CHAPTER 2

IRRIGATION IN SUB-SAHARAN AFRICA

AND CASE STUDIES

2.1 Introduction

Irrigation has a very important role to play in helping agriculture to meet the needs of food production (Table 2.1). This chapter considers the current scale of irrigation schemes and their potential role in the future given rising human population and changes in climate. This review identifies that serious attention should be given to existing irrigation systems to improve efficiency in order to realise their potential. A significant part of such improvements is the management of weeds occurring in the channels and a number of case studies in Zimbabwe and Kenya are presented (Table 2.2) in order to explore channel maintenance and management practices with respect to the growth of weeds.

2.2 Irrigation in sub-Saharan Africa

2.2.1 Types and extent of systems

Sub-Saharan Africa was the focus of the research on which this book is based. Available estimates of the extent and potential of irrigation in sub-Saharan Africa (excluding South Africa) are based on those data obtained in the early 1980's by FAO (1986) (Table 2.1). These must now be regarded as out of date, but they show that about 5 million hectares of land is irrigated in the region, more or less equally split between modern and small-scale or traditional systems. More than 90% of this area is surface irrigation, served by canal systems, as in the developing world as a whole (Field 1990).

Table 2.1 shows the relative lack of irrigation development in sub-Saharan Africa. This becomes even clearer when it is realised how much of the total irrigated area lies in two countries namely Sudan and Madagascar (35% and 20% respectively). However, there is some controversy over the irrigation potential. Estimates vary from 33 million (Table 2.1) to 20 million hectares (Field 1990). The latter would appear to be more realistic in terms of land area where irrigation may be an environmentally and socially acceptable land use, as well as technically feasible and agriculturally useful.

There is considerable scope for more irrigation development. However, it is also commonly reported that much of the existing irrigated area is not performing at maximum efficiency. It has been estimated that as much as 50% of irrigation in sub-Saharan Africa is in need of rehabilitation or modernisation (Field 1990). The failure of systems to achieve their design capacity is due in no small measure to excessive growth of aquatic weeds (Moris and Thom 1990).

Table 2.1. Estimates of irrigated areas in sub-Saharan Africa in relation to irrigation potential, 1982 (FAO 1986). (These figures exclude South Africa. na = not available.)

		Area developed 1982 ('000 ha)			
Country	**Irrigation potential ('000 ha)**	**Modern**	**Small-scale or Traditional**	**Total**	**Developed as % of potential**
Angola	6,700	0	10	10	< 1
Benin	86	7	15	22	26
Botswana	100	0	12	12	12
Burkina Faso	350	9	20	29	8
Burundi	52	2	50	52	100
Cameroon	240	11	9	20	8
CAR	1,900	0	4	4	< 1
Chad	1,200	10	40	50	4
Congo	340	3	5	8	2
Equatorial Guinea	na	na	na	na	na
Ethiopia	670	82	5	87	13
Gabon	440	0	1	1	<1
Gambia	72	6	20	26	36
Ghana	120	5	5	10	8
Guinea	150	15	30	45	30
Guinea Bissau	70	na	na	na	na
Ivory Coast	130	42	10	52	40
Kenya	350	21	28	49	14
Lesotho	8	0	1	1	13
Liberia	na	3	16	19	na
Madagascar	1,200	160	800	960	80
Malawi	290	16	4	20	7
Mali	340	100	60	160	47
Mauritania	39	3	20	23	59
Mauritius	na	9	5	14	na
Mozambique	2,400	66	4	70	3
Niger	100	10	20	30	30
Nigeria	2,000	50	800	850	43
Rwanda	44	0	15	15	34
Senegal	180	30	70	100	56
Sierra Leone	100	5	50	55	55
Somalia	87	40	40	80	92
Sudan	3,300	1,700	50	1,750	53
Swaziland	7	55	5	60	>100
Tanzania	2,300	25	115	140	6
Togo	86	3	10	13	15
Uganda	410	9	3	12	3
Zaire	4,000	4	20	24	1
Zambia	3,500	10	6	16	<1
Zimbabwe	280	127	3	130	46
Total	**33,641**	**2,638**	**2,381**	**5,019**	**14.9**

With the increase in human population, water resources are becoming scarcer per head of population, and "when annual internal renewable water resources are less than 1000 m^3 per head, water availability is considered a severe constraint on socio-economic development and environmental protection" (FAO 1993). This is predicted to occur by the year 2000 in several north African and west Asian countries, and in sub-Saharan Africa in Kenya, Burundi, Rwanda, Botswana, Malawi, Sudan and Somalia.

The irrigated areas in sub-Saharan Africa are small in terms of irrigation per capita. Approximately 10% of the world's population lives in the region but only 2.5% of world irrigation takes place there. The area under irrigation represents some 6% of the total cultivated area but 20% in terms of total production value, with a productivity per hectare of about 3.5 times that of rain-fed agriculture (FAO 1987). With much of the region's irrigation potential not being realised, the potential for this enhanced productivity is also missed.

Africa is struggling to achieve food security, but agricultural production per head has fallen during the last decade. In sub-Saharan Africa as a whole per capita food production decreased by 6% between 1979-81 and 1988-90 (World Development Report 1992). The region has not been able to benefit greatly from the Green Revolution since wheat and rice are not the main staple food crops (Tanton and Stoner 1992).

In a comprehensive overview of irrigation in Africa, Moris and Thom (1990) present the arguments both for and against increasing irrigation in Africa. The case for increasing irrigation rests on a number of interrelated arguments. Where rain-fed agriculture can no longer support the population irrigation may be one of the few options for increasing food production and employment. Irrigation can also be useful for production of valuable export crops to supplement rain-fed agriculture. It can relieve the agricultural limitations imposed by long dry seasons and be used to improve livestock production. Moris and Thom (1990) also suggest conditions in which developing irrigation would not be appropriate policy.

IPTRID (1993) suggest that "compared with the total area of arable land in sub-Saharan Africa, the potential for irrigation development is modest and is often overestimated. In some countries however, it is the only way left to grow enough food for their populations, the size of which has surpassed (or will surpass) the limits of the carrying capacity for traditional rain-fed agriculture".

Moris and Thom's overview also identifies priority areas in irrigation research warranting further attention. They identified key gaps, the lack of which contributed to the low efficiency of African irrigation. One of their findings was that the control of both terrestrial and aquatic weeds is a major problem in African irrigation. Aquatic weeds are seen as a threat to the whole water management system and pose a serious threat to irrigation production. Irrigation canal systems in the tropics provide ideal conditions for aquatic weed growth. Moris and Thom (1990) conclude that more attention should be directed to the problem of weed control, particularly in smallholder production. Another weak link they identify is that of maintenance. They suggest that there is unanimous agreement that poor maintenance constitutes the single most important unresolved problem in African irrigation. There are undoubtedly many factors which contribute to the poor maintenance record. Amongst them will be the lack of effective aquatic weed control in canals and drains.

2.2.2 Future prospects and effects of climatic change

There will be a continuing need to increase food production to keep pace with population growth and urbanisation. Irrigated agriculture has the potential to make an important contribution to this, provided improvements can be made in irrigation performance. The effects of expected climate change on the region are as yet uncertain but a precautionary approach is advisable and the best use of scarce water resources will undoubtedly be essential.

Probably the most important consequence of climate change for agriculture in the tropics is the reduced soil-water availability arising from higher potential evapotranspiration, due to the higher air and land temperatures. Even in the tropics where temperature increases are expected to be smaller than elsewhere and where precipitation might increase, the increased rate of loss of moisture from plants and soil would be considerable (Parry and Swaminathan 1992). The effect on cropping of reduced soil water would, however, vary considerably according to whether it occurs during the growing or non-growing season (Suliman 1990).

Predicted yield reductions in the mid-latitude grain exporting regions would also be likely to result in increased food prices and could seriously influence the ability of food-deficit countries to pay for food imports. Increased prices could improve the economic viability of irrigation projects which has been reduced in recent years by declining food prices.

Suliman (1990) urges that one of the questions that must be tackled scientifically and resolved politically is how agriculture is to adjust in order to not only maintain output but increase it to accommodate population growth. He suggests three types of land use change which may be considered: changes in farmed area, crop type, and crop location. He suggests that irrigation would have an enhanced role to play in the adjustment of future agriculture.

Some points made by Mintzer (1992) can usefully summarise the likely impacts of climate change on sub-Saharan Africa. Like hunger, the stresses that arise from rapid climate changes will fall most heavily on the poorest, the most vulnerable, and those least able to adopt new technology. Global climate change will increase the stress on agricultural systems, potentially decreasing yields at the very time when demand for food is growing dramatically.

The most important impacts may be due to the least predictable aspects of the climate system - changes in the frequency, distribution and severity of extreme weather events. On a global scale substantial increases in the need for irrigation are likely in order to overcome the moisture losses resulting from global warming. Tighter water-management practices will be necessary to yield higher irrigation efficiency (Parry and Swaminathan 1992). The costs of irrigation may rise substantially as a result of water supply limitations.

