the rim of the gauge should be 30 cm above the ground, and level.

We also recommend the development of one meteorological station, situated on Itona estate. The siting of the existing station though is not satisfactory. The minimum set of instrumentation needed is a rain-gauge, maximum and minimum thermometers, wet and dry bulb thermometers and an evaporation pan. A sunshine recorder and an anemometer would be of additional benefit. The data recorded would be used to assist with factory management and to investigate yield variability from year to year as well as assisting with irrigation scheduling.

The evaporation pan data should be used to check that the cumulative evaporation between one irrigation and the next is similar to that assumed in this report for planning. If there are major divergences, then the irrigation interval or application depth might have to be temporarily adjusted. One evaporation pan is sufficient for the four estates.

The responsibilities for recording the weather data, including rainfall, should be given to a relatively senior member of the management staff (and not delegated to junior staff). He/she should be trained on how to read and to record the instruments, identify errors and faults and to use the data. This should be a position of status and appropriately rewarded.

10.2 Scheduling

Using data from the local rain-gauge and the Itona evaporation pan, the manager on each estate (or his nominated senior assistant) should maintain a running water balance record for each unit. A pin-board display, such as is used in Zimbabwe for sugar cane irrigation, provides a further useful visual way of indicating when each block is due to be irrigated.

For convenience the irrigation system should normally be managed at a fixed interval between irrigations, as specified in Table 6.14.

Allowance should be made though for any significant rainfall. It is recommended that during June, July and August irrigation is delayed by 1 day for each 4 mm of rain recorded on the individual estate. (Thus if there are 12 mm of rain, irrigation can be delayed by 3 days.) During September, October and November the soil water deficit will normally be progressively increasing. Rain at this time is a bonus and, with the expected quantities, can be stored in the soil. During these months therefore, irrigation should not be delayed by rain.

It is important that irrigation should start at the earliest sensible time, since it is essential to make the best use of the streamflow during the early months when water is freely available. The first round(s) might only be a smaller application (eg. 40 mm net everywhere) started when deficits are still low, with all moves in daylight. Afterwards the schedule should move towards that given in Table 6.14. A 'stagger' in the deficits should be developed around each unit by slowly increasing applications so that subsequent irrigation takes place at the same deficit on each strip.

Once residual flows stop and water is then being taken from storage, it is then important to use the limited stored water as efficiently as possible. The timing of this moment will vary from one abstraction point to another, and from year to year. It is important then to concentrate the water on that tea which is likely to respond best (eg. the clonal tea, on any young tea at drought susceptible stages of development and on areas of tea where the soil is shallow and/or water retention is low) in order to minimise any severe defoliation or deaths of bushes.

10.3 Operation

The system has been designed to avoid night-time pipe moves (some fine tuning may be required when pipes are moved a long distance). On clonal tea, a late night 'hop' is required; staff must be given adequate lighting for this.

The same sequence of irrigation should be followed throughout the season, as stipulated in the detailed design. Typically, laterals will rotate around the block, one standard interval apart. A daily record of the locations and depths of irrigation should be recorded in the field for the manager, together with a note on any problems, delays etc. encountered.

Sprinklers should always be removed from pipes before moving, to minimise damage. Provided at least half the sprinklers on any one pump remain operational, the pump need not be stopped; otherwise the system must be temporarily switched off. Lateral inlet pressures should be reset after each move.

Hydrants and valves must be open and closed slowly to avoid water hammer; the mainline must be full before the main valve is fully opened, and the lateral full before the hydrant is fully opened. The pump should be started and stopped with the main valve three-quarters closed.

It is strongly recommended that managers make regular periodic field inspections, checking pressures, flows, uniformities, sprinkler operation and pumps, and ensuring records are accurate and up-to-date.

10.4 Maintenance

The system will be running more or less continuously for six months; good maintenance must be a priority. The manufacturer's recommended maintenance procedures should be followed; a formal recording system should be used to ensure this is done. The system should receive a thorough check immediately after each season, allowing time for obtaining spares and overhauls if needed. Each April, a pre-season operational check should be made as soon as the portable pipes are positioned. The estates should carry a reasonable stock of spare parts, particularly for the pumps. The existing portable diesel units must be kept in readiness as standbys.

10.5 Training

We recommend a short (one week) course in the operation and management of the irrigation system for all managerial staff. This would cover some basic theory about tea irrigation (such as soil/water/tea relations and simple hydraulics) with supporting practical work directly related to the systems installed (eg. on pressure and flow measurement, uniformity of application, scheduling and routine maintenance). The importance of irrigation to the success of the company could then be emphasised, to ensure the commitment of all staff.

10.6 Note on fertiliser application in the irrigation water

Since undertaking this study the question of applying fertiliser with the irrigation water and the timing of fertiliser applications on irrigated tea has been raised. Many factors need to be taken into account, but it is possible to consider applying fertiliser in the irrigation water providing that the water distribution is good. The best times to apply fertiliser to irrigated tea in Mufindi seems to be (based on very limited evidence) in August and December (a 50:50 split, for fully irrigated tea).

References

Avery, B.W. and Bascomb, C.L. (1982). Soil Survey Laboratory Methods. Soil Survey Technical Monograph No.6, Harpenden.

El Swaify, S.A. (1980). Physical and mechanical properties of Oxisols. In: Soils with Variable Charge, Ed. B.K. Theng. New Zealand Society of Soil Science, Soil Bureau, Department of Scientific and Industrial Research, Lower Hutt.

FAO (1977). Guidelines for the Field Description of soils. FAO, Rome.

FAO-UNESCO (1988). Soil map of the World; Revised Legend. Rome.

Hall, D.G.M., Reeve, M.J., Thomasson, A.J. and Wright, V.F. (1977). Water Retention, Porosity and Density of Field Soils. Soil Survey Technical monograph No.9, Harpenden.

→ Henwershott & Duquette 1986

Hodgson, J.M. (1976). Soil Survey Field Handbook. Soil Survey Technical monograph No.5, Harpenden.

Mehra, O.P. and Jackson, M.L. (1960). Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. Proceedings of the 7th National Congress on Clays and Clay minerals, pp. 317-327. Pergamon Press, New York.

Page, A.L., Miller, R.H. and Keeney, D.R. (1982). Methods of Soil Analysis: Part 2, Second Edition. American Society of Agronomy, Madison, Wisconsin.

APPENDIX I

CARR M K V (1970)

REPORT PREPARED FOR THE STONE VALLEY TEA CO. LTD ON THE POSSIBILITIES OF IRRIGATING TEA.

TEA RESEARCH INSTITUTE OF EAST AFRICA

REPORT PREPARED FOR

THE STONE VALLEY TEA CO. Ltd.

ON

THE POSSIBILITIES FOR IRRIGATING TEA

BY

M.K.V. CARR B.Sc., PhD.

TEA RESEARCH INSTITUTE OF E. AFRICA JUNE 1970.

The Case for Irrigation in the Mufindi District

Rainfall records in this district reveal that every year there is insufficient rain from June to November (inclusive) to maintain the growth rate of tea at an optimum level. Yields are reduced considerably over this period and even when the rains begin there is a further delay of about four weeks before appreciable crop is again produced. Drought results in uneven production as well as considerable loss of crop, and it would clearly be an advantage both to even out crop production over the year and to increase the total yield.

An analysis of crop yields in Mufindi, in relation to rainfall, shows that for every 25 mm of "effective rainfall*" falling in the period May to September (inclusive) one gets, over the period July to October (inclusive), an average of 25 kg made tea per hectare. This gives an approximate guide to the benefit derived from the very unreliable dry weather precipitation (under present fertilizer practice).

The results of irrigation trials carried out on Ngwazi Estate, Mufindi, show total crop can be more than doubled and that crop distribution can be considerably improved by correct irrigation during the dry months. (Tables 1 and 2).

Table 1: Annual Yields (kg mt/ha)

	No Irrigation (Rain only)	Frequent Irrigation	Benefit
1967/68	960	1620	660
1968/69	1080	2280	1200
% Increase 2nd year	14	41	

Table 2: Percentage distribution of crop crop each month 1968/69

	J	A	S	O	N	D	J	F	M	A	M	J
Rain only	1	1	2	3	2	4	21	7	21	15	18	5
Frequent Irrigation	2	2	7	14	9	13	11	10	10	10	9	3

There has been an increased benefit from irrigation in the second year of the experiment despite the fact that this seedling tea was entering the fifth year of its pruning cycle. Irrigation has also considerably improved the crop distribution in those months when low temperatures were not limiting.

The third important factor to consider, and possibly the most important, is quality. Mufindi dry-weather teas fetch much higher prices than the rains teas. Even in a wet dry-season when there is a large October flush these high prices are still maintained. It is therefore likely that irrigation will enable high quality dry weather teas to be produced every year. Pruning time could perhaps be adjusted to exploit this. For example the irrigated tea could be pruned in January, thereby reducing the pressure on the factory at this time and increasing the proportion of dry-weather tea.

In this connection, one should also be prepared to increase the rate and to alter the times of application of fertilizer to ensure that shortage of nutrients never limits the capacity of the tea to respond to irrigation.

* If the soil profile was at field capacity at the end of one month, and more than 100 mm of rain fell in the succeeding month, then the excess rain has been ignored.

..../2

Introduction to Report

This report should only be considered as a preliminary feasibility study into the possibilities that exist for irrigating tea in Mufindi. I have attempted to select those areas of tea which could be irrigated most economically. This involved looking at the areas of tea field by field, looking at likely sources of water, and obtaining an approximate measure of the maximum height necessary to pump water to cover a given area of tea. Should it be decided to irrigate, then it would be necessary for the advice and guidance of a suitably qualified irrigation engineer to be obtained. He would then design the best scheme to suit your conditions.