The pressure to enhance the productivity of irrigation systems has implications for improvements in system management and irrigation related technology (IPTRID 1993). The objectives of this book are to provide information enabling irrigation operators to manage aquatic weeds in irrigation systems more effectively, and hence play a part in the drive for improved efficiency and production.

2.3 Case study schemes

Fieldwork for this book was undertaken in Zimbabwe and Kenya on several different schemes which covered various sizes and management types. These are listed in Table 2.2. Most data were collected from Chisumbanje Estate in Zimbabawe, and the Mwea Irrigation Settlement Scheme in Kenya. The other schemes, the Triangle Sugar Estates, Zimbabwe, and the Gem Rae Irrigation Project, Kenya, are described in detail below to illustrate the context for weed management. A different view was obtained by an additional study of a drainage system at Welland and Deepings Internal

Drainage Board in UK, and this is also described below. Further fieldwork was undertaken in northern Nigeria.

Table 2.2. Summary of main characteristics of irrigation schemes studied

Country	Scheme	Size (ha)	Management	Soil type	Primary crop(s)	Rainfall (mm yr^{-1})
Zimbabawe	Chisumbanje Estate	2,400	Agricultural and Rural Development Authority (ARDA)	Vertisols	Cotton and wheat	630
Zimbabawe	Triangle Estate	13,863	Tongaat-Hulett (private company)	Sandy loam, loamy sand and sandy clay loam	Sugar cane	550
Kenya	Mwea Irrigation Settlement Scheme	12,140	National Irrigation Board (NIB)	Vertisols	Rice	
Kenya	Gem Rae	118	Scheme Committee	Medium to heavy, dark grey or black clays	Rice	1,250

2.3.1 Chisumbanje Estate, Zimbabwe

2.3.1.1 Physical environment

Chisumbanje Estate (Figure 2.1) is one of 26 agricultural estates operated by the parastatal organisation the Agricultural and Rural Development Authority (ARDA). The estate is located in the Ndowoyo Communal Area, in the south-east lowveld of Zimbabwe on the east bank of the Sabi (Save) River approximately 100 km downstream of Birchenough Bridge and about 80 km north of Chiredzi. The primary crops are cotton and wheat.

Figure 2.1. Layout of Chisumbanje Estate irrigation scheme

Zimbabwe is divided into five Natural Regions (I to V) on the basis of the adequacy and reliability of rainfall. The Chisumbanje area is classified into Natural Region V which has too low and erratic a rainfall for reliable crop production. The climate is semi-arid with an average annual rainfall of 630 mm, over 80% of which is received between November and March and is generally associated with high intensity thunderstorms which can cause damage to crops.

The average annual temperature is 22°C, with monthly averages ranging from 15°C in July to 25.5°C in January. Mean maximum temperatures of over 32°C occur during the summer months (October to March) and absolute maximum temperatures of up to 43°C have been recorded. The coldest months are June and July when mean minimum temperatures are below 9°C. Frosts, however, are rare due to the low elevation (approximately 400 m asl). High temperatures and low humidities contribute to an annual precipitation deficit of the order of 1400 mm and irrigation is necessary throughout the year for successful crop production.

The soils are dominated by vertisols derived from basalt and described as natural flood irrigation soils with an automatic water acceptance rate. These are fertile, black clay soils with characteristic soil mulching and high water retention properties. They experience marked expansion and contraction with changes in moisture content. When dry, the soils shrink and crack and the soil surface becomes very friable. The cracks, which extend into the sub-soils, gradually fill with loose surface granules. This creates great pressure in the sub-soils, resulting in heaving and churning when water is re-admitted to the soil profile and the soils swell. Such movement negates the requirement for ploughing or deep cultivation and is the basis for the expression 'self-tilling soils.'

2.3.1.2 Irrigation and drainage systems

Development of Chisumbanje Estate commenced in 1966 when 625 ha of flood irrigated land were established. The irrigated area was expanded by a further 500 ha in 1968, and in 1973 an additional 1,200 ha was commanded. Presently, an irrigated area of approximately 2,400 ha is operated by ARDA, including some 400 ha allocated to 117 smallholder settlers with holdings of 3-6 ha (Figure 2.1).

Irrigation is provided by pumping water from the normal flow of the Sabi River. The existing pumping station was constructed in 1978 and has a capacity of 1.84 m^3 /s. During the dry, winter months, river flow is occasionally supplemented by releases from the Ruti and Rusape Dams, respectively located 175 km and 275 km upstream. A new pumping station, linked to a set of infiltration boreholes in the river bed is currently under construction. This will allow the procurement of large volumes of water from the river-bed when surface flows fail during the dry season.

Water is conveyed by pipeline from the pumping station to the estate. The pipeline discharges into a concrete-lined supply canal which, in turn, gives rise to a concrete-lined secondary canal on the western side of the estate, and an unlined branch canal on the eastern side. These canals deliver water to three intermediate or storage reservoirs (known locally as dams) with capacities of 31,000 m^3, 62,000 m^3 and 160,000 m^3. Water is distributed to the fields by concrete-lined canals of 0.07 m^3/s and earthen canals ranging in capacity from 0.14-0.50 m^3/s. Irrigation is achieved via furrows, using siphons to draw water from the canals.

The drainage system comprises a network of open drains which ultimately discharge into the main drainage line formed by the Jerawachera and its tributary streams.

ARDA is wholly responsible for the operation and maintenance of the entire irrigation and drainage system.

The estate is headed by an Estate Manager who is responsible for the operational and administrative affairs of the estate. He is assisted by seven departmental heads - the Field Manager, Workshop Manager, Building and Maintenance Manager, Administration Officer, Estate Accountant, Settlement Officer and Security Officer.

Estate management activities involve the farming of summer cotton and winter wheat on irrigated land. Although irrigated cotton and wheat offer a technically sound rotation combination, they present a timing problem. Wheat must be sown early in May if it is to receive sufficient cold induction for flowering and tillering, and it requires approximately 130 days in the field. On the other hand, cotton should be planted in November and picking should commence in May.

Present practice is to plant cotton between 15 October and 15 November, the slightly earlier period of planting being dictated by the requirements of the subsequent wheat crop. Irrigation is normally necessary every 20-30 days, depending on the stage of growth, evapotranspiration rates and effective rainfall. Cotton is harvested by hand; picking commences at the beginning of March when the first bolls are open and is completed by the end of May. The rate of picking is determined by the timing of wheat sowing which should occur between 25 April and 15 May, although in practice sowing may extend from mid-April into June.

2.3.1.3 Aquatic weed management

A range of different aquatic weeds occur in the irrigation and drainage channels (see Tables 3.1 and 3.2) and the management of the aquatic weeds on Chisumbanje Estate centres on manual methods of control, principally hand-pulling and the use of 'slashers', sickles and hoes. Slashers are long, sword-like blades, the cutting end (10-15 cm) of which is bent at a right-angle to the shaft (Plate 2.1). The blade is swung, to and fro, to slash the vegetation just above ground level. The fragments of vegetation produced are not usually removed from the channels and may propagate themselves downstream.

Slashers are only effective for cutting vegetation in dry channels. Submerged plants are cut using sickles and the pared material is often removed from the channel and dumped on the channel bank.

Shallow hoeing along the banks and beds of channels removes all the above-ground plant material and some of the root systems. The method is generally more effective for clearing channels of vegetation using a sickle, but has an associated problem of drawing earth from the banks into the centre of the channel, thereby altering the channel profile.

In some instances, mechanical methods of weed control are employed. Roming disks (circular blades, drawn in rows behind tractors), are used to cut unwanted vegetation occurring in field drains. Such action is determined by local labour availability and there can be shortages at the time of the control operation.

During fallow seasons in dry canals with large quantities of accumulated sediment, a tractor and plough might be used to turn the sediment which is then shovelled out by hand. Although the exercise is aimed at improving the hydraulic performance of canals, it has obvious benefits for weed control. The recovery of vegetation in canals after ploughing, although not quantified, is reported to be slower than after other weed control operations. However, the technique is considered too expensive to be incorporated into a cycle of regular maintenance.

Most operations to control weeds in irrigation and drainage channels on Chisumbanje Estate are carried out, on a task basis, by seasonal labourers. Only during slack periods in the agricultural calendar do permanent workers participate. Labourers are loaned tools by the estate but are not provided any protective clothing. It is common to see men, wearing nothing but shorts, working in channels containing water. This exposes the labourers to the risk of contracting schistosomiasis.

The timing of weed control operations is often governed by agricultural activities and the demand for labour in the fields. Thus, slack periods, such as 'between crops' (i.e. after cotton-picking before wheat is sown, and after wheat harvesting before cotton is planted) are often associated with weed control.

Weed management on Chisumbanje Estate is summarised in Table 2.3.

2.3.2 Triangle Group Sugar Estates, Zimbabwe

2.3.2.1 Physical environment

The Triangle Group Sugar Estates are large-scale, commercial sugar estates owned by the South African-based company Tongaat-Hulett. The estates (hence referred to as Triangle Estates) are located in the south-east lowveld of Zimbabwe, in the District of Chiredzi (Natural Region V). Most of the cultivated area lies at an altitude of 410 m asl, on the east bank of the Mutirikwe River, upstream of the confluence with the Runde River.

The climate in the Triangle area is semi-arid. The average annual rainfall received is around 550 mm but rainfall is extremely variable. More than 80% of the rain falls between November and March, but 'guti' conditions are experienced at other times of the year. Mean daily temperatures for the year vary from 26°C in January to 16°C in July (averaging 22°C for the year). January is usually the hottest month in the year (mean daily maximum of 32°C) whilst the coolest month is normally July (mean daily minimum of 7°C). Frosts rarely occur.

Three main soil types dominate the Triangle area - sandy loam (clay content 18%), light-textured and free-draining; loamy sand (clay content 5 - 20%) the poorest soils on Triangle Estates, and sandy clay loam (clay content 30%) potentially the most productive soils on Triangle Estates. Generally, the soils on Triangle Estates are rich enough for sugar cane production, but leaching can be a problem on lighter soils and drainage can be limited on the heavier soils along natural drainage lines.

2.3.2.2 Irrigation and drainage systems

Irrigation on Triangle Estates has a long history, dating back to the 1930's. Presently, the irrigable area amounts to 13,863 ha of which 5,900 ha is overhead irrigation and 7,963 ha is furrow irrigation. Water for irrigation is derived from several sources. The greatest volume of water (183,512 Ml) is supplied from Mutirikwe Dam (Lake Kyle) from which water flows 100 km down the Mutirikwe River via Bangala Dam to the Nyajena (Esquilingwe) Weir. Here it passes into the Kyle Canal which has a peak flow of 20 cumec and transports the water a further 56 km to Triangle Estates.

Water is stored on Triangle Estates in 105 intermediate reservoirs locally known as dams. It is distributed to the fields via some 400 km of canals approximately 250 km of which are concrete-lined.

Table 2.3. Summary of aquatic weed management in irrigation and drainage systems on Chisumbanje Estate, Zimbabwe. (A Section is a division of the Chisumbanje Estate, hence Section A2 and Section B2)

Irrigation Unit	Dimensions	Principal Plants	Control Operation	Task (m^2/day)	Unit Cost of Control Operation (Z$/$m^2$) *a*	Effectiveness of Control Operation
Concrete-lined main supply canal	*c.* 4.50 m wide 1.84 m^3/s	Grasses alongside canal	Slashing alongside canal - three times a year, during wet season	-	-	-
Earthen branch canal	*c.* 1.50 m deep *c.* 12.50 m wide	*Commelina* sp. *Cyperus articulatus* *Eriochloa* sp. *Ludwigia stolonifera* *Persicaria* sp.	Slashing within channel - three times during wet season and twice during dry season	-	-	Effective for up to 4 weeks Effective for 6-8 weeks
			Hoeing within channel - twice a year, before crop establishment in May and October	-	-	
Concrete-lined secondary canals	-	Grasses alongside canal	Slashing alongside canal - up to three times a year during wet season	-	-	-

Table 2.3. Summary of aquatic weed management in irrigation and drainage systems on Chisumbanje Estate, Zimbabwe (cont.)

Irrigation Unit	Dimensions	Principal Plants	Control Operation	Task (m^2/day)	Unit Cost of Control Operation (Z$/$m^2$) a	Effectiveness of Control Operation
Night-storage dams	31,000 m^3 - 160,000 m^3 capacity	*Cyperus articulatus* *Commelina diffusa* *Dichanthium annulatum* *Ischaemum afrum* *Paspalum scrobiculatum* *Persicaria* sp.	No maintenance required	-	-	-
Concrete-lined field canals	0.07 m^3/s	*Potamogeton* sp. Grasses and broad-leaved plants alongside canal	Slashing or hoeing alongside canal - up to three times a year, twice during wet season and once during dry season before wheat establishment	-	-	Slashing effective for up to 4 weeks; hoeing effective for 6-8 weeks
Earthen field canals						
Section A2 canals	c.0.60-0.80m deep c.3.50-4.00m wide 0.140m^3/s	*Dichanthium annulatum* *Echinochloa colona* *Ludwigia stolonifera*	Hoeing within channel - twice a year, before crop establishment in May and October	300 (75 m of canal)	0.026 - 0.050	-

Table 2.3. Summary of aquatic weed management in irrigation and drainage systems on Chisumbanje Estate, Zimbabwe (cont.)

Irrigation Unit	Dimensions	Principal Plants	Control Operation	Task (m^2/day)	Unit Cost of Control Operation (Z$/$m^2$) a	Effectiveness of Control Operation
			Slashing within channel as required before irrigations	600 (150 m of canal)	0.013 - 0.025	-
			Ploughing within channel	-	-	-
Settlers blocks canals	*c.* 0.55-0.90 m deep *c.* 3.50-4.80 m wide 0.280 m^3/s	*Commelina* sp. *Echinochloa colona* *Lucwigia stolonifera*	Slashing alongside canal	-	-	-
			Hoeing/hand-pulling within channel	-	-	-
			Ploughing within channel	-	-	-
Section B1 canals	c.0.50-0.95 m wide c.4.40-5.80 m wide 0.200-0.600 m^3/s	*Commelina* sp. *Cyperus difformis* *Ludwigia stolonifera* *Potamogeton* sp.	Hoeing within channel as required before irrigations	750 (150 m of canal)	0.011-0.020	Effective for 6-8 weeks, longer in dry season
			Slashing within channel as required before irrigations	1250 (250 m of canal)	0.006-0.012	Effective for up to 4 weeks
			Ploughing within channel			

Table 2.3. Summary of weed management in irrigation and drainage systems on Chisumbanje Estate, Zimbabwe (cont.)

Irrigation Unit	Dimensions	Principal Plants	Control Operation	Task (m^2/day)	Unit Cost of Control Operation (Z$/$m^2$) a	Effectiveness of Control Operation
Section B2 canals	*c.* 0.50 - 0.90 m deep *c.* 4.70 - 5.70 m wide 0.367 m^3/s	*Cyperus difformis* *Ludwigia stolonifera* *Potamogeton* sp.	Hoeing within channel - twice a year before crop establishment in May and October	250 (100 m of half-canal)	0.032 - 0.060	-
			Slashing within channel as required before irrigations	500 (200m of half-canal)	0.016 - 0.030	-
			Ploughing within channel	-	-	-
Field drains		*Cyperus articulatus* *Dichanthium annulatum* *Eriochloa* sp. *Sesbania* sp. *Typha latifolia*	Slashing and burning within drain - once a year, before cotton establishment	-	-	-
			Roming within drain - once a year, between January and March	-	-	-
Secondary drains		Corchorus olitorius Eriochloa sp. Phragmites australis Typha latifolia	Slashing and burning within drain - once a year	-	-	-

Table 2.3. Summary of weed management in irrigation and drainage systems on Chisumbanje Estate, Zimbabwe (cont.)

Irrigation Unit	Dimensions	Principal Plants	Control Operation	Task (m^2/day)	Unit Cost of Control Operation (Z$/$m^2$) a	Effectiveness of Control Operation
Main drain		*Cyperus involucratus* *Dichanthium annulatum* *Echinochloa colona* *Eriochloa* sp. *Typha latifolia*	Hand-pulling in excavated section - intervals of six weeks	-	-	-
			Slashing and burning within drain before crop establishment in May and October and as required before irrigations	-	-	-

a Figures based on rates for seasonal and permanent labour respectively

Drainage of Triangle Estates centres around the Cheche, Kamba and Makari Rivers and their tributary streams. In-field drains unite to form main drains which then discharge, via estate drains, into the above river systems. These rivers ultimately discharge into the Mutirikwe River.

The command area of Triangle Estates is divided into areas and sections. For example, Section 19 extends for 675.5 ha, irrigation water entering the section via a concrete-lined main canal. From the main canal, water can either be diverted to night-storage dams, or distributed directly to the fields by concrete-lined crest canals (or feeders) which give rise to concrete-lined feeders and earth feeders. Surface water is removed from the fields by shallow surface drains which discharge into deep in-field drains or main drains. These also receive water from tile-drains. Drainage leaves the estate via main watercourses known as estate drains.

2.3.2.3 Organisation and management

All agricultural operations are directed by the Agriculture Division of Triangle Estates, headed by the Director of Agriculture, and sub-divided into four departments - the Agriculture Department, the Agriculture-Technical Department, the Agronomy and Training Department and the Cane Haulage Department.

The Agriculture Department, under the supervision of the Agriculture Manager, undertakes all field operations on Triangle Estates, including land preparation, planting, irrigation at the section-level and harvesting. Triangle Estates are divided into five areas, each headed by a Field Manager. The areas are, in turn, split into sections (totalling 30 and ranging in size from 320 ha to 659 ha) administered by Section Managers. Each section is run as a separate farm entity under a bonus system.