Throughout the report I have been unable to be specific with regards to the exact area of tea which could be irrigated from any particular water supply. This was because I have no figures available on the rate of stream flow during the dry season. These data should be obtained as soon as possible and, in the Appendix, I have included details of the simple V-notch weir which can be used to estimate the rate of flow of water in a stream. These data will enable you to calculate the total area of tea which can be irrigated and to decide whether or not a storage dam is necessary. Regular stream flow measurements should be taken throughout the dry season.

At the end of each section of my report I have given an approximate indication of the volume of water needed to irrigate each area of tea. These figures refer, in all cases, to the stream flow necessary in October to allow a <u>net</u> 125 mm of water (gross 150 mm) to be applied over the whole area. I have assumed that water will be pumped from the stream 20 hours a day, seven days a week, 30 days a month. During the cooler months a somewhat smaller volume of water will be adequate.

Similarly I have included the maximum volume of water which would need to be stored to enable enough water to be applied to the tea through October, if the streams should run dry during September. This has been calculated by simply multiplying the area of tea to be covered by a depth of 300 mm. This should be the absolute maximum volume of water required for irrigation to continue over a six week period at that time, after allowing for evaporation and small seepage losses from the dam. In most years it will not be necessary to irrigate the tea during November.

In some instances it will be necessary to extract water from several points on the same stream. Therefore when making stream flow measurements due allowance must be made for the water extracted upstream. If it is found that there is insufficient water in a stream to irrigate all the proposed areas then it is worth remembering that one quarter of the area of tea tea to be irrigated can be pruned each year. This will correspondly reduce the volume of water required by one quarter. When the water supply is plentiful, then pruning can be delayed until January to increase the proportion of dry weather tea, as mentioned above.

If, even after making these allowances, there is still insufficient water, then those high yielding fields closest to the water should be irrigated in preference to other areas. The cost of pumping is approximately proportional to the height the water has to be pumped. I have therefore listed the <u>maximum</u> pumping height necessary to cover each area.

The metric system has been used throughout the report. A flow rate of 28.3 litres per second (l/sec) is approximately equivalent to 1 cu sec. Remember to ensure that you are legally entitled to extract water from any particular water source.

..../3

Stone Vallye Tea Estate

There are 230 ha of tea on this estate all planted since 1945. The estate is divided into four divisions:-

Kinga Fields	1-7:	58 ha
Kisima "	1-7:	64 ha
Factory "	1-7:	52 ha
Mlanje "	1-7:	56 ha

The estate is bordered on its North Western boundary by the Kidofi river which is later joined by a stream which flows along the Eastern boundary. There are several other small tributaries which feed into the main Kidofi river within the estate. The Msiwazi river flows on the South Eastern boundary but is too far below the tea to be considered.

The Forest Department shares a common boundary with the estate along the upper third of the Kidofi river. Downstream the land on both sides of the river belongs to the Company.

Kinga

At the time of the visit (mid-January), about one month after the start of the rains, the rate of flow of water at the top end of the Kidofi river (source 1) was still low. The maximum area of tea which can be irrigated from here will depend entirely on the actual dry weather stream flow and on the volume of water which can be stored, either in the main stream or in the re-entrant between fields 2 and 3 Kinga. Any storage in the main stream will have to take into consideration the fact that far bank belongs to the Forest Department. However the river bank on the far side is about 6m high and a dam would cause the water to flood the flat marshy area on the Company's side.

The high point for fields 1,2 and 3 Kinga (23 ha) is only 53 m above the river. The high point for the whole division and also for Kisima division (on the ridge between fields 1 Kisima and 7 Kinga) is 85 m above the water. The rather irregular shaped fields 6 and 7, Kinga, slope away to the S.E. The whole of this division (58 ha), and one might also include fields 1 and 2 Kisima (20 ha), is therefore within an economic pumping height from the water. To cover the whole of this area one would require an October stream flow of about 55 l/sec, but I doubt whether there will be sufficient water to cover the whole area from this source. If not, then only the fields closest to the water should be considered.

Kisima

The Kidofi river is joined by another small stream which flows out from between fields 2 and 3 Kisima (source 2). A small dam originally used for a nursery still exists. More water could be stored in this re-entrant by building an earth dam where the road now fords the stream. The stream is reported to flow all through the dry weather.

It would be necessary to pump water a height of about 60 m to cover fields 3,4 and 5 Kisima (26 ha). A net stream flow of about 18 l/sec would be required in October.

Field 6 Kisima might be difficult to irrigate in view of its shape but the Eastern part might be included in any Factory division scheme. At present the field is still very low-yielding and would not be worth irrigating until the nutrition levels have been increased. Field 7 is even worse and irrigation should not be considered here until yields have risen considerably through improved nutrition.

..../4

Factory

This is generally a very low-yielding division, all the tea having been planted on old pyrethrum shambas. Yields should rise in the future, with adequate fertilizer, but any initial irrigation scheme need not, at present, include this division. However, when yields do rise then irrigation can and should be considered providing there is sufficient water.

The high point for this division (between fields 1 and 2 Factory) is about 100 m above the Kidofi river. However the dam below the manager's house (source 3) is only about 63 m below this high point. I am not sure how much water flows into this dam in the dry season but if there is sufficient water then it would probably be more economical to pump water from here to certain parts of the Factory division (e.g. Fields 1 and 2 Factory and part of field 6, Kisima; a total of 24 ha). An October stream flow of about 17 l/sec would be required.

The lower dam (on the same stream which flows below the house) could easily be enlarged, either to ensure that there is sufficient water to pump from here to (for example) field 7 Kisima (8 ha) or, more likely, to store water which can be released to a lower storage dam on the Kidofi river when needed. The stream here is reported to flow throuhout the dry season despite the fact that this water is used for domestic, nursery and factory purposes.

Fields 3,4 and 5 Factory (20 ha) could probably be best irrigated from the Kidofi river (source 4). The maximum pumping height is 76 m to the high point at the top of field.3 Factory. At this point on the river the land on both banks belongs to the Company; dam construction would therefore no l longer pose a problem.

Mwanje

There is an old nursery dam on the stream on the Eastern boundary (source 6). This dam could be enlarged if the October stream flow is less than about 25 l/sec. However this would result in the flooding of non-Company land on the far bank. This should not be an insoluble problem.

Water from this source could be used to irrigate fields 1,2 and 7 (less 2 ha), Mwanje (a total of 20 ha) and possibly also fields 6 and 7 Factory (16 ha). The maximum pumping height is about 67 m. Field 1 Mwanje is mainly T.T.Co. Clone 1 which, although it responds well to irrigation, produces a low-quality tea. This might be important if the purpose of irrigation is to produce high-quality dry-weather tea. However there should be sufficient extra seedling leaf to mix with the clone 1 leaf. Field 7 Mwanje is all young tea and likely to respond well to irrigation. Field 2 Mwanje is at present low yielding.

Fields 3,4,5 and 6 Mwanje (35 ha) can be irrigated from the Kidofi river (source 5). There is plenty of water at this end of the river. The maximum pumping height would be only about 50 m. This is, in my opinion, by far the most suitable site on the estate.

Discussion

This is a very compact estate which is ideally suited to irrigation providing there is adequate water during the dry season. An exact evaluation of the area of tea which can be irrigated will have to await the results of stream flow measurements, and an estimation of the volume of water which can be stored with the aid of simple earth dams. These measurements should begin as soon as possible.

..../5

A summary of the total volume of water required for each area is given below.

Source	Site	Height (m)	Area (ha)	Stream Flow (l/sec)	Storage(m^3)
A. Kidofi River					
Source 1	Kinga 1-7) Kisimal-2)	85	78	55	234,000
Source 2	Kisima 3,4,5	60	26	18	78,000
Source 3 (House Str.)	Factory 1,2 Kisima 6(part)	63	24	17*	72,000
Source 4	Factory 3,4,5	76	20	14	60,000
Source 5	Mwanje 3,4,5,6	50	35	25	105,000
Total Kidofi River			183	129	549,000
B. Eastern Stream					
Source 6	Mwanje 1,2,7) Factory 6,7)	67	36	25	108,000

N.B. * Not including domestic, factory and nursery requirements.

....../6

Idetero Estate

The tea on this estate is still young, all except 29 ha having been planted since 1960. Yields are generally low, especially in these areas which have had a recent history of cultivation, but with improved nutrition the yield potential of this estate should be considerably increased.

The total area of tea is about 230 ha. This has been divided into eight divisions as follows:-

Division A	fields	1-4:	35 ha
B	"	1,2:	22 ha
C	"	1	3 ha
D	"	1-4:	37 ha
E	"	1-4:	25 ha
F	"	1,2:	17 ha
G	"	1-4:	28 ha
H	"	1-5:	53 ha

There is one main stream flowing through the middle of the estate; it is hereafter referred to as the Idetero river. A series of water storage dams have already been constructed on this river. The fast-flowing Fikiri river forms the estate's Northern boundary with Lupeme Estate. There is another stream, possibly a tributary of the Wazo river, which flows into the estate and then out towards Kilima estate on the South side.

Source 1 - Headwaters of the Wazo river

An earth dam is in the process of being constructed by hand on the estate boundary. The whole of 'B' division (22 ha) lies within a height difference of about 55 m. This is a level area of tea, which could easily be irrigated with water taken from this source providing the water supply is sufficient. A streamflow of about 16 l/sec. would be required to enable all this tea to be irrigated in October. Alternatively there should be sufficient storage capacity for about 66,000 m^3 of water. There is a large marshy re-entrant below field B2 which could be used to store more water. Kilima estate is downstream on this river and may also wish to extract water for irrigation.

Source 2 - Upper dam on the main Idetero river

The high point of 'A' division near the main entrance is about 93 m above this water source. This is towards the upper limit for economic pumping of water for irrigation in this area; however, most of this tea is within a height difference of about 60 m of the dam. Assuming the whole of this division (35 ha) is irrigated from this source, a stream flow of about 25 l/sec would be required during October. Water is reported to pass over the spillway throughout the dry season. Sufficient extra storage capacity would be necessary to supplement the dry-weather flow.

Source 3 - Existing dam below field D3

This is a larger dam than the one referred to above. The high point for field E3 is 60 m above this water and both fields E3 and E4 (13 ha) could be irrigated from here. At the same time it might be possible to irrigate field D3 (9 ha) on the other bank with the same supply. For both areas (22 ha) the net October stream flow would need to be 16 l/sec, otherwise increased storage capacity would be required.

..../7

Source 4

A tributary to the main Idetero river flows in from the North between fields F1,F2 and E1, E2. This is joined by another stream which flows between fields E1,E2 and E3, E4. Both streams are reported to stop flowing during the dry season but there are excellent facilities here for storing water during the rains. If there is enough water, fields F1 (½ only) F2, E1 and E2 (26 ha) could be irrigated from here. Some of the tea cover in fields F1 and F2 is at present rather thin but it is expected to improve.

I am note sure when these streams run dry, but to be able to irrigate all 26 ha one would require a minimum stream flow in October of 18 l/sec. A storage dam would need to hold a maximum of 78,000 m^3 of water to enable irrigation to be continued through October.

If there is insufficient water then this is still a good place to store water during the rains; this water can then be released when required into a lower dam, to enable a larger area of tea downstream to be irrigated.

Source 5 - Various house dams

These dams, I think, are rather too far from the existing tea to enable them to be considered as sources of water for irrigation.

Source 6 - Lower dam on the Idetero river

This is a small dam near the estate boundary. The area of tea which can be irrigated from here will depend entirely on the volume of water remaining in the river after extraction has taken place upstream. Should there be sufficient water, then it would be necessary to pump water a maximum height of 82 m to reach the high point between fields D2 and D4. This would cover a total area of 28 ha (Fields D1, D2 and D4). A net stream flow of 20 l/sec would be required in October.

Source 7 - Upper end of the Fikiri river

The tea in field G2 extends close to this river. Water could be extracted from a point near here to cover fields G2,G3, half of F1 and part of G1 (c.28 ha). The remainder of G1 and G4 (14 ha) might be included but might make the scheme more expensive in view of the long, narrow nature of the fields, which would increase the length of piping required.

The maximum pumping height would be about 60 m. A minimum October streamflow of 30 l/sec would be required to irrigate all 42 ha, but there is an excellent site for a dam near the proposed point of extraction.

Source 8 - Lower end of the Fikiri river

The river is fast-flowing at this point below 'H' division. All 53 ha of this division are within a height difference of about 63 m from the river. A net October streamflow of about 38 l/sec would be required to irrigate the whole area.

Discussion

All the tea on this estate is within relatively easy access of water and, providing there is sufficient dry weather stream flow and adequate facilities for water storage, most of this estate could be profitably irrigated. One exception is the irregular horse-shoe shaped field C1.

The estate is fortunate in having well-designed water storage facilities already in existence to provide the basis for a good scheme.

Summary

Source	Site	Height (m)	Area (ha)	Stream Flow (l/sec)	Storage(m^3)
A. Source 1	'B' Div.	55	22	16	66,000
B. Idetero River					
Source 2.	'A' Div.	60	35	25	105,000
Source 3	E3,4 &D3	60,38	22	16	66,000
Source 4	E1 &2, F1*&2	51,73	26	18	78,000
Source 6	D1,2,4	82	28	20	84,000
Total Idetero River			111	79	333,000
C. Fikiri River					
Source 7	G1,2,3,4 F1*	60	42	30	126,000
Source 8	'H' Div.	63	53	38	159,000
Total Fikiri River			95	68	285,000

* Part of field F1 only

..../9

Maganga Estate

This is a small 80 ha estate which was planted between 1963 and 1966. Unfortunately most of the tea is planted on the very top of a steep-sided hill as far away from any water as possible. Future irrigation was obviously the last thing in anybody's mind when this tea was planted. The tea on the Stone Valley side is very exposed to the wind and 284 m above the Msiwazi river! Irrigation is clearly impossible here even though the tea suffers badly in the dry weather as a result of the shallow soil, as indicated by the rocky outcrops.

On the other side of the hill one could irrigate part,possibly 25 ha , of Section 3 whithin a pumping height of 60 m from the nursery dam. Similarly the lower part of Section 3 could be irrigated from the Nyamalango river; but this estate is so distant from Stone Valley that adequate supervision of an irrigation scheme would be difficult. It would be far better to concentrate on Stone Valley and Idetero estates where, in addition to other advantages, the yield potential of the tea is probably higher.

Itona Estate

Most of the tea on this estate (total area = 60 ha) is in such poor condition that irrigation is at present out of the question. The only tea which looks at all healthy is that which has recently been pruned and given remedial applications of potassium and phosphate. Clearly there are major nutritional problems on this estate to be overcome. When these are overcome then there are sites where the tea could be irrigated, notably that tea near to the Walihanga river e.g. field 3 Itona, field 4 Walihanga (c.13 ha) and fields 2 and 3 Walihanga (c.6 ha). Both blocks are however rather too small; there is also the additional problem of maintaining adequate supervision on this outlying estate.

June 1970.

M.K.V. Carr,
(Hydrologist).

APPENDIX II

SOIL PROFILE DESCRIPTIONS

AND

ANALYTICAL RESULTS

Profile No.1: Stone Valley I (Itona series)

Location: Stone Valley Tea estate, Mufindi, Southern Highlands, Tanzania. Southern sector, at the southern extremity of Field No.6 (old field numbers) near the boundary to Field No.7.

Date: 20/6/90 **Surveyor:** R.W. Payton

Relief: Strongly undulating hilly terrain. Convex midslope (6°) of convex spur from ridge. Land falls away to major valley to the west.

Aspect: SW **Elevation:** 1730 m

Parent material: Colluvial deposits over deeply weathered granitic saprolite.

Soil classification: Humic Ferralsol (FAO-UNESCO 1988). Itona series.

Soil drainage class: Well drained

Land use: Mature tea. Good yields from this part of the field.

Profile description:

0-30 cm Ah
Dark reddish brown (5YR 3/3) moist stoneless sandy clay (field texture: loam) weak fine subangular blocky breaking to moderate fine granular structure; extremely porous; low packing density; very weak ped strength; very friable; abundant fine fibrous and fine and medium woody tea roots; clear smooth boundary.

30-54 cm E/Bws
Reddish brown (5YR 4/4) to yellowish red (5YR 4/6) moist stoneless clay (field texture:loam); (5YR 5/6 rubbed); weak medium subangular blocky breaking to fine moderate granular structure; very porous; low packing density; moderately weak ped strength; friable; slightly sticky and moderately plastic when wet; common fine and medium fibrous roots; irregular gradual boundary.

54-150 cm Bt&Bws
Red (2.5YR 5/8) moist stoneless clay (field texture: clay loam); variable structure with moderate fine and medium blocky breaking to medium granular structure interspersed with medium granular structure; variable soil consistence, moderately firm blocky ped strength with friable consistence when crushed in some parts but very firm ped strength

in others (moderately strong ped strength when dry), granular areas are loose; moderately sticky and very plastic after manipulation when wet; semi-deformable to brittle failure of blocky peds; very porous; low to medium packing density; common continuous dark reddish brown (5YR 3/6 to yellowish red (5YR 4/6) clay coats on on blocky ped faces; common fine woody roots and common medium fibrous roots between and within peds; irregular gradual boundary.

150-225 cm Bws1
Red (2.5YR 4/8 to 5/8) moist stoneless clay (field texture:loam); massive with widely spaced vertical planes of weakness breaking to moderate fine granular structure; very porous; low packing density; moderately weak soil strength; friable; semi-deformable; moderately sticky and very plastic after manipulation when wet; few fine woody roots and few medium fibrous roots; smooth diffuse boundary.

225-300 cm Bws2
Yellowish red (5YR 4/8) moist stoneless fine sandy clay (field texture: snady clay loam); massive breaking to fine granular structure; very porous; low packing density; moderately weak soil strength; very friable; slightly sticky and moderately plastic after manipulation when wet; few fine woody roots and few medium fibrous roots; lower boundary unobserved.

Comments: Irregular development of the blocky argic Bt horizon with some parts having strongly developed blocky to prismatic peds with prominent continuous clay coats on peds and very firm consistence when moist, other parts having moderately or weakly developed fine and medium blocky structure with moderately firm ped strength breaking easily to friable fine granular material, and yet other parts having a very porous very friable fine granular structure. The horizon thus has structural characteristics of both argic Bt horizons and ferralic Bws horizons. The blocky Bt horizons tongues into the underlying more uniform ferralic Bws1 horizon giving an irregular boundary.

Soil samples collected:

Bulk samples: 1. 0-30cm; 2. 30-54cm; 3. 54-150cm; 4. 150-225cm; 5. 225-300cm.

Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C: 50-55cm; 3A,B and C. 100-105cm; 4A,B and C. 200-205cm.