The Agriculture-Technical Department is responsible for agricultural and irrigation engineering on Triangle Estates. It is involved in the design and construction of irrigation and drainage works, and the operation and maintenance of the irrigation network, including the 35 pumping stations, as far as the section-level. Whilst the department monitors the distribution and use of irrigation water across Triangle Estates it is not responsible for irrigation at the field level, which comes under the Agriculture Department.

2.3.2.4 Aquatic weed management

A range of aquatic species grow in the irrigation and drainage channels and night-storage dams (Table 2.4). The use of stillage effluent as a fertiliser generated during ethanol production from the sugar cane has reduced dependence on manufactured fertilisers. However, it is also believed to be responsible for an increase in both the number and quantity of weed species occurring in the drainage lines.

Table 2.4. Summary of weed management in irrigation and drainage systems on Triangle Estates, Zimbabwe

Irrigation Unit	Dimensions	Principal Plants	Control Operation	Task (m^2/day)	Unit Cost of Control Operation (Z$/$m^2$)	Effectiveness of Control Operation
Main canal (concrete-lined)	*c.* 0.50 - 1.00 m deep *c.* 1.50 - 2.00 m wide	*Cynodon dactylon* *Echinochloa* sp. *Euphorbia hirta* *Euphorbia serpens* *Gomphrena celesoides* *Portulaca oleracea* *Stenotaphrum secundatum*	Slashing along shoulders of canal - three times a year	100	0.10	Effective for up to 4 weeks in wet season; and longer in dry season
Night-storage dams	3.0 Ml to 19.5 Ml capacity	*Cyperus articulatus* *Panicum repens* *Persicaria* sp. *Typha latifolia*	Slashing inside dam - three times a year	150		-
			De-silting (mechanically)	-		Effective for up to 5 years
Crest feeders (concrete-lined)	*c.* 0.30 - 0.70 m deep *c.* 0.50 - 1.00 m wide	See Main canal	Hoeing along shoulders of canal - four times per year	150	0.07	Effective for up to 4 weeks in wet season and 3-4 months in dry season
Concrete feeders	*c.* 0.30 m deep *c.* 0.50 m wide	See Main canal	Slashing along shoulders of canal - four times per year	100	0.10	Effective for up to 4 weeks in wet season and longer in dry season

Table 2.4. Summary of weed management in irrigation and drainage systems on Triangle Estates, Zimbabwe (cont.).

Irrigation Unit	Dimensions	Principal Plants	Control Operation	Task (m^2/day)	Unit Cost of Control Operation (Z$/$m^2$)	Effectiveness of Control Operation
Earth feeders	*c.* 0.30 - 0.50 m deep *c.* 0.50 - 1.25 m wide	*Cynodon dactylon* *Euphorbia hirta* *Launaea cornuta* *Stenotaphrum secundatum*	Hoeing within channel and along shoulders of canal - four times a year	150	0.07	Effective for up to 4 weeks in wet season and 3-4 months in dry season
Surface drains	c. 0.30 m deep c. 0.50 m wide	*Cyperus esculentus* *Echinochloa* sp. *Eclipta alba* *Gomphrena celesoides* *Nesaea* sp. *Oldenlandia* sp.	Hoeing within drain - twice a year	150	0.07	-
In-field drains	*c.* 1.00 - 2.00 m deep > 1.50 m wide	*Cynodon dactylon* *Cyperus difformis* *Cyperus involucratus* *Echinochloa* sp. *Eclipta alba* *Euphorbia hirta* *Eragrostis* sp. *Ludwigia stolonifera* *Nesaea* sp. *Stenotaphrum secundatum* *Typha latifolia*	Slashing within drain- four times a year Hoeing / re-aligning drain profile - once a year, in June	100 5 m^3/day	0.10 1.954/m^3	Effective for up to 4 weeks in wet season and 3-4 months in dry season -

Table 2.4. Summary of weed management in irrigation and drainage systems on Triangle Estates, Zimbabwe (cont.)

Irrigation Unit	Dimensions	Principal Plants	Control Operation	Task (m^2/day)	Unit Cost of Control Operation (Z$/$m^2$)	Effectiveness of Control Operation
Main drains	> 1.50 m deep > 2.00 m wide	See In-field drains	Slashing within drain - twice a year	150	0.10	-
			Hoeing / re-aligning drain profile - once a year, in June	5 m^3/day	1.954/m^3	-
			Mechanical clearance once every two years	120 m/day	15.00	*Typha latifolia* recovers within 12 months
Estate drains	Variable	*Cyperus involucratus* *Ludwigia stolonifera* *Phragmites australis* *Typha latifolia*	Slashing within drain- once a year	150	0.07	-
			Mechanical clearance once every two years	120 m /day	15.00	*Typha latifolia* recovers within 12 months

Table 2.5. Weed management in irrigation and drainage channels at Mwea Irrigation Settlement Scheme

Channel	Dimensions	Flow Regime	Principal Weeds	Maintenance Activity
Main Canal[a]	13330 m total length 2.90-6.50 m base width 0.80-1.50 m canal height 0.56-1.31 m water depth 1.95-6.35 $m^3 s^{-1}$	Flow year round - water supplied for domestic use as well as irrigation	*Acmella caulorhiza* *Commelina* sp. *Cyperus dives* *Polygonum senegalense*	Dredging to remove silt and weeds, once per year, in January/February Manual clearance of weeds, using pangas, hoes or spades, twice per year in June and September
Branch Canal[a]	45580 m total length 0.30-3.50 m base width 0.30-1.40 m canal height 0.12-1.23 m water depth 0.04-2.73 $m^3 s^{-1}$	Flow dependent on cropping program - February to November	*Acmella caulorhiza* *Ageratum conyzoides* *Commelina* sp. *Cyperus latifolia* *Eclipta alba* *Leersia hexandra* *Ludwigia abyssinica* *Panicum repens* *Polygonum senegalense* *Rhynchosia* sp.	Dredging to remove silt and weeds, once per year, before area served by canal is irrigated Manual clearance of weeds, using pangas, hoes or spades, twice per year
Main / Unit Feeder	*c.* 1.50-3.00 m bank top 0.028 $m^3 s^{-1}$ / 20.25 ha (1 cumec / 50 acres)[b]	Flow dependent on cropping program - February to November	*Acmella caulorhiza* *Ageratum conyzoides* *Centella asiatica* *Commelina* sp. *Cynodon dactylon* *Leersia hexandra*	Dredging to remove silt and weeds, infrequently, as required Manual clearance of weeds, using pangas, hoes or spades, twice per year, during production period
Feeder	*c.* 0.50-2.00 m bank top 0.028 $m^3 s^{-1}$ / 20.25 ha (1 cumec / 50 acres)[b]	Flow dependent on cropping program - February to November; period varies from 6-10 months	*Commelina* sp. *Cynodon dactylon* *Leersia hexandra*	Manual clearance of silt and weeds, using pangas and hoes, three times per year, before flooding, before transplanting and before top-dressing
Field Drain	*c.* 1.50-3.00 m bank top 0.003 $m^3 s^{-1}$ / 1 ha) (0.85 cumec / acre)[b]	Flow dependent on cropping program - February to December; period varies from 6-10 months	*Commelina* sp. *Cynodon dactylon* *Echinochloa colona* *Fimbristylis* sp. *Leersia hexandra* *Ludwigia stolonifera*	Dredging to remove silt and weeds, infrequently, as required Manual clearance of weeds, using pangas and hoes, three times per year, before flooding, before transplanting and before draining for harvest
Collector Drain	*c.* 1.50-3.50 m bank top 0.003 $m^3 s^{-1}$ / 1 ha) (0.05 cumec / acre)[b]	Flow dependent on cropping program - February to December	*Commelina* sp. *Cynodon dactylon* *Leersia hexandra* *Ludwigia stolonifera* *Panicum repens*	Dredging to remove silt and weeds, infrequently, as required Manual clearance of weeds, using pangas, hoes or spades, twice per year, in April/May and November/December
Main Drain[a]	32800 m total length 1.50-15.00 m base width 0.70-3.20 m canal height 0.42-2.83 m water depth 1.00-40.90 $m^3 s^{-1}$	Flow dependent on cropping program - February to December	*Commelina* sp. *Cynodon dactylon* *Echinochloa colona* *Echinochloa pyramidalis* *Leersia hexandra* *Marsilea* sp. *Polygonum senegalense* *Typha latifolia*	Dredging to remove silt and weeds, once per year Manual clearance of weeds, using pangas, hoes or spades, two or three times per year, before rains

[a] design specifications JICA (1989)
[b] design specifications Chambers and Moris (1973)

The management of vegetation in irrigation and drainage channels and night-storage dams on Triangle Estates is given considerable accord and general recommendations for weed control operations have been issued by the Agronomy and Training Department. These take into consideration soil conservation measures linked to plant growth in and along channels. The vegetation in irrigation and drainage channels and night-storage dams is generally controlled by manual techniques, based around the use of slashers, pangas, hoes and shovels. To try and lessen the problem of soil erosion on Triangle Estates, it is recommended that the growth of the grasses *Cynodon dactylon* and *Stenotaphrum secundatum* be actively encouraged on the 'shoulders' (earthen berms) along concrete-lined and earth canals and on the banks of drainage channels. *Cynodon dactylon* is also advocated to stabilise the soils inside earth feeders. In this respect, the Agronomy and Training Department suggests the adoption of weed control techniques, in the following order, according to requirements: hand-pulling, slashing, hoeing or shovelling. However, such recommendations are not always adhered to by operational staff and it is common to see channels completely denuded of vegetation.