Horizon	Ah	E/Bws	Bt&Bws	Bws1	Bws2
Depth (cm)	30	54	150	225	300
Chemical analyses					
Soil pH (H2O)	4.7	4.6	5.6	6.0	6.4
(1N KCl)	4.1	4.1	5.3	5.9	6.2
Organic carbon % w/w	2.59	1.28			
Exch. cations mm+ 100g-1 with 0.1M BaCl2					
Ca	1.17	1.14	2.26	2.09	1.47
Mg	0.25	0.23	0.31	0.31	0.28
K	0.21	0.19	0.15	0.15	0.14
Al (1M KCl)	2.15	1.51	0.16	0.10	0.10
Exch. acidity (1M KCl) mm+ 100g-1	2.67	1.87	0.43	0.20	0.15
CEC mm+ 100g-1					
ECEC (0.1M BaCl2)	4.30	3.43	3.15	2.75	2.04
CEC (NH4OAc)	6.74	3.60			
Avail. P ppm (Bray 1)	3.07	1.0	0.84	1.60	2.04
Dithionite extr. Fe %	1.41	1.50	1.69	1.80	1.89
Physical analyses					
Sand 600um-2mm%	9	7	3	8	8
200-600um%	28	24	19	17	17
100-200um%	8	9	9	9	9
60-100um%	4	4	4	5	6
Silt 2-60um%	11	3	19	20	21
Clay <2um%	40	43	46	41	41
Bulk density g cm-3	0.95	1.24	1.41	1.19	1.19
Total porosity vol%	63	52	46	54	54
Air capacity vol%	38	21	12	22	22
Available water					
0.1-15 bar vol%	12.19	15.67	10.09	10.90	10.90
mm cm-1	1.22	1.57	1.00	1.09	1.09
Easily available water					
0.1-2 bar vol%	10.70	9.83	7.59	9.77	9.77
mm cm-1	1.07	0.98	0.76	0.98	0.98
Moisture retention					
0.05 bar vol%	26.83	33.63	35.31	35.76	35.76
0.1 bar vol%	24.32	31.25	33.56	32.64	32.64
0.4 bar vol%	20.47	27.03	30.68	28.63	28.63
2.0 bar vol%	13.16	21.42	25.97	22.87	22.87
15 bar vol%	12.13	15.58	23.56	21.7021.70	

Profile No.2 Stone Valley II (Stone Valley series)

Location: Stone Valley Tea estate, Mufindi, Southern Highlands, Tanzania. Eastern sector, Field No.1 (old numbering system).

Date: 23/6/90 **Surveyor:** R.W. Payton

Relief: Strongly undulating hilly terrain with long convex ridge tops (0-5°) falling away to long moderate 6-11° slopes on ridge sides before falling steeply into narrow valleys. Site occupies upper slope on convex ridge top. Land slopes at 5° along line of the ridge which is aligned N-S.

Aspect: North **Elevation:** 1800 m

Parent material: Deeply weathered granite saprolite.

Soil classification: Humic Acrisol (FAO-UNESCO 1988). Stone Valley series.

Soil drainage class: Well drained.

Land use: Mature tea. (N.b. Leaves of tea plants yellow early in the dry season along these ridge top soils probably due to drought stress).

Soil profile description:

0-30 cm Ah

Very dark greyish brown (10YR 3/2) moist stoneless sandy clay loam; weak fine granular structure; loose to veryweak ped strength; very friable; extremely porous; very low packing density; many fine and medium woody roots and many fine fibrous roots; clear wavy boundary with tongues down abandoned coarse root channels 5cm wide penetrating to 65cm depth.

30-72 cm E

Brown (10YR 5/3 to yellowish brown (10YR 5/4) moist stoneless sandy clay loam with common faint medium-sized yellowish brown (10YR 5/5) mottles; massive to very weak coarse angular blocky structure; very porous with abundant root channels and irregular voids (vughs); low packing density; moderately weak soil strength; friable; semi-deformable failure; moderately sticky and slightly plastic after manipulation when wet; common fine fibrous roots and common fine woody roots; irregular tongued clear boundary.

72-110 cm Bt

Yellowish red (5YR 5/8) moist stoneless clay; moderate to strongly developed medium prismatic structure with continuous yellowish red (5YR 54 to 4/6) moderately thick clay coatings on ped faces and in abandoned root channels; moderately porous; medium packing density; moderately to very firm ped strength; friable when crushed; moderately to very sticky and very plastic after manipulation when wet; common fine fibrous roots; tongues of paler 10YR 5/3 material penetrate along fissures between peds often associated with degrading clay coatings of the same colour; diffuse irregular boundary.

110-140 cm Bt(g)
Reddish yellow (5YR 6/8) moist gritty clay with common distinct coarse sharply defined pale yellow (5Y 7/4) to reddish yellow (7.5YR 7/6) irregularly distributed mottles; common very small angular quartz particles and a few strongly weathered pale yellow or white rotted small granite fragments with moderately weak strength and brittle failure; moderately developed coarse prismatic to fissures massive structure; slightly porous with very occasional root channels; medium to high packing density; many thick continuous yellowish red (5YR 5/6 and reddish brown (5YR 4/4) clay coatings on fissure walls, ped faces and in channels; compact, very firm; semi-deformable failure; moderately sticky and moderately plastic after manipulation when wet; occasional fine fibrous roots along fissures but otherwise absent roots; clear irregular boundary.

140-180 cm BC
Light red (2.5YR 6/8) moist finely gritty crumbly fine micaceous clay loam; common strongly weathered white-speckled rotted granite corestones up to 5cm diameter; massive with occasional widely-spaced (10-20 cm) clay-lined fissures; moderately compact and slightly porous; medium to high packing density; very few clay-lined abandoned fine root traces; slightly sticky and slightly plastic after manipulation when wet; diffuse irregular boundary.

180-300 cm Cr
Light red (2.5YR 6/6) moist deeply weathered granite with abundant fine white (5YR 8/2) angular speckles consisting of kaolinized feldspars;finely gritty micaceous loam (silty feel when crushed); massive; very slightly porous; high packing density; compact and very firm in place but only moderately firm strenght in hand specimen; roots absent except for very occasional fine root along clay lined fissure (one such root observed to penetrate to 250 cm depth); lower boundary unobserved.

Soil samples collected:

Bulk samples: 17. 0-30cm; 18. 30-72cm; 19. 72-110cm; 20. 110-140cm; 21. 140-180cm; 22. 180-300cm.

Moisture tins (in triplicate): 1A,B and C: 10-15cm; 2A,B and C. 50-55cm; 3A,B and C. 100-105cm; 4A,B and C. 200-205cm.

Thin section samples: 1. E horizon 50-60cm; 2. Bt1 horizon; 3. Bt2 horizon; 4. BC horizon; 5. Cr horizon.

Horizon Depth (cm)	Ah 30	Eb 72	Bt 110	Bt(g) 140	BC 180	Cr 300
Chemical analyses						
Soil pH (H2O)	5.63	5.89	6.09	6.00	6.19	
(KCl)	4.72	5.31	5.49	5.28	5.73	
Organic carbon % w/w	2.86	0.59				
Exch. cations						
mm+ 100g-1 (0.1M BaCl2)						
Ca	5.50	3.56	3.16	2.53	2.35	
Mg	0.58	0.48	0.46	0.39	0.28	
K	0.17	0.13	0.13	0.15	0.14	
Al (1M KCl)	0.11	0.10	0.05	0.10	0.10	
Exch. acidity (1M KCl)						
mm+ 100g-1	0.22	0.30	0.10	0.20	0.20	
CEC mm+ 100g-1						
ECEC (0.1M BaCl2)	6.47	4.47	3.85	3.27	3.01	
CEC (NH4OAc)	13.06		8.50	4.84		
Avail. P ppm (Bray 1)	5.08	1.52	1.34	0.64	0.82	
Dithionite extr. Fe %	0.71	0.84	1.14	1.09	0.85	
Physical analyses						
Sand 600-200um%	19	21	16	16	12	20
200-600um%	23	18	11	8	12	11
100-200um%	8	8	6	2	10	2
60-100um%	6	6	3	4	3	4
Silt 2-60um%	12	11	8	21	33	41
Clay <2um%	32	36	56	49	30	22
Bulk density g cm-3	1.05	1.34	1.34			1.44
Total porosity vol%	59	49	48			46
Air capacity vol%	30	22	19			12.37
Available water						
0.1-15 bar vol%	17.23	9.16	8.58			13.90
mm cm-1	1.72	0.92	0.86			1.39
Easily available water						
0.1-2 bar vol%	12.30	7.19	6.01			6.78
mm cm-1	1.23	0.72	0.60			0.78
Moisture retention						
0.05 bar vol%	31.78	28.11	30.12			36.36
0.1 bar vol%	29.03	26.64	28.99			35.18
0.4 bar vol%	25.15	24.11	27.06			32.97
2.0 bar vol%	16.73	19.45	22.98			28.40
15 bar vol%	11.80	17.48	20.41			21.28

Profile No. 3 Stone Valley III (Stone Valley series, gleyic variant)

Location: Stone Valley Tea estate, Mufindi, Southern highlands, Tanzania. Sloping ridge top in the north eastern part of the estate in the centre of Field No. 7 (old numbering system).

Relief: Convex ridge top in strongly undulating hilly terrain on upper slope (4°). Land falls away in long convex to straight moderate slopes (6-9°) to the west and east finally dropping more steeply into narrow concave valley bottoms.

Aspect: NNE 30° **Elevation:** 1790 m.

Parent material: Deeply weathered granite saprolite.

Soil classification: Humic Acrisol (shallow stagnic phase). Stone Valley series, shallow stagnic phase.

Soil drainage class: Moderately well to imperfectly drained.

Land use: Mature pruned tea. (N.b leaves yellow early in the dry season, probably due to drought stress).

Soil profile description:

0-28 cm Ah
Dark reddish brown (5YR 2/2) moist stoneless sandy clay loam; moderately developed fine granular structure; extremely porous; very low packing density; loose to very friable with very weak ped strength; slightly sticky and slightly plastic after manipulation when wet; abundant fine fibrous roots and common fine to coarse woody roots; clear wavy boundary with tubular extensions to 40 cm depth along abandoned coarse root channels.

28-40 cm E
Brown (10YR 5/3) moist stoneless sandy clay (field texture: sandy clay loam); massive to weakly developed medium subangular blocky structure; very porous; low packing density; loose or very weak soil strength with brittle failure; very friable when crushed; slightly sticky and non-plastic after manipulation when wet;common very fine fibrous roots; few medium and coarse woody roots; clear smooth boundary.

40-80 cm E/Bt(g)
Light yellowish brown (2.5Y 6/4) moist stoneless sandy clay with common medium and coarse clear yellowish brown (10YR 5/6) mottles; weakly developed medium and

coarse subangular blocky structure; very to moderately porous; low to medium packing density; moderately firm soil strength but friable when crushed; semi-deformable failure; moderately sticky and moderately plastic after manipulation when wet; common fine fibrous roots and few medium woody roots; many irregularly shaped discrete voids and abandoned root channels have stripped surfaces with loose exposed quartz grains; abrupt smooth boundary.

80-88 cm
Stoneline consisting of medium and small angular quartz fragments.

88-130 cm 2Bt(g)
Brownish yellow (10YR 6/6) moist stoneless clay loam with many coarse clear very pale brown (10YR 6/6) and strong brown (7.5YR 5/8) mottles;moderately developed coarse prismatic structure with continuous moderately thick clay coatings on ped faces; compact, slowly permeable, slightly porous; high packing density; moderately strong ped strength; semi-deformable failure; moderately sticky and moderately plastic when wet; many waxy clay coatings affected by mottling plugging former root channels and irregularly shaped voids; occasional fine fibrous roots follow clay-lined vertical fissures but fail to penetrate ped interiors; diffuse irregular boundary.

130-190 cm BC/Cr
Mixed horizon with areas of undisturbed weathered granite saprolite (Cr horizon, see description below) and light red (2.5YR 6/6) moist finely gritty, micaceous loam (silty feel when crushed); massive with occasional clay-lined vertical fissures; moderately porous but few interconnected voids (mainly voids left after mineral grain weathering); medium packing density;compact and very firm in place but moderately firm, brittle and crumbly in hand specimen; slightly sticky and non-plastic after manipulation when wet; very occasional fine fibrous roots in fissures or occasional clay-lined root channels but largely unexploited by roots; common white soft kaolinized felspar grains; broken diffuse boundary.

190-250 cm Cr
Light red (2.5YR 6/6) deeply weathered granite saprolite with abundant fine angular soft white (5YR 8/2) kaolinized feldspar grains; massive, compact and very firm in place but moderately firm and brittle in hand specimen, crushing to a finely gritty micaceous loam (distinctly silty feel when crushed); non-sticky and non-plastic after manipulation when wet; moderately porous but mainly unconnected irregularly shaped to angular voids left after mineral weathering; occasional clay-lined fine root channels and fissures penetrate to about 220 cm depth; living roots absent; becoming more gritty

and paler in colour (2.5YR 7/6) with depth with white corestones of rotted granite surrounded by reddish yellow (7.5YR 6/8) halos of iron oxidation.

Comments: This profile represents a Humic Acrisol with undisturbed deeply weathered granite at relatively shallow depth, probably due to erosion of upper soil layers. The compact, mottled argic Bt(g) horizon is slowly permeable and impedes water percolation causing periods of seasonal waterlogging. The smaller volume of the soil exploitable by roots will reduce the amount of available water and therefore increase droughtiness during the dry season.

Soil samples collected:

Bulk samples: 33. 0-28cm; 34. 28-40cm; 35. 40-80cm; 36. 88-130cm; 37. 130-190cm; 38. 190-250cm.

Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 55-60 cm; 3A,B and C. 110-120cm.

Thin section samples: 1. 50-60cm; 2. 110-120cm.

Analytical data

Horizon	Ah	Eb	E/Bt(g)	2Bt(g)	BC/Cr	Cr
Depth (cm)	28	40	80	130	190	250
Chemical analyses						
Soil pH (H2O)	4.20	4.46	4.59	5.36	5.47	
(KCl)	3.87	4.07	4.03	5.07	5.04	
Organic carbon % w/w	3.22	0.76				
Exch. cations						
mm+ 100g-1 (0.1M BaCl2)						
Ca	0.88	1.34	1.62	2.15	1.79	
Mg	0.22	0.20	0.24	0.34	0.29	
K	0.20	0.17	0.18	0.14	0.12	
Al (1M KCl)	2.78	1.21	1.03	0.10	0.10	
Exch. acidity (1M KCl)						
mm+ 100g-1	3.40	1.51	1.18	0.20	0.15	
CEC mm+ 100g-1						
ECEC (0.1M BaCl2)	4.70	3.22	3.22	2.83	2.35	
CEC (NH4OAc)	10.21			3.62		
Avail. P ppm (Bray 1)	3.88	1.70	1.18	0.20	0.15	
Dithionite extr. Fe %	0.68	0.78	0.82	0.99	0.72	
Physical analyses						
Sand 600-200um%	6	12	15	11	8	13
200-600um%	23	23	12	10	11	15
100-200um%	13	13	13	5	8	8
60-100um%	6	7	5	5	4	4
Silt 2-60um%	9	8	11	29	42	41
Clay <2um%	33	37	44	40	27	16
Bulk density g cm-3	0.98		1.37	1.45		
Total porosity vol%	61		47	44		
Air capacity vol%	32		19	11		
Available water						
0.1-15 bar vol%	14.75		10.88	5.86		
mm cm-1	1.48		1.09	0.59		
Easily available water						
0.1-2 bar vol%	7.96		7.65	2.68		
mm cm-1	0.80		0.77	0.27		
Moisture retention						
0.05 bar vol%	31.77		29.60	34.02		
0.1 bar vol%	29.08		27.99	33.31		
0.4 bar vol%	25.20		25.22	31.83		
2.0 bar vol%	21.12		20.34	30.63		
15 bar vol%	14.33		17.11	27.45		

Profile No.4 Idetero I (Idetero series)

Location: Idetero Tea estate, Mufindi, Southern Highlands, Tanzania. North eastern sector of the estate, Field No.44.

Date: 22/6/90 **Surveyor:** R.W. Payton

Relief: Strongly undulating bifurcating convex ridges and hills with narrow intervening valleys. Predominantly long 6-10° convex to straight slopes on ridge flanks with 1-5° convex slopes on ridge tops. Site lies on convex 8° slope on ridge spur.

Aspect: North 30° **Elevation:** 1840 m

Parent material: Colluvial deposits over deeply weathered coarse-grained granite and vein quartz..

Soil classification: Humic Ferralsol (FAO-UNESCO 1988). Idetero series.

Soil drainage class: Well drained.

Land use: Mature tea with good yields.

Soil profile description:

0-30 cm Ah
Dark reddish brown (5YR 3/3) moist stoneless sandy clay (field texture: loam); (5YR 3/4 to 4/4 rubbed colour);strongly developed fine granular structure; extremely porous; very low packing density; very friable; very weak ped strength;slightly sticky and slightly plastic when wet; abundant fine fibrous roots ramify all parts of the soil; common medium and coarse woody roots; abrupt wavy to irregular boundary with tubular extensions down coarse root channels to 35 or 40cm in places.

30-70 cm E/Bws
Strong brown (7.5YR 4/6) slightly moist clay (field texture:loam); massive to weak fine and medium subangular blocky structure breaking easily to fine subangular blocky and granular structure; very porous; low packing density; very friable; moderately weak ped strength; brittle to semi-deformable failure i.e. ruptures suddenly to many smaller peds; slightly sticky and moderately plastic when wet; many fine woody roots; common coarse woody roots; gradual irregular boundary.

70-130 cm Bt/Bws
Red (2.5YR 4/8) moist stoneless clay (field texture: clay loam) with slightly duller coloured ped faces (2.5YR 4/6); moderately developed coarse blocky and medium prismatic structure breaking easily to fine subangular blocky; very porous with many fine root channels; low packing density; friable; moderately weak to moderately firm ped strength; moderately sticky and moderately plastic after manipulation when wet; common fine fibrous roots; common moderately thick patchy clay coatings on ped faces; common continuous clay coatings in abandoned root channels; diffuse irregular boundary.

130-198 cm Bt
Dark yellowish brown (10YR 4/8) stoneless clay with slightly duller ped faces (10YR 4/6); strongly developed medium and coarse prismatic structure breaking to coarse angular blocky structure; moderately porous; medium packing density; friable to firm consistence with brittle failure breaking to fine subangular to granular peds; moderately firm to very firm ped strength; moderately sticky and moderately plastic after manipulationwhen wet; common roots as above; continuous dark yellowish brown (10YR 4/6) clay coatings on ped faces and in abandoned root channels;diffuse irregular boundary.

198-240 cm BCt
Red (2.5YR 5/8) moist gritty clay loam; many very small angular quartz grains; common soft strongly weathered granite corestones forming coarser sandy or coarse loamy areas up to 20 cm in diameter and increasing in frequency with depth; few slightly hard small to medium granite stones and small fragments of angular vein quartz; massive; moderately porous with many interstitial macrovoids left after weathering of mineral grains and occasional clay-lined fissures less than 0.2 mm wide; medium packing density; moderately firm soil strength; brittle failure breaking to a friable mass of fine subangular blocky units and loose grains; moderately sticky and slightly plastic when wet; few fine fibrous roots; few fine woody roots; common broken or locally continuous clay coatings in former root channels and angular voids left after mineral grain weathering; gradual irregular boundary.

240-300 cm BC/Cr
Strong brown (7.5YR 5/8) moist gritty loam; many medium and large soft sandy corestones of strongly weathered coarse-grained granite; a few slightly hard weathered granite fragments; massive; moderately porous; medium packing density; moderately weak to moderately firm soil strength (does not cohere easily); brittle failure breaking

to a mass of lose grains and weak aggregates of grains; few fine roots with surface of this horizons but absent below 260 cm depth; diffuse irregular boundary.