Each year, for two or three weeks in June, the Regional Water Authority closes the Kyle Canal for maintenance. During this period, Triangle Estates takes the opportunity to close down its irrigation and drainage systems for maintenance. Weed control operations are usually carried out by seasonal labour. However, at this time of year, permanent staff are also drafted to maintenance operations since they are not required to perform their normal duties. The post-harvest stress period (time between cane-cutting and stalk elongation) and drying off period (when water is withheld from the field before cutting) also allow for the deployment of permanent staff to weed control operations. Workers are issued with tools, protective clothing (gumboots and smock), a water container and a daily food supplement of mahewu (a form of gruel). Payment is organised on a task basis at the rate (in 1994) of Z$9.77 per day (Z$254.00 per month) for seasonally employed labour and Z$12.96 (Z$337.00 per month) for permanent labour.

During the wet season when plant growth is reported to be most prolific, the majority of the available labour is employed in the removal of crop weeds, and maintenance of irrigation and drainage channels is of secondary importance. The management of vegetation in the drainage network particularly tends to be reactive, carried out in response to flooding.

The night-storage dams provide for a rich flora including a range of grasses, sedges and broad-leaved plants with abundant growth of the emergent weeds *Typha latifolia*, *Panicum repens*, *Cyperus articulatus*, *Schoenoplectus* sp. and *Persicaria* spp. sometimes extending across the entire bed of shallow dams. An abundance of the submerged weed *Najas* sp. has also been recorded. Ordinarily the vegetation in the dams is controlled, by slashing, approximately three times each year. In some instances, this operation requires that the dam be drained.

Many of the dams are heavily silted and operate considerably below design capacity. As part of a programme to reinstate dams, through the mechanical removal of silt, attention is being directed towards the control of vegetation in these structures. The original design of many night-storage dams is such that their cross-sectional profile is very shallow, a condition which promotes invasion of the water body by emergent plants including those species described above. It is now the policy of the Agriculture-Technical Department to re-profile night-storage dams during the course of de-silting operations to provide steeper slopes and a water depth greater than 1.5 m in order to prevent re-colonisation by emergent vegetation. In some instances, a thick sward of the creeping grass *Stenotaphrum secundatum* has also been encouraged in order to discourage the re-growth of the emergent weed *Typha latifolia*. The regular cycle of draw-down in these dams is also believed to retard the development of emergent vegetation.

Very little vegetation occurs in the concrete-lined canals (including main canals, crest feeders and concrete feeders). Those plants which are present (e.g. *Eclipta alba* and *Echinochloa* sp.) usually arise from cracks in the concrete lining or are rooted above the lining and trail into the channels. The shoulders which run alongside the concrete-lined canals support grasses and broad-leaved plants such as *Cynodon dactylon, Stenotaphrum secundatum, Euphorbia serpens, Euphorbia hirta, Portulaca oleracea,* and *Gomphrena celesoides.* The development of these species is checked by slashing or hoeing, three or four times annually. Such operations usually take place once during the dry season and once every month during the wet season.

The earth feeders generally support a sparse growth of the grasses *Cynodon dactylon* and *Stenotaphrum secundatum* which frequently occur along the shoulders of the earth feeders and occasionally invade the channels; other broad-leaved species which exist in and along the earth feeders include *Euphorbia hirta, Launaea cornuta* and *Boerhavia* sp. Excess growth of these plants is removed by slashing, on average, four times per year.

The surface drains are very narrow, shallow depressions which trap any run-off from the furrows between the cane lines. Plants recorded in the surface drains include the emergent weeds *Cyperus esculentus, Echinochloa* sp., *Eclipta alba, Gomphrena celesoides, Nesaea* sp. and *Oldenlandia* sp. These are generally removed from the drains by hoeing twice annually.

The main and in-field drains tend to be deep, relatively narrow watercourses which flow year-round. During the dry season, they operate at a level far below their capacity, but during the wet season they are required to remove large volumes of water from the cane fields. Many sub-surface tile-drains discharge into the main and in-field drains, and if these are to function correctly, it is imperative that the vegetation occurring in the open drains is controlled to allow 1.5 - 2.0 m freeboard. The flora in the main and in-field drains is fairly diverse, including grasses (e.g. *Cynodon dactylon, Stenotaphrum secundatum* and *Phragmites australis*), sedges (e.g. *Cyperus difformis, Cyperus esculentus* and *Cyperus involucratus*) and broad-leaved species (e.g. *Commelina* sp. and *Ludwigia stolonifera*). However, the emergent weed *Typha latifolia* is considered to be the major weed in the drainage lines.

The maintenance of the drainage lines takes two forms: the removal of vegetation as part of de-silting operations; and the removal of vegetation by slashing. The former operation generally takes place around the June shut-down period on an annual basis, whilst the latter task occurs two to four times, usually on an *ad hoc* basis, in response to flooding during the wet season. Most Section Managers aim to maintain the entire length of their drainage lines during the course of a year.

In years past, more than 100 km of the main drainage lines were cleared mechanically, every two years, using ditch-cleaning buckets mounted on the arms of hydraulic excavators. However, those excavators are now defunct, but there is an intention to replace them.

2.3.3 Mwea Irrigation Settlement Scheme, Kenya

2.3.3.1 Physical environment

Mwea Irrigation Settlement Scheme (hence referred to as Mwea ISS) is located near Embu, in the Kirinyaga District of Central Province, Kenya. It extends over 12,140 ha and draws water for irrigation from the Thiba and Nyamindi Rivers, both tributaries of the Tana River which flows to the west of the scheme (Figure 2.2). Surplus irrigation water and excess precipitation are drained from the scheme into the Thiba and Nyamindi Rivers.