300 cm + R
Strongly weathered moderately hard coarse-grained granite.

Comments: The BC/Cr horizon of this soil is less compact and coarser in texture than the micaceous feeling light red granite saprolite encountered elsewhere on the estates. It probably represents a coarser grained variant of the granite or the site may occur over coarser vein intrusions of different compostion.

Soil samples collected:

Bulk samples: 6. 0-30cm; 7. 30-70cm; 8. 70-130cm; 9. 130-198cm; 10. 198-240cm; 11. 240-300cm.

Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 50-55cm; 3A,B and C. 150-155cm.

Analytical data

Horizon	Ah	E/Bws	Bt/Bws	Bt	BCt	BC/Cr
Depth (cm)	30	70	130	198	240	300
Chemical analyses						
Soil pH (H2O)	4.65	5.11	4.65	4.81	4.85	
(KCl)	4.10	4.28	4.05	4.16	4.21	
Organic carbon % w/w	3.07	1.50				
Exch. cations						
mm+ 100g-1 (0.1M BaCl2)						
Ca	1.08	2.34	0.98	1.38	0.80	
Mg	0.26	0.25	0.15	0.24	0.22	
K	0.22	0.16	0.14	0.18	0.12	
Al (1M KCl)	2.72	1.47	1.08	0.87	0.76	
Exch. acidity (1M KCl)						
mm+ 100g-1	3.08	1.79	1.64	1.02	0.91	
CEC mm+ 100g-1						
ECEC (0.1M BaCl2)	4.64	4.54	2.91	2.82	2.05	
CEC (NH4OAc)	11.98		6.44	3.78		
Avail. P ppm (Bray 1)	3.54	2.70	2.62	1.79	1.40	
Dithionite extr. Fe %	1.12	1.44	1.46	1.70	1.24	
Physical analyses						
Sand 600-200um%	18	14	19	18	25	31
200-600um%	18	14	15	12	10	11
100-200um%	6	6	6	4	3	3
60-100um%	3	3	2	2	1	2
Silt 2-60um%	13	15	9	12	26	35
Clay <2um%	40	48	49	51	35	18
Bulk density g cm-3	0.97	1.07	1.26			
Total porosity vol%	62	59	52			
Air capacity vol%	35	23	21			
Available water						
0.1-15 bar vol%	12.44	13.50	9.96			
mm cm-1	1.24	1.35	1.00			
Easily available water						
0.1-2 bar vol%	8.99	9.86	6.55			
mm cm-1	0.90	0.99	0.66			
Moisture retention						
0.05 bar vol%	28.50	38.02	33.05			
0.1 bar vol%	26.40	35.70	31.37			
0.4 bar vol%	22.96	31.57	29.07			
2.0 bar vol%	17.41	25.84	20.67			
15 bar vol%	13.96	22.23	21.41			

Profile No. 5 Idetero II (Stone Valley series)

Location: Idetero Tea estate, Mufindi, Southern highlands, Tanzania. Approximately 100 m from the south eastern corner of Field No.H3.

Date: 22/6/90 **Surveyor:** R.W. Payton

Relief: Elevated convex ridge top sloping 3° NNW in strongly undulating hilly terrain. Ridge extends NW to SE. Land falls away to the east and west with moderate 8° slopes towards narrow steeper-sided valleys.

Aspect: NNW 320° **Elevation:** 1810 m

Parent material: Deeply weathered granite saprolite.

Soil classification: Humic Acrisol (FAO-UNESCO 1988). Stone Valley series.

Soil drainage class: Well drained.

Land use: Mature tea on land originally cleared from forest.

Soil profile description:

0-35 cm Ah
Dark reddish brown (5YR 3/3) slightly moist stoneless medium sandy clay loam,moderately devloped fine granular structure; loose to very friable; extremely porous; very low packing density; slightly sticky and slightly plastic when wet; abundant fine fine fibrous roots ramify all parts of the soil mass; common fine to coarse woody roots; clear irregular boundary.

35-64 cm EB
Strong brown (7.5YR 4/6, 7.5YR 5/6 to 5/8 rubbed) slightly moist stoneless snady clay (field texture: loam); massive to very weak medium subangular blocky structure; very porous; low packing density; friable; moderately weak soil strength; brittle failure; slightly sticky and slightly plastic when wet; common fine fibrous roots; few fine and medium woody roots; diffuse irregular boundary.

64-145 cm Bt
Red (2.5YR 4/8 to 5/8) moist stoneless clay; strongly developed medium prismatic structure breaking to coarse angular blocky with continuous clay coatings (2.5YR 4/6 to 5/6) on ped surfaces and in root channels; moderately porous; moderate packing

density; very firm ped strength but still friable when crushed breaking to many fine angular blocky aggregates; very sticky and very plastic after manipulation when wet; common fine fibrous roots; few fine to coarse woody roots; clear wavy boundary.

145-180 cm BC
Light red (2.5YR 6/6) moist stoneless micaceous loam (distinctly silty feel); massive with occasional closed vertical fissures plugged with continuous (2.5YR 4/6 to 5/6) clay coatings; moderately to slightly porous; medium packing density; very firm soil strength; slightly sticky and moderately plastic when wet; brittle failure breaking to fragments; occasional patchy clay coatings in abandoned root channels; occasional to few fine woody or fibrous roots mainly along fissures; diffuse wavy boundary.

180-300 cm Cr
Light red (2.5YR 6/6) slightly moist compact deeply weathered granite saprolite with abundant soft white (5Y 8/3) angular speckles consisting of kaolinized feldspar grains; common higher chroma staining (2.5YR 6/8); massive, slightly porous and very firm in place with brittle failure in hand specimen breaking to a loose mass consisting of finely gritty micaceous loam to silt loam; very strong soil strength in parts where less weathered with many hard or slightly hard weathering granite corestones below 250cm depth; very few fine woody roots penetrate to this depth but are absent below; a few abandoned clay-lined fine root channels to 250 cm depth;lower boundary unobserved.

Comments: Granite saprolite can be cut with a spade with some difficulty between 180 and 250 cm depth but becomes harder below. It represents in situ constant volume weathering and disintegration of this crystalline igneous rock. The material can be augered with some difficulty and appears as soil material once disturbed by the auger bit but has a distinctive texture and consistence. Horizons transitional to hard rock such as this are very firm and compact in place with little interconnected void space and generally prevent the penetration of roots.

Soil samples collected:

Bulk samples: 12. 0-30cm; 13. 35-64cm; 14. 64-145cm; 15. 145-180cm; 16. 180-250cm.

Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 90-95cm; 3A,B and C. 170-175cm.

Rock samples collected:

2. 250-300cm from granite saprolite transitional to disintegrating granite zone.

Analytical data

Horizon	Ah	EB	Bt	BC	Cr
Depth (cm)	35	64	145	180	300+
Chemical analyses					
Soil pH (H2O)	4.79	4.72	4.78	5.05	
(KCl)	3.92	4.01	4.15	4.28	
Organic carbon % w/w	2.68	1.11			
Exch. cations					
mm+ 100g-1 (0.1M BaCl2)					
Ca	0.77	0.95	1.38	1.25	
Mg	0.24	0.21	0.27	0.38	
K	0.70	0.01	0.01	0.01	
Al (1M KCl)	2.31	1.93	1.01	0.76	
Exch. acidity (1M KCl)					
mm+ 100g-1	2.87	2.29	1.06	0.91	
CEC mm+ 100g-1					
ECEC (0.1M BaCl2)	4.58	3.46	2.72	2.55	
CEC (NH4OAc)	15.20		3.53		
Avail. P ppm (Bray 1)	2.94	2.33	1.71	0.96	
Dithionite extr. Fe %	0.86	1.11	0.74	1.07	
Physical analyses					
Sand 600-200um%	20	15	14	17	19
200-600um%	29	23	13	13	11
100-200um%	8	8	5	3	3
60-100um%	3	3	2	2	2
Silt 2-60um%	10	12	7	38	47
Clay <2um%	30	39	59	27	18
Bulk density g cm-3	1.05		1.32	1.45	
Total porosity vol%	59		49	45	
Air capacity vol%	34		14	9	
Available water					
0.1-15 bar vol%	11.70		8.60	9.44	
mm cm-1	1.17		0.86	0.94	
Easily available water					
0.1-2 bar vol%	5.01		4.44		
mm cm-1	4.44		0.44		
Moisture retention					
0.05 bar vol%	25.75		35.88	36.99	
0.1 bar vol%	24.60		34.85	36.99	
0.4 bar vol%	21.63		32.94	34.00	
2.0 bar vol%	19.59		27.38		
15 bar vol%	12.90		26.25	26.69	

Profile No. 6 Itona I (Itona series)

Location: Itona Tea estate, Mufinidi, Southern Highlands, Tanzania. Recently cleared (1987) area in the north eastern sector of the estate under newly established tea, formerly under evergreen montane forest.

Date: 23/6/90 **Surveyor:** R.W. Payton

Relief: Upper slope (7°) of convex ridge in strongly undulating hilly terrain. Slope falls to narrow valley 500 m to the south.

Aspect: SES 160° **Elevation:** 1760 m

Parent material: Colluvial deposits over deeply weathered granite saprolite.

Soil classification: Humic Ferralsol (FAO-UNESCO 1988). Itona series.

Soil drainage class: Well drained

Land use: Young tea recently planted on former montane evergreen forest site prior to 1987.

Soil profile description:

0-40 cm Ah
Dark brown (7.5YR 3/3) moist stoneless sandy clay (field texture: loam); weakly to moderately developed fine granular structure; extremely porous; very low packing density; very friable; many fine fibrous roots and common fine woody roots; common coarse dead woody tree roots; clear irregular boundary.