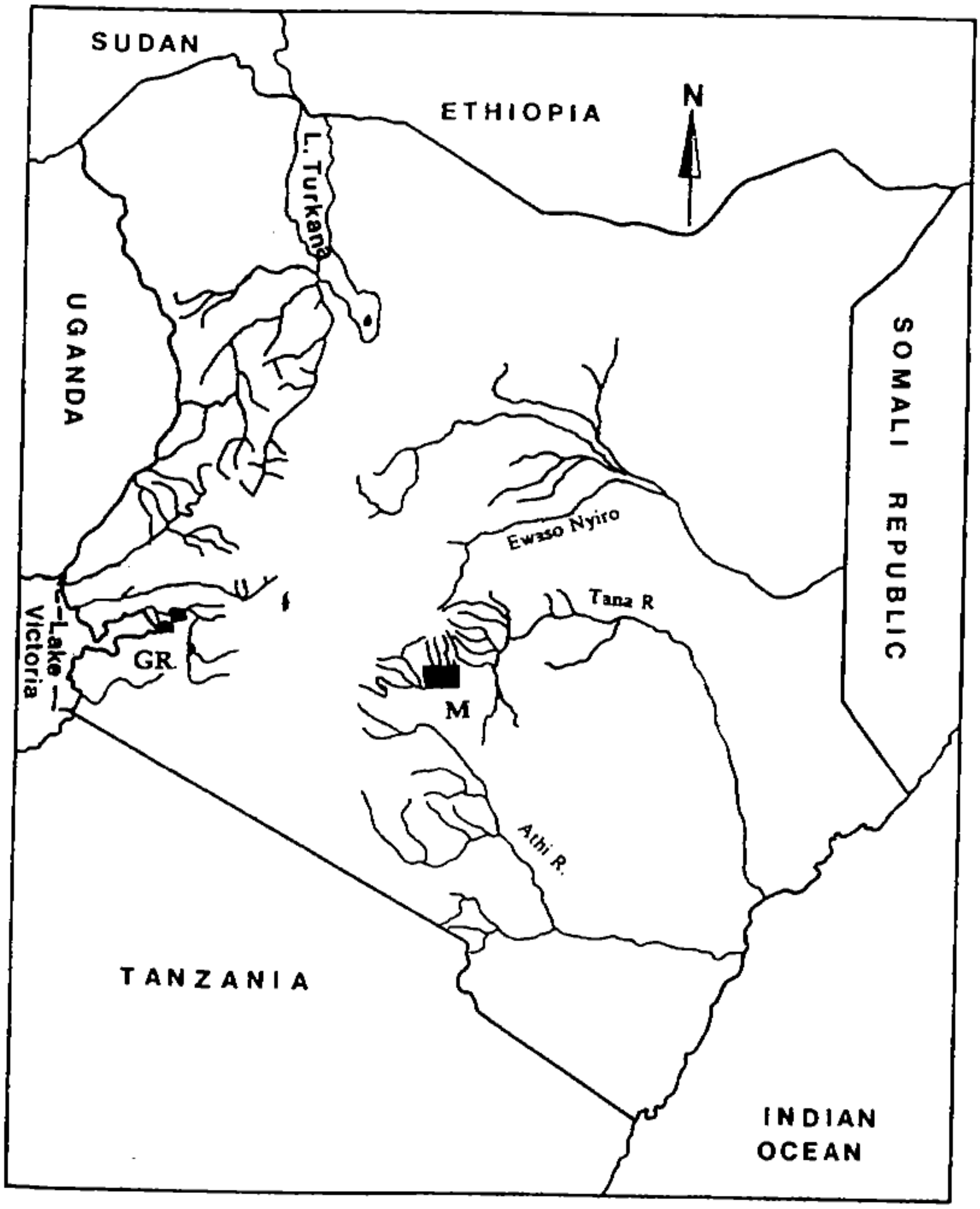

Figure 2.2. Location of the Mwea Irrigation Settlement Scheme (M) and Gem Rae Irrigation Project (GR), Kenya

Mwea ISS is the largest producer of rice in Kenya, accounting for over 70% of the total production (JICA 1988). The scheme is managed by the National Irrigation Board (NIB), and supports approximately 300 NIB administrative staff in eight departments (Figure 2.3). Crop production, however, is carried out by tenant farmers in accordance with a cropping schedule prepared by the NIB management (Figure 2.4). Each farmer is licensed to cultivate 1.6 ha (4 acres) of irrigated rice. Farm inputs such as land preparation services, irrigation water, fertilisers and transport for harvested paddy are supplied for a nominal fee by the NIB. Farmers are required to deliver all their produce to the NIB for marketing.

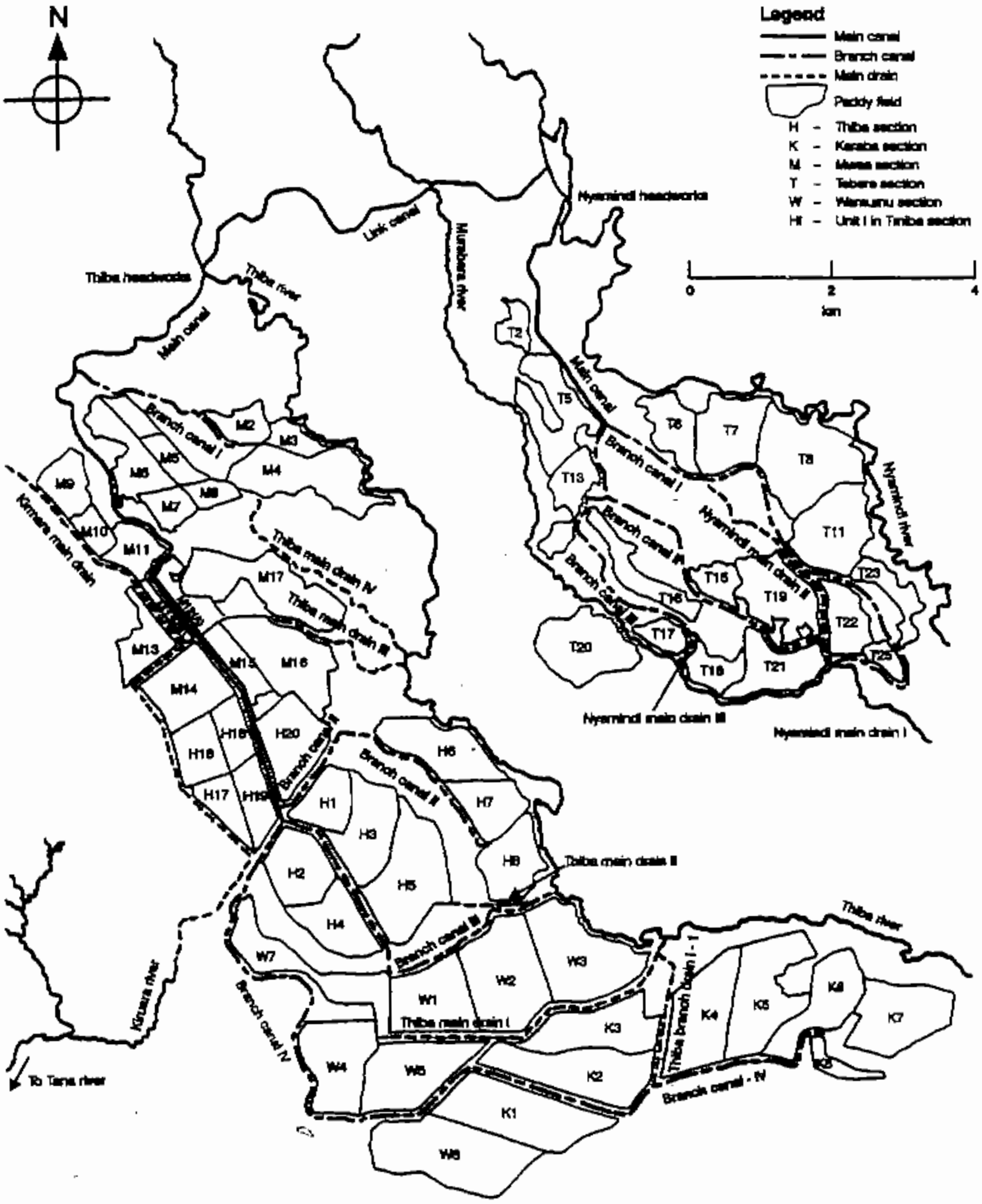

Figure 2.3. Layout of the Mwea Irrigation Settlement Scheme

2.3.3.2 Irrigation and drainage system

Mwea ISS is divided into sections (e.g. Thiba Section in Figure 2.2), each of which is administered by a NIB Irrigation Officer. The individual sections vary in size from 1,900 - 3,000 ha and are sub-divided into units (e.g. Unit H1 of Thiba Section in Figure 2.2) which, in turn, are split into fields. From the headworks on the rivers, water is conveyed by gravity through a network of open channels via link canals and main canals (primary channels) and branch canals (secondary channels) into the sections (Figure 2.2). Main or unit feeders (tertiary channels) carry water from the main and branch canals to the individual units (Figure 2.5). Within the units, water is supplied to individual fields by feeders (quaternary channels) (Figure 2.5). Each feeder serves two lines of fields. The standard field measures 0.4 ha (1 acre) and is rectangular, with one short side abutting on the feeder and the other adjoining the field drain.

Drainage at Mwea ISS is provided by a system of drains which discharge into one of four rivers: the Kiruara, Thiba, Murubara and Nyamindi. Excess water from the fields is collected by field drains (quaternary channels) which run almost parallel to the feeders on the opposite sides of the fields. Field drains discharge into collector drains (tertiary channels) which evacuate water from the units (Figure 2.5). In places where units are located along a river, field drains or collector drains may deliver drainage water directly to the river; elsewhere they flow into main drains (primary or secondary channels). The layout of the irrigation and drainage systems at Mwea ISS is typical of schemes throughout the developing world (see, for example, Kay 1986).

Most of Mwea ISS is underlain by vertisols, i.e. impermeable black cotton soils. Consequently, the irrigation and drainage networks comprise almost entirely of unlined open channels. Only in areas where the primary and secondary canals pass through more permeable red soils are short reaches of the channels concrete-lined.

The main crop grown at Mwea ISS is rice and the cropping cycle is summarised in Figure 2.4.

A range of aquatic weeds species grow in the channels (Table 3.3) reducing the efficiency of the system. The NIB, in conjunction with the tenant farmers, has developed a channel maintenance programme integrated into the crop production cycle (Table 2.5, page 30). The NIB spends ZSh. 11.5 million per year on maintenance at Mwea ISS, i.e. ZSh. 2,000 ha^{-1}.

Schistosomiasis is present in the area and labourers working in the water are at risk of contracting the disease.

2.3.3.3 Aquatic weed management

The management of weeds in irrigation and drainage facilities at Mwea ISS is apportioned between the NIB Works Department and the tenant farmers. The Works Department is wholly responsible for the primary and secondary channels (link canals, main canals, branch canals and main drains) and employs both mechanical and manual means of weed control. The mechanical control involves the use of hydraulic excavators (Plate 2.2) to remove silt and weed from the channels whilst the manual control comprises the clearance of weeds and some silt with simple hand-tools such as machetes.

The individual farmers on Mwea ISS are obliged to maintain the irrigation and drainage facilities which directly serve their holdings (feeders and field drains, i.e. the quaternary channels). Channel clearance is carried out by hand, as described above. Most farmers require direction from a NIB Field Assistant before they undertake such maintenance work. Farmers are usually instructed to clear their feeders three times per year, prior to land-soaking, transplanting and top-dressing operations, and clear their field drains three times per year, before land-soaking, transplanting and pre-harvest draining (i.e. periods when channels must perform efficiently).

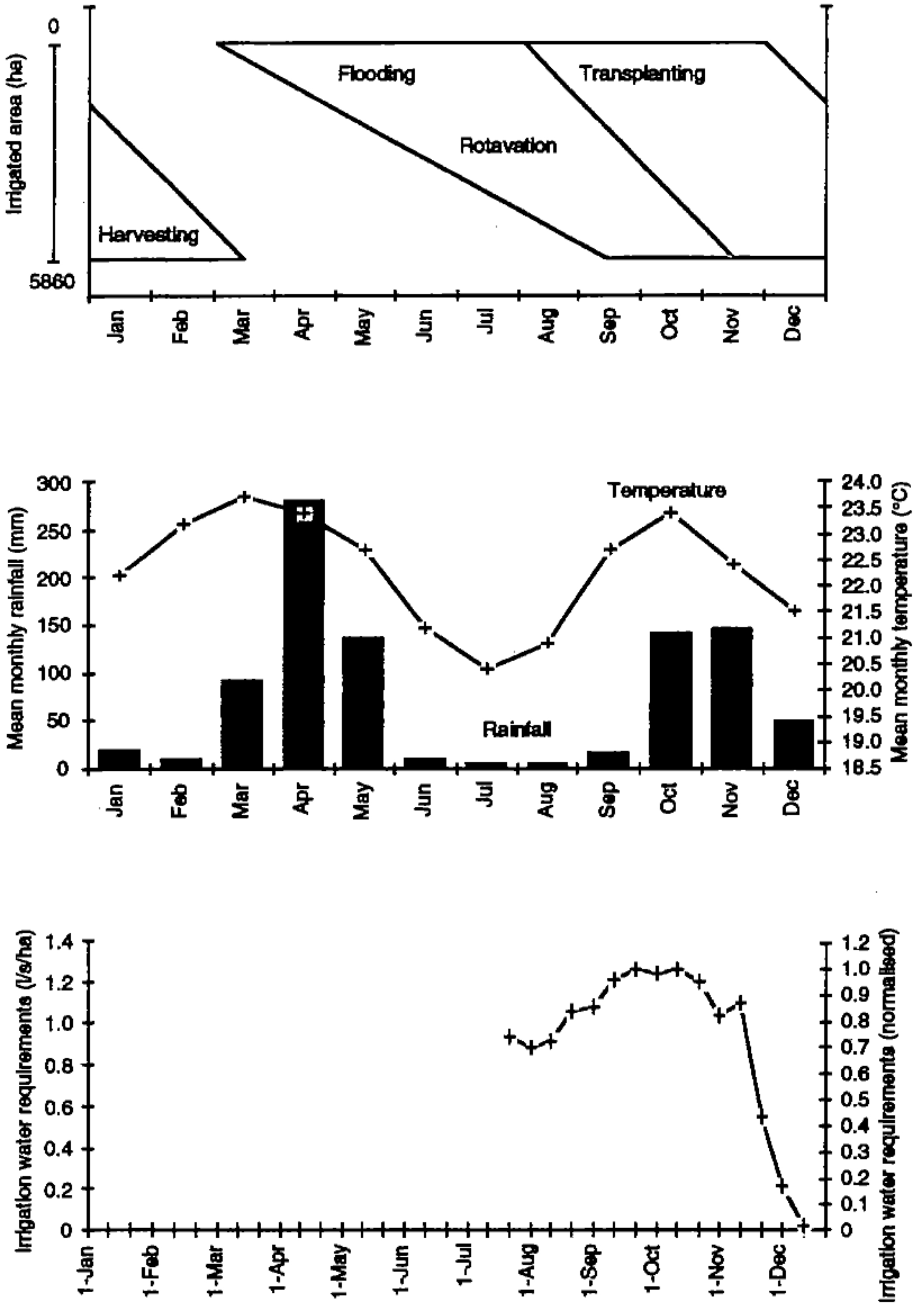

Figure 2.4. Mwea Irrigation Settlement Scheme: (a) Cropping schedule, (b) Mean monthly rainfall and temperature, and (c) Irrigation water requirements

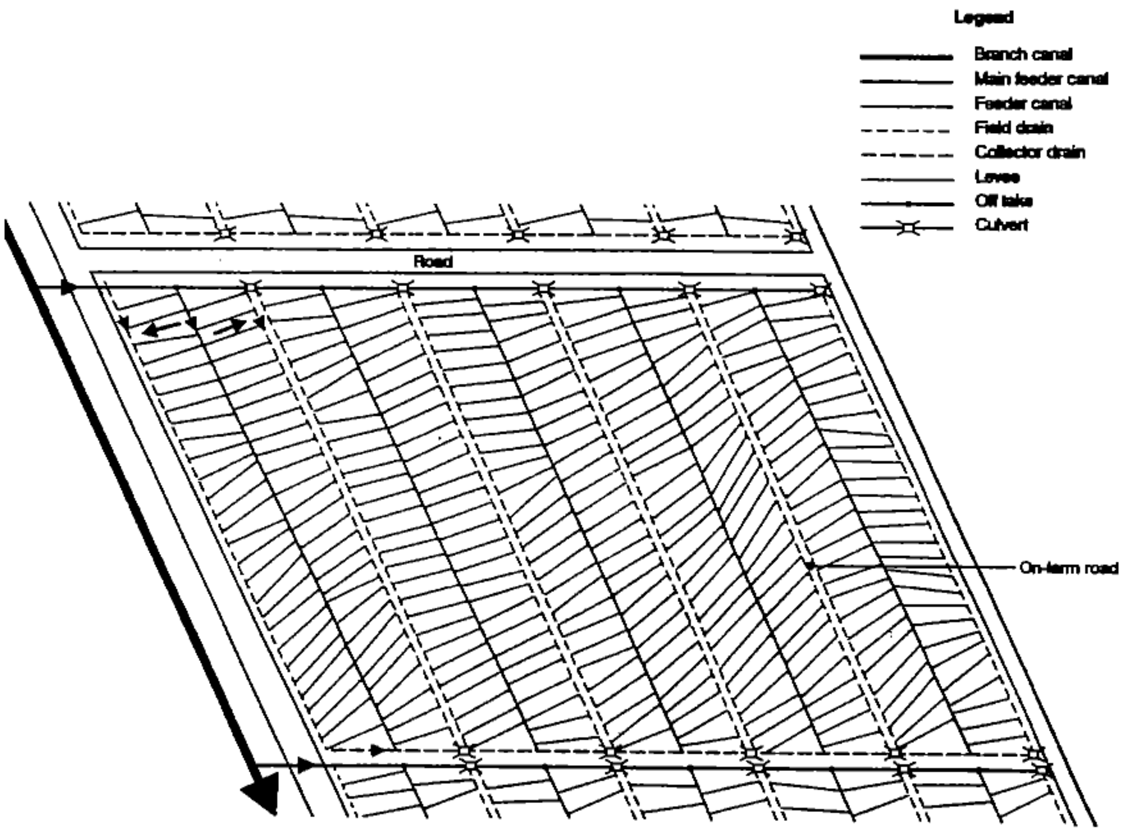

Figure 2.5. Detail of channels in a section of the Mwea Irrigation Settlement Scheme

The management of weeds in main or unit feeders and collector drains at Mwea ISS is undertaken, in part, by both the Works Department and the farmers. The Works Department generally shoulders the responsibility when the channels have accumulated large volumes of silt which require removal. Management on the part of farmers involves a communal effort by those individuals served by a particular watercourse. Ordinarily, main or unit feeders are cleared on two occasions during the crop production season, and collector drains are maintained twice, in preparation for the long rains in March/April and the short rains and pre-harvest draining in November/December (Figure 2.4).

The Works Department's weed management programme is largely dictated by the cropping calendar (specifically the requirement for water in the fields) and the available resources of labour and hydraulic machinery. The Department recognises periods in the cropping calendar when the irrigation system and the drainage system respectively must perform efficiently and therefore aims to maintain the particular system in advance of such critical periods. During non-critical periods, maintenance of a particular system assumes secondary importance.

Between December and March the rice fields are dry, and, following harvest in December to mid-March, are free from any crop. Consequently any 'in-field' maintenance which requires machinery is carried out at this time so that plant can pass freely through the fields. During the same period management of the irrigation system commences with the primary canals and those canals serving the fields which are to be rotavated by tractor early in the year. Drainage is not an important function at this time; however, major drains are excavated during this period in preparation for the long rains in March/April. Ideally, this activity occurs in January/February so that the vegetation partially recovers before the rains arrive and can provide bank protection.