40-72 cm EB
Yellowish brown (10YR 5/6) moist sandy clay loam; massive; very porous with many abandoned root channels and intergrain voids between clean washed quartz grains;low packing density; moderately weak soil strength breaking to a friable mass; slightly sticky and slightly plastic when wet; common fine and medium woody roots; diffuse irregular boundary.

72-110 cm Bt&Bws
Red (2.5YR 4/8, 2.5YR 5/8 rubbed colour) moist stoneless clay (field texture: clay loam); areas of weakly developed medium prismatic structure interspersed with massive structure breaking easily to fine and medium granular structure with a friable

consistence; prisms are moderately firm and have a medium to low packing density and a semi-deformable failure; massive to granular structured areas are very porous with a low packing density; moderately sticky and moderately plastic after manipulation when wet; common fine and medium woody roots; diffuse irregular boundary.

110-200 cm Bt
Red (2.5YR 5/8) moist stoneless clay (field texture clay loam); moderately developed medium prismatic structure breaking to a friable mass of fine subangular blocky aggregates; moderately to very porous; medium packing density; very firm or moderately firm ped strength; moderately sticky and very plastic after manipulation when wet (n.b. only slightly plastic according to FAO methods); common fine woody roots; diffuse wavy boundary.

200-300 cm Bws
Red (2.5YR 5/8) moist stoneless clay (field texture clay loam); granular to massive structure; very porous; low packing density; moderately weak soil strength; semi-deformable failure; very friable; slightly sticky and moderately plastic after manipulation when wet; few fine woody roots; lower boundary unobserved.

Comments: A mixed horizon with the physical properties of both a ferralic Bws horizon and an argic Bt horizon occurs above an argic Bt horizon which in turn overlies a ferralic Bws of considerable depth. Under the new FAO-UNESCO classification guidelines (1988) such a soil is classed as a Ferralsol as it meets all the chemical criteria.

Soil samples collected:

Bulk samples; 23. 0-40cm; 24. 40-72cm; 25. 72-110cm; 26. 110-200cm; 27. 200-300cm.

Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 55-60cm; 3A,B and C. 120-125cm; 4A,B and C. 200-205cm.

Analytical data

Horizon	Ah	EB	Bt&Bws	Bt	Bws
Depth (cm)	40	72	110	200	300+
Chemical analyses					
Soil pH (H2O)	4.93	4.92	4.49	4.40	4.61
(KCl)	4.12	4.17	4.06	4.26	4.35
Organic carbon % w/w	3.11	0.54			
Exch. cations mm+ 100g-1 (0.1M BaCl2)					
Ca	1.48	0.95	0.80	0.82	0.99
Mg	0.60	0.40	0.48	0.47	0.67
K	0.14	0.12	0.02	0.07	0.02
Al (1M KCl)	1.88	1.46	1.53	0.62	0.54
Exch. acidity (1M KCl) mm+ 100g-1	2.34	1.61	1.69	0.77	0.69
CEC mm+ 100g-1					
ECEC (0.1M BaCl2)	4.56	3.08	2.99	2.13	2.37
CEC (NH4OAc)	11.91		4.82	4.89	
Avail. P ppm (Bray 1)	2.47	1.45	1.65	1.87	1.58
Dithionite extr. Fe %	0.96	0.91	1.24	1.16	1.19
Physical analyses					
Sand 600-200um%	14	12	8	7	9
200-600um%	25	27	15	15	12
100-200um%	10	11	7	7	5
60-100um%	2	3	3	3	2
Silt 2-60um%	10	12	6	18	25
Clay <2um%	39	35	61	50	47
Bulk density g cm-3	1.03	1.30		1.28	1.26
Total porosity vol%	60	50		51	51
Air capacity vol%	27	18		18	19
Available water					
0.1-15 bar vol%	12.57	9.84		8.75	8.97
mm cm-1	1.26	0.98		0.88	0.90
Easily available water					
0.1-2 bar vol%	11.10	6.57		6.04	
mm cm-1	1.11	0.66		0.60	
Moisture retention					
0.05 bar vol%	35.07	33.47		34.42	34.25
0.1 bar vol%	32.79	32.00		33.10	32.54
0.4 bar vol%	28.61	29.30		30.89	30.38
2.0 bar vol%	21.69	25,43		27.06	
15 bar vol%	20.22	22.16		24.35	23.57

Profile No. 7 Itona II (Itona series)

Location: Itona Tea estate, Mufindi, Southern Highlands, Tanzania. South eastern sector of the estate, Field 8 (old numbering system.

Date: 24/6/90 **Elevation:** 1770 m

Relief: Strongly undulating hilly terrain. Straight midslope (7°) falling to slightly concave lower slope 150 m to the south before falling more steeply into anarrow valley.

Parent material: Colluvial deposits over deeply weathered granite.

Soil classification: Humic Ferralsol (FAO-UNESCO 1988). Itona series.

Soil drainage class: Well drained.

Land use: Mature tea; yields well.

Soil profile description:

0-38 cm Ah
Dark reddish brown (5YR 3/2) slightly moist stoneless clay (field texture: loam); moderately developed fine granular structure; loose; very friable when moist; extremely porous; very low packing density; slightly sticky and slightly plastic when wet; abundant fine fibrous roots ramify all parts of the soil mass; few coarse woody roots; clear to abrupt irregular boundary tonguing down coarse abandoned root channels to 45 cm depth.

38-55 cm EB
Strong brown (7.5YR 4/6) moist clay (field texture:loam); massive breaking easily to fine granular structure; very porous; low packing density; very friable; moderately weak soil strength; soft and brittle when dry; slightly sticky and moderately plastic when wet (n.b. non-plastic according to FAO assessment); common to many fine fibrous roots; common fine and medium woody roots; diffuse smooth boundary.

55-150 cm Bws1
Red (2.5YR 4/8) moist stoneless clay (field texture: loam); massive with very weak soil strength breaking easily to fine granular structure; very porous with mainly channels or inter granular ped voids; low packing density; very friable; moderately sticky and moderately plastic after manipulation when wet (n.b. slightly plastic according to FAO

method of assessment); common fine fibrous roots; common fine and medium woody roots; some areas have very weakly developed coarse prismatic structure but vertical fissure uncoated; diffuse irregular boundary.

150-220 cm Bws2
Yellowish red (5YR 4/6) stoneless clay (field texture: loam); some parts have weakly developed coarse prismatic structure with patchy clay coatings on ped faces which appear partially degraded and porous rather than waxy; moderately porous; medium packing density; very firm or moderately firm ped strength breaking with brittle failure to fine subangular blocky aggregates; other parts are massive and very porous with very weak soil strength breaking easily to fine granular structure and having a low packing density and a friable consistence; moderately sticky and moderately plastic after manipulation when wet; common fine fibrous roots (slightly less than above); diffuse irregular boundary.

220-300 cm Bws3
Red (2.5YR 5/8) moist stoneless clay (field texture: loam); massive breaking to fine granular structure; very porous; low packing density; moderately firm soil strength with brittle failure crushing to friable mass; slightly sticky and moderately plastic after manipulation when wet (n.b. slightly plastic according to FAO method of assessment); common fine fibrous roots; few fine woody roots; few indistinct vertical planes of weakness; lower boundary unobserved.

Soil samples collected:

Bulk samples: 28. 0-38cm; 29. 38-55cm; 30. 55-150cm; 31. 150-220cm; 32. 220-300cm.

Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 60-65cm; 3A,B and C. 160-165cm.

Thin section samples: 1. 10-20cm; 2. 70-80cm; 3. 170-180cm.

Analytical data

Horizon	Ah	EB	Bws1	Bws2	Bws3
Depth (cm)	38	55	150	220	300
Chemical analyses					
Soil pH (H2O)	5.19	5.37	5.23	5.62	5.73
(KCl)	4.51	4.52	4.44	5.03	5.31
Organic carbon % w/w	3.32	1.31			
Exch. cations					
mm+ 100g-1 (0.1M BaCl2)					
Ca	3.84	2.04	1.51	1.41	1.11
Mg	1.58	0.58	0.64	0.46	0.52
K	0.84	0.29	0.01	0.01	0.01
Al (1M KCl)	0.20	0.20	0.26	0.10	0.10
Exch. acidity (1M KCl)					
mm+ 100g-1	0.46	0.40	0.51	0.25	0.15
CEC mm+ 100g-1					
ECEC (0.1M BaCl2)	6.72	3.31	2.67	2.13	1.79
CEC (NH4OAc)	14.26		5.40	3.53	
Avail. P ppm (Bray 1)	1.22	1.84	1.24	0.78	0.73
Dithionite extr. Fe %	1.69	1.90	2.49	2.41	2.16
Physical analyses					
Sand 600-200um%	12	11	8	8	9
200-600um%	19	18	13	12	11
100-200um%	7	7	5	5	5
60-100um%	3	4	3	3	3
Silt 2-60um%	9	9	10	14	13
Clay <2um%	50	51	61	58	59
Bulk density g cm-3	0.93		1.08	1.02	
Total porosity vol%	63		59	61	
Air capacity vol%	34		27	27	
Available water					
0.1-15 bar vol%	9.16		13.28	13.86	
mm cm-1	0.92		1.33	1.39	
Easily available water					
0.1-2 bar vol%	8.18		10.49	11.93	
mm cm-1	0.82		1.05	1.19	
Moisture retention					
0.05 bar vol%	31.32		34.88	37.21	
0.1 bar vol%	29.78		31.83	33.21	
0.4 bar vol%	29.78		31.03	33.21	
2.0 bar vol%	21.60		21.34	21.28	
15 bar vol%	17.62		18.55	19.35	

Profile No.8: Maganga (Maganga series)

Location: Maganga tea estate, Mufindi, Southern Highlands, Tanzania. Northern slopes of the estate facing Stone Valley.

Date: 16/6/9 **Surveyor:** R.W. Payton

Relief: Steep hilly terrain with common spheroidally weathered granite outcrops. Straight upper midslope (21°) 5 m from rock outcrop.

Aspect: NNW **Elevation:** 1870 m

Parent material: Weathered granite.

Soil classification: Ferralic Cambisol (FAO-UNESCO 1988). Maganga series.

Soil drainage class: Well drained

Land use: Mature tea. Poor patchy growth with many gaps.

Profile description:

0-23 cm Ah
Dark reddish brown (5YR 3/3) moist gritty sandy loam; few large subrounded granite stones; weak fine granular structure; extremely porous; low packing density; very weak ped strength; very friable; many fine fibrous and fine woody roots; clear wavy boundary.

23-60 cm Bw1
Yellowish red (5YR 5/6) slightly moist gritty sandy loam; few to common large subrounded granite stones; single grain structure; low packing density; very porous; loose; slightly sticky and slightly plastic; common fine fibrous roots; clear wavy boundary.

60-90 cm Bw2
Red (2.5YR 5/8) slightly moist gritty sandy clay loam; common large subrounded granite stones; massive structure; low packing density; very porous; few fine fibrous roots; abrupt irregular boundary.

90 cm+ Cr
Light red (2.5YR 6/6) with abundant white speckles which represent soft weathered feldspars; compact granite saprolite forming a micaceous loam when crushed with a distinctly silty feel; massive with rock structure preserved; medium packing density;

moderately porous; very firm soil strength prevents root penetration; roots absent; lower boundary unobserved.

Comments: These soils are always associated with granite outcrops and pass laterally into Humic Acrisols of the Stone Valley series and, in places, Humic Ferralsols of the Idetero series. These three series and the associated rock outcrops are mapped as the Maganga complex. These soil are unsuited to irrigation due to the altitude and steep slopes and were not sampled for further analyses.

Profile No.13 Itona III (Walihanga series)

Location: Itona Tea estate, Mufindi, Southern Highlands, Tanzania. Bowl-like depression due south of the Walihanga Dam under newly planted young tea at the edge of Field no. Itona 1.

Date: 14.6.90 **Surveyor:** R.W. Payton

Relief: Concave depression on the margins of the Walihanga basin. 6° concave lower slope.

Aspect: N 10° **Elevation:** 1745 m

Parent material: Colluvium over lacustrine clays.

Soil classification: Mollic Gleysol (FAO-UNESCO 1988). Walihanga series

Soil drainage class: Poorly drained.

Land use: Recently planted young tea. Poor performance recorded on this site.

Soil profile description:

0-24 cm Ahg
Black (5Y 2/1) very moist organic-rich stoneless sandy clay loam; massive to very weak fine granular; very porous; low packing density; very weak soil strength; friable; few fine fibrous roots; sharp smooth boundary.

24-90 cm Bg
Olive grey (5Y 4/2) wet stoneless sandy clay loam with many light grey (5Y 6/2) mottles; massive structure; moderately porous; medium packing density; moderately sticky and moderately plastic; very few fine fibrous roots; abrupt smooth boundary.

90-120 cm 2CG1
Light grey (5Y 6/2) wet stoneless clay with very many sharp coarse white mottles and common brownish yellow (10YR 6/8) mottles; slightly porous; compact with high packing density; very sticky and very plastic; roots absent; clear smooth boundary.

120-230 cm 2CG2
Yellow (5Y 7/6) wet stoneless clay with many grey (5Y 6/1) and yellowish red (7.5YR 6/8) mottles; massive structure; slightly porous; compact with very high packing density; very sticky; very plastic; sharp smooth boundary.

230-300 cm 3CG

Pale yellow (5Y 7/4) wet gritty sandy clay loam; massive; moderately porous; medium packing density; moderately permeable; moderately sticky and plastic; lower boundary unobserved.

Analytical data

Horizon	Ahg	Bg	2CG1	2CG2
Depth (cm)	24	90	120	230
Chemical analyses				
Soil pH (H2O)	5.35	5.50	5.58	5.88
(KCl)	4.77	4.58	4.50	4.38
Organic carbon % w/w	3.78	1.93		
Exch. cations				
mm+ 100g-1 (0.1M BaCl2)				
Ca	5.83	4.15	2.15	1.84
Mg2.12	1.08	0.64	0.73	
K	1.22	0.77	0.26	0.35
Al (1M KCl)	0.10	0.09	0.15	0.21
Exch. acidity (1M KCl)				
mm+ 100g-1	0.20	0.22	0.39	0.60
CEC mm+ 100g-1				
ECEC (0.1M BaCl2)	9.37	6.22	3.44	3.52
CEC (NH4OAc)		6.11		
Avail. P ppm (Bray 1)	4.33	1.18	2.01	2.02
Dithionite extr. Fe %	0.56	1.00	0.22	0.51

Profile No.14 Itona IV (Wanji series)

Location: Itona Tea estate, Mufindi, Southern highlands, Tanzania.

Depression in Field Walihanga 5 just north of the western end of the Walihanga lake.

Date: 23.6.90 **Surveyor:** R.W. Payton

Relief: Concave depression leading downslope into the Walihanga basin in otherwise undulating lower slope site. 6° concave.

Aspect: S 6° **Elevation:** 1735 m

Parent material: Colluvium over water-laid sands.

Soil classification: Mollic Gleysol/Gleyic Arenosol (FAO-UNESCO 1988). Wanji series.

Soil Drainage: Imperfectly drained.

Land use: Mature tea. No evidence of poor growth.

Soil profile description:

0-35 cm Ah
Black (10YR 2/1) moist stoneless sandy clay loam; well developed medium granular structure; very porous; low packing density; friable; slightly sticky and slightly plastic when wet; many fine fibrous and common fine to medium woody roots; diffuse smooth boundary.

35-140 cm 2bAh/Bh
Black (5Y 2/1) moist gritty organic-rich sand to sandy loam; single grain structure; extremely porous; low packing density; loose; permeable; few fine fibrous roots; sharp smooth boundary.

140-250 cm 3Bg
White (5Y 8/1) and pale yellow (5Y 8/3) very moist mottled stoneless sandy clay loam; massive; moderately porous; medium packing density; moderately sticky and moderately plastic; roots absent; sharp smooth boundary.

250-300 cm 4CG
Olive grey (5Y 6/2) wet stoneless sand; single grain structure; extremely porous; low packing density; permeable; lower boundary unobserved.

Analytical data

Horizon	Ah	2Ah/Bh	3Bg
Depth (cm)	35	90	120
Chemical analyses			
Soil pH (H2O)	5.78	5.84	5.95
(KCl)	5.14	5.05	4.49
Organic carbon % w/w	4.87		
Exch. cations			
mm+ 100g-1 (0.1M BaCl2)			
Ca	12.06	1.59	0.89
Mg	3.16	2.04	0.68
K	1.07	0.81	0.33
Al (1M KCl)	0.21	0.22	0.43
Exch. acidity (1M KCl)			
mm+ 100g-1	0.42	0.33	0.66
CEC mm+ 100g-1			
ECEC (0.1M BaCl2)	16.71	4.77	2.56
CEC (NH4OAc)			
Avail. P ppm (Bray 1)	2.40	1.70	0.79
Dithionite extr. Fe %	0.35	0.33	0.15

Soil Analytical Methods

All soil chemical analyses were carried out on < 2mm air dried soil. Soil pH was measured with a combined glass electrode both in a stirred 1:2.5 suspension of soil and water and in a stirred 1:2.5 suspension of soil and 1M KCl after equilibriation for 30 minutes. Exchangeable calcium, magnesium, potassium and sodium were measured by the barium chloride method of Hendershot and Duquette (1986). Sodium was absent or present in only trace amounts and is therefore not reported in the tables above. Exchangeable aluminium and exchangeable acidity were measured by the potassium chloride method (Page et al 1982). Effective cation exchange capacity was estmated by addition of the barium chloride extractable basic cations and exchangeable acidty and gives a good estimate of ECEC at the natural pH of the soil. Cation exchange capacity was also measured on selected samples by the ammonoium acetate method buffered at pH 7.0 (Page et al 1982) for classification purposes. Available phosphorous was determined by the Bray 1 method given in Page et al (1982). Dithionite extractable iron was determined by the buffered citrate-dithionite-bicarbonate method of Mehra and Jackson (1960). Soil physical analyses including: bulk density, particle density, moisture retention and particle size analysis were carried out according to the methods detailed in Avery and Bascomb (1982). Available water and easily water were calculated for horizons and for profiles to effective rooting depth according to procedures given in Hall et al (1977), but using the 0.1 bar tension figure as equivalent to field capacity as recommended by El Swaify (1980) for Ferralsols.

APPENDIX III

A SOIL MAP OF THE ITONA TEA ESTATE, MUFINDI

B SOIL MAP OF THE STONE VALLEY TEA ESTATE, MUFINDI

C SOIL MAP OF THE IDETERO TEA ESTATE, MUFINDI

D SOIL MAP OF THE MAGANGA TEA ESTATE, MUFINDI

Notes

1. The base maps used in this report are photographically reproduced from local surveys. No responsibility is taken for their accuracy.

2. The contour levels shown appear to be from incorrect datums. For levels to the national datum (1:50000 maps):

Estate	Add
Itona	190 m
Stone Valley	335 m
Idetero	100 m
Maganga	10 m

3. The field names shown have been superseded. See Tables 5.1 to 5.4 and Figs. 7.1 to 7.4 for relationships to new field names. The report uses new field names except where prefixed by (old).