With the arrival of the long rains in March/April, resources are re-directed to drainage maintenance to prevent water-logging (and bogging down of tractors) in the fields, and to prevent water from over-topping drains and flooding in-field roads thereby restricting vehicular access.

Irrigation system maintenance recommences in May/June, canals being cleared systematically in advance of irrigation and rotavation of the fields they serve. September and October represent a critical period for water management. The demand for water at the field level is high since all the fields are under crop and high temperatures cause considerable evapo-transpiration (Figure 2.4). Coincidentally, river flows are at their lowest during this period. Thus, it is imperative that the irrigation system has been maintained and is performing efficiently by this time.

During the period September-November the focus of the maintenance program reverts to the drainage system in preparation for the short rains in October/November and for the pre-harvesting drying-off period (Figure 2.4). At this time main drains are maintained and flood protection works are carried out in the river channels.

The Works Department's management of weeds in irrigation and drainage channels is not confined to mechanical excavation. The recovery rate of vegetation is very rapid. Consequently, in order to sustain channel efficiency, the Works Department is required to deploy maintenance gangs to clear weeds from the channels by hand. Ordinarily, this occurs two or three times per year, usually prior to, or during critical periods for channel function, i.e. between June and October for canals and in March/April and October/November for drains.

2.3.4 Gem Rae Irrigation Scheme, Kenya

2.3.4.1 Physical environment

Gem Rae Irrigation Scheme (hence referred to as Gem Rae) is a small-scale, farmer-managed scheme located in Nyanza Province, approximately 30 km from Kisumu (Figure 2.2). Situated in the Awach Kano Delta area (a former swampland) Gem Rae is in close proximity to three other schemes - Kopudo, Nyachoda and Awach - all of which use the Awach River as their water source.

Although rice cultivation using simple check structures and flood irrigation has occurred in the area since 1938, formal irrigation at Gem Rae did not commence until 1986. The present scheme covers an irrigated area of 90 ha with 270 plots and approximately 230 land-owners (Hide 1994). A further 28 ha is occupied by farmers on the margins of the scheme utilising excess water from Gem Rae and flow in the Awach River downstream from the offtake to Gem Rae.

Most of Gem Rae is underlain by medium to heavy, dark-grey or black clays. Other soils include black cotton clays and medium to heavy clays suitable for rice production due to their impermeability. Annual precipitation in the area is 1,250 mm peaking in April and November, the time of the 'long' and 'short rains' respectively. Temperatures are fairly constant throughout the year, monthly average maxima ranging from 25-35°C and minima between 15°C and 19°C.

Gem Rae is used exclusively to produce a single rice crop per year. Nominally, land preparation commences in June and the grain harvested in December, but in practice, the production season is usually late to start. For the remainder of the year farmers grow maize and sorghum under rain-fed conditions outside the scheme.

Gillott (1994) describes the consequences of the deferred agricultural calendar namely that irrigation often continues through April, contrary to the intended schedule. Heavy rains at this time contribute to high flows in rivers, allowing them to transport heavy concentrations of sediment. Thus, irrigation in April at Gem Rae introduces large volumes of sediment into the scheme which exacerbates the problem of cleaning canals. As a consequence, canal cleaning takes longer and may further delay the onset of cultivation in the following season.

2.3.4.2 Irrigation and drainage systems

The design and construction of the present irrigation scheme at Gem Rae was funded by the Kenyan and Dutch governments. The irrigation system consists of a main canal, three secondary canals and nine tertiary canals. The design cross-section of the main canal is constant along its 2.4 km length with a bed-width of 1.5 m and a side-slope of 1:1.5, however, sections of the canal have become considerably reduced in size as a result of siltation and weed growth. The tertiary canals are approximately 200 m apart and each serves 3-15 ha. The flow of water is continuous to all tertiary canals. Water distribution is achieved by proportional division boxes constructed from concrete blocks. No provision is made for manual control of the water.

Basin irrigation is the exclusive practice at Gem Rae. Each plot is divided into basins which vary in size from 100-2500 m^2. Following abstraction from the tertiary canals, irrigation water passes from basin to basin through depressions in the bunds on a 24 hour basis.

No formal drainage system exists at Gem Rae because of a reluctance on the part of farmers to excavate and maintain the channels.

The operation and management of Gem Rae is conducted by the Scheme Committee with advice from the local extension officer. The Committee is comprised of 24 members who convene at the beginning and end of the production season. Although the Committee is supposed to play a directoral role at Gem Rae, its administrative capacity is weakened by the fact that it has no powers to enforce scheme rules. Furthermore, a recent study (Hide 1994) noted that, contrary to outward impressions, the Scheme Committee was beset by internal disputes and did not function correctly. At a lower level of organisation farmers are divided into groups sharing a common tertiary canal.

2.3.4.3 Aquatic weed management

The control of weeds in the irrigation system at Gem Rae is a secondary benefit of maintenance activities directed at accumulated sediments rather than a specific management priority. The responsibility for maintenance of the main and secondary canals at Gem Rae rests with the entire scheme under the direction of the Scheme Committee. The tertiary canals should be maintained by the farmers. Hide(1994) suggests a major drawback to the system employed at Gem Rae arises because individual farmers are responsible for the section of tertiary canal adjacent to their plot which provides the individual farmer with a strong disincentive to clear the canal until farmers upstream have completed their sections. Hide (1994) concludes that the lack of co-operation between farmers and poor leadership from the Scheme Committee, in addition to the deposition of large amounts of sediment in the canals are leading to a downward spiral in the operation of the scheme.

2.3.5 Welland and Deepings Internal Drainage Board

Extensive areas of the United Kingdom have a high dependency on complex networks of flood defences and drainage systems. Within England and Wales, such areas of dependency invariably fall within drainage districts where protection from the sea and the management and evacuation, as necessary, of inland water combine to provide conditions within which land use can be sustained. The principal organisations charged with maintaining adequate standards of flood protection and land drainage within drainage districts in England and Wales are the Environment Agency and Internal Drainage Boards such as Welland and Deepings Internal Drainage Board.

Welland and Deepings Internal Drainage Board is responsible for a drainage district covering 32,415 ha in Lincolnshire, eastern England. The total length of drains maintained in the district is approximately 670 km.

The Board's aquatic plant management practices are capital intensive, based on sophisticated weed-cutting machinery, including a weed-cutting launch, a 'Bicycle' tractor, a 'Spider' tractor, and land based excavators and tractors equipped with weed-cutting buckets. Such equipment demands a heavy investment in terms of maintenance and, in this respect, the Board is self-contained, having its own workshop and three mechanical fitters.

The maintenance programme is based on experience, developed traditions and available finances. Most of the drainage network is maintained at fixed times in the year, with fixed frequencies and fixed techniques. The weed-cutting machinery is deployed in May and remains in operation until December. During this period, each channel is cleared of vegetation at least twice; some are cleared three times. The programme is revised occasionally if access to a channel is restricted because land is under crop.

The selection of weed-cutting machinery is largely determined by the dimensions of the drainage channels and access to the watercourses. To maximise efficiency, it is usual for machinery to follow a similar route around the drainage district each year, and each machine is normally driven by the same driver.

During the winter months (January to April), the mechanical excavators are employed in channel dredging operations which are carried out on a five year cycle. The multi-functional use of heavy plant is important to recuperate costs. The other weed-cutting machinery is overhauled during these months.

In the past, the primary management concern of Internal Drainage Boards was to maintain channels for water conveyance. Hence, complete channels were cleared of vegetation. In recent years, however, internal drainage boards, under pressure from conservation lobbies and as a result of environmental legislation, have been forced to recognise the value of their systems for nature conservation and adapt their management practices accordingly. This has prompted a general move away from herbicides towards mechanical techniques. Drainage engineers are encouraged to exercise caution towards their weed-cutting practices, and leave half-channels or single banks uncut to provide for wildlife.

Conditions which prevail at Welland and Deepings Internal Drainage Board are very different from those in say, Zimbabwe or Kenya. A lack of foreign exchange and technical expertise in Africa generally prohibits use of the specialist equipment currently operated by the Board, although large state-owned or commercially managed irrigation projects in Africa may be an exception to this rule. The feeling amongst staff at Welland and Deepings Internal Drainage Board is that the technology employed by the Board in the 1960's (manual techniques and self-propelled pedestrian machines) is perhaps more transferable to the developing world.

Welland and Deepings Internal Drainage Board maintains detailed records of the costs of aquatic plant management practices. These have been used as a basis to develop a methodology for financial and economic comparison of different methods of control.

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Plate 2.1 Use of tools for manual aquatic weed control: (a) slasher, (b) and (d) sickle, Chisumbanje Estate, Zimbabwe; and (c) hoeing, Mwea Irrigation Settlement Scheme.

Plate 2.2 Mechanical attachments for aquatic weed control: (a) dredger bucket, (b) weed cutting backet with reciprocating cutter blades; (c) tractor mounted flail mower.

Plate 2.3 Shading using trees, Hadejia Jama'are River Basin Irrigation Scheme, Nigeria